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Innovative and Alternative Technology Assessment Manual

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INNOVATIVE AND ALTERNATIVE

TECHNOLOGY ASSESSMENT

MANUAL

OFFICE OF WATER PROGRAM OPERATIONS
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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DISCLAIMER

This manual has been prepared by the Office of Research and Development's Municipal Environmental Research Laboratory in cooperation with the Office of Water and Waste Management's Municipal Construction and Facilities Requirements Divisions.

The baseline cost and energy information contained in the Municipal Treatment Technology Fact sheets (Appendix A) was developed by Burns and Roe, Consulting Engineers; Paramus, New Jersey using substantial input from previous EPA cost estimating publications, including the Areawide Assessment Procedures Manual published by EPA in July, 1976.

In approving this manual, both the Office of Research and Development and the Office of Water and Waste Management wish to emphasize that the baseline cost and energy information contained herein is based on the best available information using both detailed standard estimating techniques and field verification from as built cost records. This cost information is deemed acceptable for use in verifying comparative technology cost estimates within the accuracy limits shown, but should not be used as an absolute cost reference.

The contents of the manual are intended to be instructive and informational, providing interpretative insights into both Congressional and Agency goals in the formulation and administration of the innovative and alternative technology provisions of the Clean Water Act of 1977. It is intended to be used as an aid to both the developers and reviewers of facility plans submitted for federal grant assistance under the innovative and alternative technology provisions of the Clean Water Act of 1977.

NOTES

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TO: Users of the Innovative and Alternative Technology Assessment Manual

Enactment of Public Law 95-217 has marked a significant milestone in meeting the Nation's environmental quality goals. The provisions of the Act and its legislative history have clearly established the Congressional intent of meeting the Nation's water quality goals by much greater use of systems that reclaim and reuse wastewater, productively recycle wastewater constituents, and otherwise eliminate the discharge of pollutants or recover energy.

The keystones of the new Act in achieving these goals are the provisions for the identification and use of innovative and alternative municipal treatment technology.

The Environmental Protection Agency in accepting this challenge has moved forward swiftly in developing the regulations and guidelines necessary to achieve the goals of the Act while still maintaining the momentum of the Construction Grants Program.

This Innovative and Alternative Technology Assessment Manual, produced jointly by EPA's Office of Research and Development and Office of Water and Waste Management, has been designed specifically to aid Federal and State review authorities in the administration of the innovative and alternative technology requirements of the Construction Grants Program as well as to provide the same basic methodological and technological information to the engineering and planning personnel preparing facility plans.

The manual contains a user's guide, an innovative and alternative technology screening methodology, cost and energy effectiveness analysis criteria and procedures as well as a set of comprehensive fact sheets for commonly employed and emerging municipal technology processes, systems and subsystems. Each fact sheet addresses the applicable regulatory criteria for innovative and alternative technology including estimated cost and energy utilization figures.

Eckardt C. Beck Assistant Administrator Office of Water and Waste Management	Stephen J. Gage Assistant Administrator Office of Research and Development

ABSTRACT

This four chapter, six appendix manual presents the procedures and methodology as well as the baseline cost and energy information necessary for the analysis and evaluation of innovative and alternative technology applications submitted for federal grant assistance under the innovative and alternative technology provisions of the Clean Water Act of 1977.

The manual clarifies and interprets the intent of Congress and the Environmental Protection Agency in carrying out the mandates of the innovative and alternative provisions of the Clean Water Act of 1977.

FOREWORD

The innovative and alternative technology provisions of the Clean Water Act of 1977 clearly established the Congressional and Environmental Protection Agency's intent to encourage the development and use of innovative and alternative technology for the treatment of the Nation's municipal wastewaters.

Alternatives to conventional treatment and discharge, and innovative designs leading to greater cost and energy savings have been strongly encouraged by the provisions of increased federal assistance and guarantee of system success during the first two years of operation. Major emphasis has been placed in the planning, design, and construction of cost effective municipal treatment works that maximize the recycle and reclamation of water, nutrients, and energy while minimizing adverse environmental and public health impacts.

The new emphasis toward innovative solutions to environmental control problems under PL 95-217 presents a challenging opportunity for contemporary planners and engineers to depart from traditional practice by the development and construction of acceptable higher risk, higher benefit municipal wastewater treatment facilities.

This Innovative and Alternative Technology Assessment Manual, produced jointly by EPA's Office of Research and Development and Office of Water and Waste Management, has been designed specifically to aid Federal and State review authorities in the administration of the innovative and alternative requirements of the Construction Grants Program as well as providing the same basic methodological and technological information to the engineering and planning personnel preparing facility plans.

This manual was published in draft form in September, 1978, and has been subjected to extensive public review during the past year including a public review meeting held in Washington, D.C. on June 25, 1979. This final version reflects careful Agency consideration and incorporation of comments received during this public comment period. The body of the manual including the methodological approach and use of the Innovative and Alternative Technology Guidelines remains substantially the same. The Municipal Treatment Technology Fact Sheets have been extensively updated to reflect new cost, performance, and energy utilization information received during the public comment period.

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ACKNOWLEDGEMENTS

This manual has been prepared by the Environmental Protection Agency, Office of Research and Development, Municipal Environmental Research Laboratory, Cincinnati, Ohio, in collaboration with the Office of Water and Waste Management, Municipal Construction and Facilities Requirements Divisions.

Significant technical contribution and direction has been provided by the following EPA programs.

Municipal Environmental Research Laboratory (Cincinnati, Ohio)

Wastewater Research Division
Urban Systems Management Section
Physical-Chemical Treatment Section
Biological Treatment Section
Ultimate Disposal Section
Systems and Economic Analysis Section

Robert S. Kerr Environmental Research Laboratory (Ada, Oklahoma)

Wastewater Management Branch

Office of Water Program Operations (Washington, D.C.)

Municipal Construction Division
Facilities Requirements Division

In addition to EPA staff contributions, Appendix A of this manual has been partially prepared by Burns and Roe, Consulting Engineers, Paramus, New Jersey; under Contract No. WA-77-B037.

In publishing this manual in final form the Environmental Protection Agency wishes to acknowledge those individuals and organizations furnishing comments and participating in the June 25, 1979 public meeting.

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CHAPTER 1

INTRODUCTION

1.0 General

The Clean Water Act of 1977 clearly established the intent of Congress to encourage the use of innovative and alternative technology in the Environmental Protection Agency's multi-billion dollar Municipal Treatment Construction Grant Program.

The legislation contains specific sections that refer to innovative and alternative technology. These provisions are included in Appendix B of this manual. The Environmental Protection Agency, in fulfilling its mandate under the Clean Water Act of 1977, has published final regulations pertaining to innovative and alternative technology. These are also presented in Appendix B.

Extensive review of the legislative history of the Act along with consideration of the voluminous public comment and results of public hearings have led to the formulation of the Innovative and Alternative Technology Guidelines identified as Appendix E of the final regulations and also presented as Appendix E of this manual.

The underlying concept of the Innovative and Alternative Guidelines is the provision of a basic monetary incentive, i.e., a grant increase from 75% to 85% for the design and construction of municipal treatment technology that represents an advancement of the current state-of-the-art technology with respect to meeting the specific national goals of: (a) greater recycling and reuse of water, nutrients, and natural resources; (b) increased energy recovery and conservation, reuse, and recycling; (c) improved cost effectiveness in meeting specific water quality goals; and (d) improved toxics management.

The legislation, guidelines, and Agency policy have been structured to provide additional incentives to both the public and private segments of the municipal construction industry most directly responsible for implementation of improved wastewater management systems. Specific efforts have been made to encourage the use of innovative concepts in the planning and design of municipal treatment facilities by providing indemnification of risk through the provision of 100% Federal grants for modification or replacement of facilities which fail within the first two years of operation. Additionally, the Agency is presently in the process of clarifying the applicability of the standard government patent provisions (40 CFR Part 30, Subpart D) to innovative technology developed under Section 35.908 of the Innovative and Alternative Technology Guidelines for a three-year period beginning

October 1, 1978. As of this writing, a final decision on the patent issue has not been reached. This information will be provided as a separate guidance document when available.

For conventional concepts of treatment, innovative technology must meet a 15% life cycle cost reduction or a 20% net primary energy reduction over non-innovative alternatives. The criteria for qualifying alternative technology as innovative includes either the above-mentioned cost or energy reduction criteria or any one of the four additional criteria of: (a) improved toxics management; (b) improved operational reliability; (c) improved environmental benefit; or (d) improved joint industrial municipal treatment potential. These last four criteria are referred to as improved applications criteria and are fully described in Chapter 3.

Supplementing these basic economic incentives is the latitude granted the EPA Regional Offices in administering the Innovative and Alternative Technology Program. The regulations provide for discretionary authority to approve as innovative technology facility plans that provide substantial public benefit. Additional guidance for use of this discretionary authority is provided in Chapter 2. The regulations further provide for maximum state and local government participation including modification of state priority lists to allow eligibility of innovative or alternative technology projects.

It must be emphasized that because of the comprehensive nature of the innovative and Alternative Technology Guidelines ultimate success of the program will depend on the highest possible standards of engineering excellence and judgement on the part of both the designers and reviewers of innovative and alternative technology applications.

1.1 User's Guide

1.1.1 Intended Users

This Innovative and Alternative Technology Assessment Manual has been prepared specifically as an aid to State and Federal review authorities charged with the responsibility of reviewing the conformance of facility plans for the construction of municipal treatment works initiated after September 30, 1978, with the Innovative and Alternative Technology Guidelines contained in Appendix E of the regulations and also included as Appendix E of this manual.

Because of the short three year time frame for implementation of the innovative and alternative provisions of the Act and the Environmental Protection Agency's desire for maximum participation and understanding of the requirements, the manual will be concurrently distributed to planners, engineers, and other interested parties engaged in the formulation, development, design, and construction of municipal treatment works.

The manual is intended to be informative rather than prescriptive in nature. The basic objectives are to provide a concise description and interpretation of the enabling legislation, Agency regulations, program guidelines, and information needed to efficiently implement the provision of the Act.

The manual has been designed for the use of planners, engineers, and analysts engaged in the development and review of facility plans for the construction of municipal wastewater treatment facilities. Emphasis has been placed on: (a) describing and interpreting the applicable EPA regulations and guidelines; (b) presenting a sequential classification and screening methodology; and (c) identifying, collecting, and presenting state of the art cost and energy information needed to judge the conformance of proposed designs against the applicable qualifying criteria.

Because of the emphasis on cost and energy considerations in the guidelines, a major effort has been devoted in Appendix A of this manual to the development and presentation of baseline cost and energy data for the most commonly used municipal treatment technologies.

1.1.2 Applicability for Plan Development and Review

As stated earlier, this manual is intended both for those engaged in the development and review of facility plans. It must be emphasized that the information contained herein, especially that related to baseline cost and energy is not to be used as an absolute reference, but rather as a general guideline for the development of cost and energy estimates consistent with the levels of sensitivity normally employed in Step 1 facility plans. Conformance with the estimates presented herein should not be interpreted by either the designer or reviewer as a guarantee of approval or satisfaction of the Agency's requirements for meeting cost or energy qualifying criteria. Substantial deviation from the estimates, however, should be used as a guide for requiring further documentation of the cost or energy estimates presented. Final decisions regarding the conformance with qualifying criteria will be made by the State or Federal review staff based on their comprehensive analysis of individual facility plans. It should be noted that State or Federal review staffs will require greater documentation and more detailed development of cost and energy estimates for Step 1 plans submitted to qualify as innovative technology. These requirements are further discussed in Chapter 2.

Recognizing that the cost and energy estimating sensitivity at the Step 1 stage may be less than that ultimately required for some of the innovative technology qualifying criteria, the final innovative and alternative technology regulations have been modified to include the right to reject or modify Step 1 innovative qualifying decisions during subsequent Step 2 review.

1.1.3 Organization

This manual contains four chapters and six supporting appendices. The development of both the main body of the manual and the appendices are user oriented. Textual material has been minimized while emphasis has been placed on graphical displays, simplified equations, example calculations, logic and process flow diagrams, and tabular information. Although the manual contains an extensive bibliography and is well referenced, a special attempt has been made to identify, extract, and summarize available information on applicable regulations and guidelines and state-of-the-art baseline cost and energy information needed for the efficient analysis and review of facility plans.

Listed below is a synopsis of Chapters 2 through 4 and Appendices A through F.

Chapter 2 Innovative and Alternative Technology Decision Methodology

This chapter contains a discussion and summary of the innovative screening criteria as required by the innovative and alternative regulations, along with a graphically displayed decision methodology to allow the recommended portion(s) of facility plans to be screened and a decision reached as to their classification as innovative or alternative technologies. Each step of the decision methodology is described in detail and refers to other sections or appendices of the report and to other documents for information such as typical cost and energy utilization for commonly used and engineering technology. This chapter also includes a discussion of the window of acceptable risk and guidance for the use of the Regional Administrators' discretionary authority.

Chapter 3 Improved Application Criteria

This chapter contains an extensive discussion of Appendix E's improved applications criteria (reliability, toxics management, improved joint treatment, and environmental impact) for qualifying alternative technology as innovative. Emphasis is placed on improved toxics management including discussion and quantification of adsorbability, volatility, biodegradability, and transformations of toxic materials in soils. This chapter also describes the September 13, 1979, RCRA requirements as they apply to improved applications of alternative technology.

Chapter 4 Innovative Technology Concepts and Applications

This chapter includes a discussion and elaboration of specific criteria and requirements for innovative technology with emphasis on innovative planning approaches, concept development, risk-benefit analysis, and the incorporation of novel equipment in innovative process and system designs.

Appendix A Municipal Treatment Technology Fact Sheets

This appendix contains a series of two-page municipal treatment technology fact sheets. Each fact sheet contains a process description, discussion of process applicability, common process modifications, technology status, process limitations, typical equipment, performance and design criteria, a discussion of improved application criteria (toxics management, environmental impact, O&M, and joint treatment) along with a flow diagram, energy balance, construction cost curve, and O&M cost curve.

Appendix B Legislation, Regulations, and Program Guidance Summary

A concise presentation of the legislation, regulations, and program guidance information pertaining to innovative and alternative technology. Program requirement memorandum modifying and clarifying Agency position and policy on land application and small wastewater systems are presented.

Appendix C Cost and Locality Factor Index

The construction and operation and maintenance (O&M) costs presented in this manual have all been adjusted to a September 1976 (constant dollar) base except as noted. The EPA Sewage Treatment Plant Construction Cost Index and O&M Cost Index needed to adjust this data to the date of analysis is presented in this appendix.

In addition to adjusting to current dollars, Locality Factors have been calculated from available statistics which permit the localizing of national average cost data for construction labor, construction materials, total construction cost, operation and maintenance labor, and power costs. The use of the Locality Factors to modify national average costs will result in more accurate cost estimates than possible using the national average indexes alone.

Appendix D Energy Utilization Curves and Conversion Factors

This appendix summarizes the energy utilization of the more energy intensive municipal treatment unit processes such as pumping and aeration, as well as specific energy utilization and recovery curves for the analysis of the energy recovery alternative technologies identified in Appendix E of the Innovative and Alternative Technology Guidelines. The appendix contains a list of commonly used cost and energy conversion factors, a specific set of energy utilization and recovery curves for anaerobic digestion, sludge dewatering, and incineration processes. This appendix also contains example calculations illustrating the use of the energy curves and figures along with a table of factors needed to compute the present worth of constant and variable O&M costs.

Appendix E Innovative and Alternative Technology Guidelines

A reprint of the final version of innovative and alternative guidelines (Appendix E of Regulations).

Appendix F Cost Effectiveness Analysis Guidelines (CEAG)

A reprint of the final cost effectiveness guidelines (Appendix A of Regulations).

CHAPTER 2

INNOVATIVE AND ALTERNATIVE TECHNOLOGY DECISION METHODOLOGY

2.1 General Classification and Screening Approach

Section 201(g)5 of the Clean Water Act of 1977 requires all facility plans initiated after September 30, 1978, to consider innovative and alternative technology. Figure 2-1 presents a generalized classification scheme for review and analysis of these plans. Referring to Figure 2-1, all potentially innovative technology facility designs are classified as alternative technology or conventional concepts of treatment. Facility designs classified as alternative technology may qualify as innovative technology by meeting any one of the six qualifying criteria shown. Facility designs classified as conventional concepts of treatment must meet either the cost or energy criteria to qualify as innovative technology.

Alternative technologies are fully proven methods which provide for the reclaiming and reuse of water, productively recycle wastewater constituents, or otherwise eliminate the discharges of pollutants, or recover energy. All alternative technologies identified in the guidelines are listed in Figure 2-1.

Conventional concepts of treatment are generally defined as biological or physical chemical processes conventionally used for the treatment of wastewater and which result in a point source discharge to surface waters.

2.2 Innovative and Alternative Decision Methodology

2.2.1 Description of the Methodology

Presented in Figure 2-2 is a basic decision methodology to be used in the analysis and evaluation of facility plans (Step 1) or plans and specifications (Step 2) submitted for consideration as innovative and alternative technology.

A simplified three-step procedure for determining the classification and funding eligibility of proposed projects is described below first for alternative technology, then for conventional concepts of treatment.

Referring to the upper portion of Figure 2-2, the procedure for alternative technology is as follows:

Beginning with Point A

A - Determine if the proposed alternative technology has been proven in

FIGURE 2-1

GENERALIZED CLASSIFICATION OF INNOVATIVE AND ALTERNATIVE TECHNOLOGY

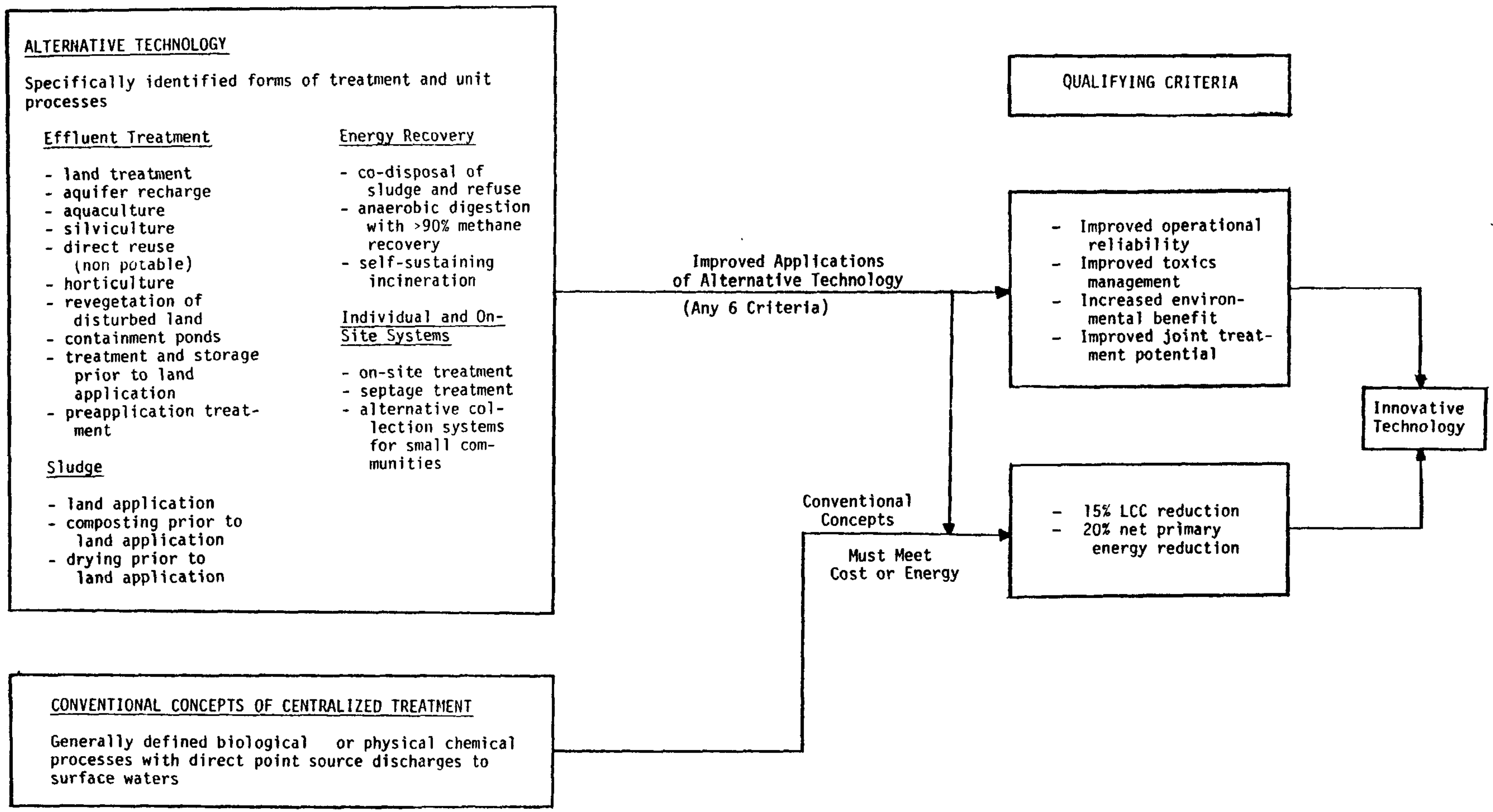
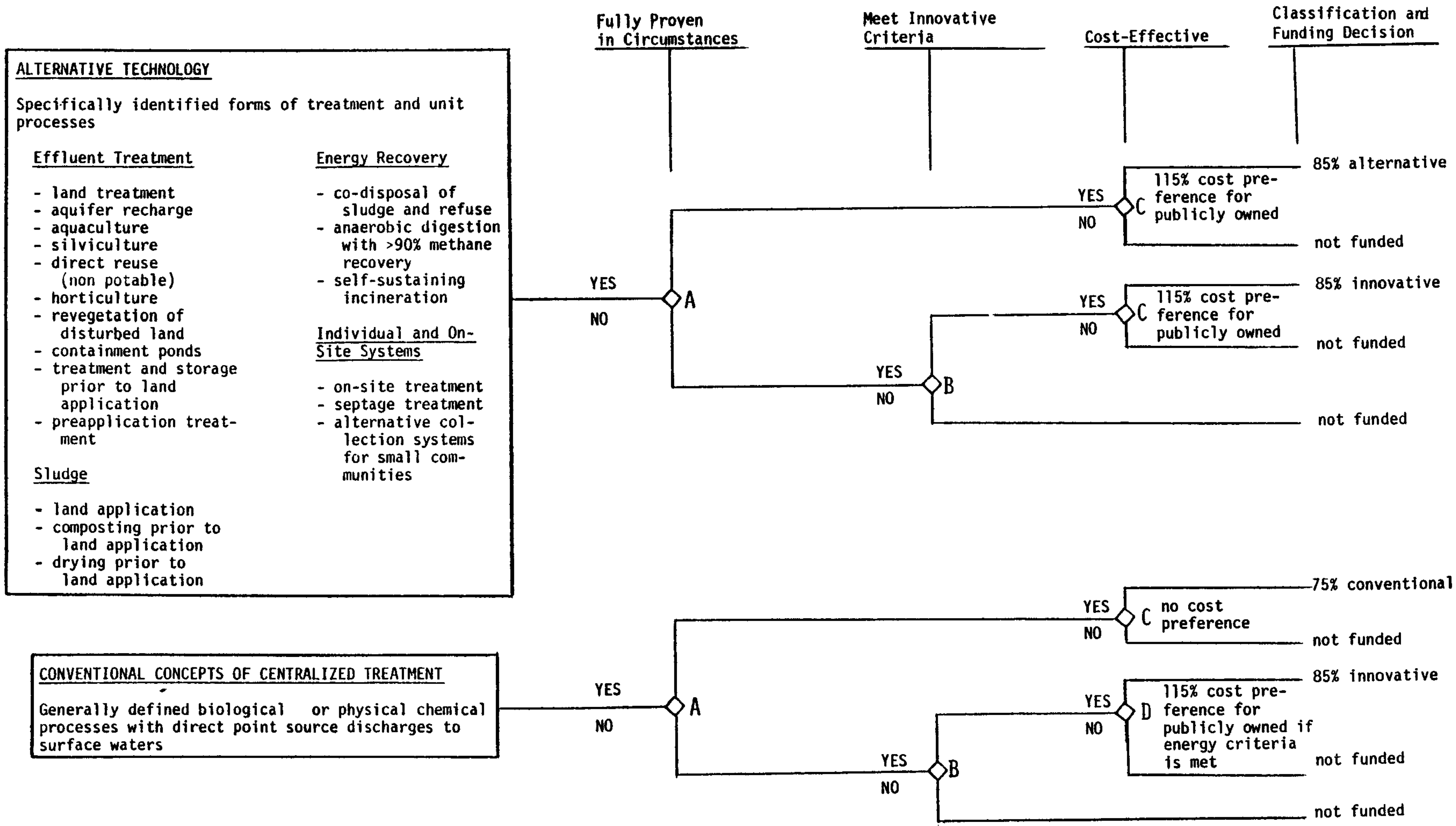


FIGURE 2-2

INNOVATIVE AND ALTERNATIVE TECHNOLOGY DECISION METHODOLOGY



the circumstances of its intended use.
If YES - Proceed to Point C
If NO - Proceed to Point B

B - Determine if the technology meets any one of the six qualifying criteria for innovative technology listed in Figure 2-1.
If YES - Proceed to Point C
If NO - Not Funded

C - Determine if the technology cost is within 115% of the most cost-effective alternative.
If YES - 85% Funding
If NO - Not Funded

Referring to the lower portion of Figure 2-2, the procedure for conventional concepts of treatment is as follows:

Beginning at Point A

A - Determine if the proposed technology has been proven in the circumstances of its intended use.
If YES - Proceed to Point C
If NO - Proceed to Point B

B - Determine if the proposed technology meets either the 15% life cycle cost reduction <u>or</u> the 20% net primary energy reduction criteria.
If YES - Proceed to Point D
If NO - Not Funded

C - Determine if the technology is the most cost-effective alternative.
If YES - 75% Funding
If NO - Not Funded

D - For technologies that have met the energy criteria, determine if they are within 115% of the cost of the most cost-effective alternative.
If YES - 85% Funding
If NO - Not Funded

Technologies that reach Point D by achieving a 15% life cycle cost reduction have already demonstrated cost effectiveness.

2.2.2 Detailed Description of Decision Points A, B, C, and D

2.2.2.1 Decision Point A - Developed Technology Not Fully Proven for Contemplated Use

Traditional engineering practice has always dictated a very low element of risk for the construction of full scale public works projects supported by federal expenditures. In passing Public Law 95-217, Congress clearly intended that a higher degree of risk be permitted for the set-aside funds for innovative technology. This intent should be recognized in judging the state of development of potentially innovative technology. The permitted degree of risk should be compared to the potential for significant state-of-the-art advancement. High risk, high potential state of the art advancement projects may be judged acceptable where high risk, low potential state of the art advancement projects may be deemed unacceptable.

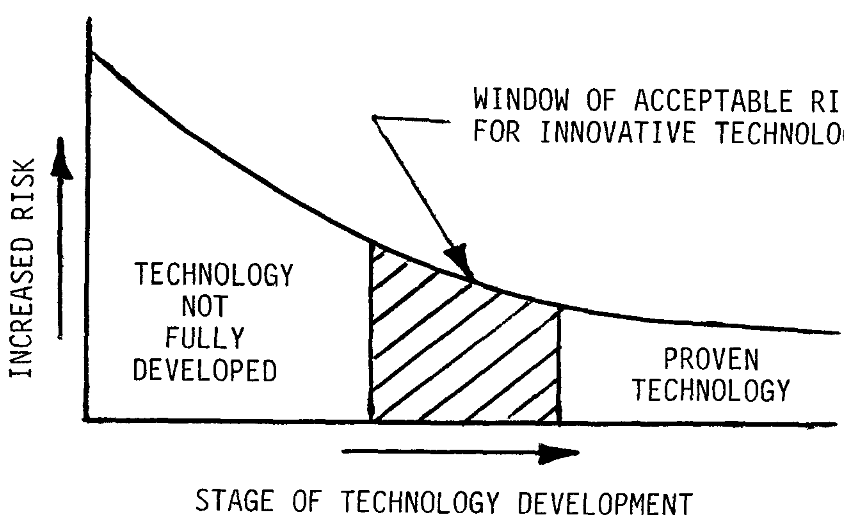
The first decision point in the methodology (Point A) is a determination whether the proposed technology is developed but is not proven in the circumstances of its contemplated use. This is a two-part determination. The first is to insure that the technology is developed to the extent that the risk of full-scale use is acceptable, while the second part, i.e., the test for fully-proven technology is intended to eliminate those technologies that are fully proven and should not be granted the incentive of an innovative grant increase.

The goal of the Innovative and Alternative Technology Program is to encourage the use of technologies that lie between these two extremes as shown by the window of acceptable risk in Figure 2-2(a) below.

A determination of whether processes and techniques are fully developed requires consideration of the stage of development of a particular unit process or specific piece of equipment, as well as the degree of change in the application of processes, techniques, or equipment that is substantially different

FIGURE 2-2(a)

WINDOW OF ACCEPTABLE RISK



from the original intended use. Technologies to the left of the window of acceptable risk in Figure 2-2(a) are considered not fully developed. For technologies within the window of acceptable risk, the development should have progressed beyond the laboratory or bench scale stage and have been successfully tested or demonstrated in a field application or pilot plant program that has met the following general requirements.

1. The size of the principle components must be such that physical, chemical, or biological processes are accurately simulated.

2. Process variables normally expected in full-scale application have been simulated.

3. All recycle streams have been considered.

4. Variations in influent characteristics substantially affecting performance in full-scale application have been anticipated and simulated.

5. The time of testing has been adequate to insure process equilibrium.

6. Full control of all major process variables has been demonstrated.

7. The service life of high maintenance or replacement items has been accurately estimated.

8. Basic process safety, environmental, and health risks have been considered and found to be within reasonable limits.

9. Type and amount of all required process additives have been determined.

Where full-scale application requires multiple components, the size of the units under No. 1 above should be judged in comparison to the smallest size anticipated in modular or multiple system designs.

Technologies meeting the "developed" criteria above but are not considered fully proven (i.e., are within the window of acceptable risk) in the proposed application and represent an advancement in the state of the art should be further considered as potentially innovative and proceed to Step B in the methodology. The state-of-the-art advancement must represent a benefit commensurate with the increased risk. The risk/benefit assessment of potentially innovative technology is further described in Chapter 4 of this manual.

2.2.2.2 Innovative Criteria

2.2.2.2.1 General

The second step in the decision methodology is to determine if the proposed technologies meet the innovative criteria specified in the Appendix E guidelines. As shown in Figure 2-1, projects or portions of projects that are originally classified as alternative technology can qualify as innovative by meeting any one of the six qualifying criteria while those projects classified as conventional concepts of treatment must meet either the 20% net primary energy reduction or the 15% life cycle cost reduction.

The improved applications criteria of: (a) improved operational reliability; (b) improved toxics management; (c) improved environmental benefit; and (d) improved joint treatment potential differ from the cost and energy criteria in that there are no quantitative levels of improvement specified in the guidelines as being necessary for qualification as innovative technology. These four criteria are fully described in Chapter 3.

2.2.2.2.2 Cost Criteria

For both the cost and energy criteria, specific reference is made in the guidelines to comparison of innovative designs with non-innovative alternatives. The specific language of these guidelines is shown below.

1. The life cycle cost of the eligible portions of the treatment works excluding conventional sewer lines is at least 15% less than that for the most cost effective alternative which does not incorporate innovative wastewater treatment processes and techniques (i.e., is no more than 85% of the life cycle of the most cost effective non-innovative alternative).

2. The net primary energy requirements for the operation and maintenance of the eligible portions of the treatment works excluding conventional sewer lines are at least 20% less than the net energy requirements of the least net energy alternative which does not incorporate innovative wastewater treatment processes and techniques (i.e., the net energy requirements are no more than 80% of those for the least net energy non-innovative alternative). The least net energy non-innovative alternative must be one of the alternatives selected for analysis under Section 5 of Appendix A. (Appendix A of 40 CFR Part 35 is included as Appendix F of this manual.

In the above life cycle cost comparisons, the following apply.

1. The non-innovative alternative must be clearly identified. Where an upgrading or expansion of an existing treatment works is encountered, only the portions associated with the increased capacity or level of treatment shall be considered in the cost analysis.

2. The cost effectiveness of the non-innovative alternative will be judged against the best available state of the art cost information. The construction cost information contained in Appendix A of this manual and the referenced material contained therein may be used as a general estimating guide in the analysis, but in no way should be taken as an absolute construction cost standard.

3. The basis of the comparison is the lowest present worth cost with the cost effective analysis for each system being conducted in accordance with the Cost Effectiveness Analysis Guidelines.

4. Aggregation of component cost savings is permitted providing all applicable provisions of the Cost Effectiveness Analysis Guidelines are met. Each separate component included in the aggregation must include risk as described in decision point A.

5. The cost comparison between the proposed innovative and non-innovative alternatives must be made on a completed treatment works basis (grant eligible portions excluding conventional sewer lines) even though the proposed potentially innovative portion is a sub-system or component.

6. In the comparative analysis, both systems must provide equivalent levels of pollutant control. Equivalency of the following factors must be considered.

   - Design minimum effluent quality standards
   - System reliability with respect to effluent quality and residual disposal
   - Residual treatment and disposal
   - Level of toxic material control
   - Environmental benefit

   For cases where innovative sub-system components are analyzed or aggregated in the total plant cost comparison, only the cost of the appurtenant equipment uniquely necessary for the proper functioning of the candidate innovative or alternative technology component or piece of equipment should be included as a part of the component cost. For example, if an activated sludge plant with a potentially innovative air diffusing system is compared to a conventional activated sludge plant on a total plant basis as required by item (5) above, an air cleaning or filtering system uniquely necessary to pretreat air for a proposed innovative air diffusing system may be included as a part of the aeration component while items such as blowers, portions of plant electrical distribution system, etc., would not be eligible. A good test for determining if a component is uniquely necessary is on the basis of whether it would have to be modified or replaced to correct a failure of the innovative system.

In the above total system cost comparison, the present worth cost of the proposed design with innovative components must be a minimum of 15% less than that of the most cost effective non-innovative alternative to qualify as innovative technology.

2.2.2.2.3 Energy Criteria

The energy analysis compares the net primary energy utilization of the proposed innovative alternative with that of the least net primary energy utilization non-innovative alternative. In this analysis, the required 20% net primary energy savings must be made on the total treatment works basis (eligible portions excluding conventional sewer lines) including treatment and disposal of all residuals except where an upgrading or expansion of an existing treatment works is encountered. In this case, only the treatment works associated with the increased capacity and/or level of treatment shall be considered for inclusion in the energy analysis. All increases in energy use in other portions of the plant must be accounted for in the above net 20% energy savings calculation. The energy audits for the potentially innovative and non-innovative alternative technologies must be made on an equivalent basis. The following general requirements and conditions should be considered.

1. The boundaries and boundary conditions of system or system components receiving energy audits must be fully described including all flow streams entering or leaving the treatment works.

2. A materials balance for all significant influent and effluent streams including flow, mass, temperature, etc., must be included in the analysis

3. Differences in hydraulic profile required of different treatment systems must be accounted for in the energy analysis.

4. The system's energy balance must include the treatment and disposal (including transportation) of all residuals.

5. In determining the energy consumed to dewater sludge, the energy balance point is the sludge stream entering the dewatering process or the thickening process when thickening is required. All energy balances required to document energy recovery will be based on annual values. The sludge mass to be used in the analysis is the average annual sludge mass projected over the project planning period.

6. The energy utilization and heat transfer efficiency of commonly cited components or unit processes of similar size and design must be equivalent.

7. For processes where the energy utilization is a function of influent flow, the energy analysis must consider the increase in plant flow over the project planning period as permitted by the cost effective analysis guidelines. In the absence of a detailed analysis of projected flow increases and energy use, the average annual daily flow over the project planning period may be used in the analysis.

8. The net primary energy reduction of 20% specified in the innovative and alternative technology guidelines does not distinguish the form or location of the energy savings. The savings should be computed at the boundary of the proposed treatment works in BTU or KwH/year. The conversion efficiency of fossil fueled electrical power generation and distribution to the plant site may be taken as a 32.5%. A heat to electrical power conversion of 10,500 BTU/KwH may be used. See Tables D-4 and D-5 of Appendix D for other representative energy conversion and representative heat of fuels values.

9. Energy savings credit may be granted for lower grade fuel substitutions. The credit basis must be approved through the EPA regional office.

10. Net primary energy is the net energy consumed for the complete treatment of wastewater, including the transportation and ultimate disposal of all residuals.

11. Aggregation of energy savings may be permitted if adequately documented and other factors such as degree of technology advancement, increased risk, and energy recycle aspects are present for each aggregated component.

The non-innovative alternative that is to be used as the least net primary energy using alternative baseline must be one of the alternatives selected for analysis under Section 5(c) of the cost effectiveness analysis guidelines. Section 5(c) is presented below.

> 5(c) Selection of Alternatives (From Cost Effectiveness Analysis Guidelines
>
> The identified alternatives shall be initially screened and analyzed to determine which systems have cost effectiveness potential and which should be fully evaluated according to the cost effectiveness analysis procedures established in the guidelines.

This requirement ensures that the baseline energy technology would have roughly comparable cost effectiveness for the particular application, thus basing the energy savings analysis on a reasonable comparison.

For facility planning begun after September 30, 1978, Regulation 35.917-1(d)9 requires an analysis of the primary energy requirements for each alternative system considered. The alternatives selected shall propose adoption of measures to reduce energy consumption or to increase recovery as long as such measures are cost effective. This regulation further requires a detailed energy analysis for those processes and techniques claiming innovation under the energy criteria. Although the above energy analysis requirements originate under different sections of the regulations, they are consistent in encouraging energy reduction and conservation while still maintaining total project cost effectiveness.

Appendix E guidelines mention two specific processes, anaerobic digestion and incineration that, under certain energy-related conditions, qualify as alternative technology. The condition that must be met for anaerobic digestion is that greater than 90% of the methane gas produced must be recovered and used as fuel. Although the most common fuel use is for digester heating, all other uses that reduce the net primary energy requirements of the treatment works, including on-site as well as any off-site use qualify as meeting this requirement. Export of fuel that meets the requirements of applicable program requirements memoranda may also be eligible. The condition for eligibility of incineration as alternative technology is that the energy recovered and productively used is greater than the energy required to dewater the sludge to an autogenous state. Productive use of the energy is defined as any use that reduces the net primary energy requirements of the treatment works, including that used for disposal of the effluent or residuals generated during treatment. Export and reuse of energy that meets the requirements of the applicable program requirements memoranda may also be considered eligible.

Because of the large number of energy reuse and conservation possibilities that exist within the sludge handling and disposal portions of conventional and alternative treatment technologies, and also because contemporary designers do not have broad experience in energy optimization, Appendix D of this manual has been prepared as a specific aid for the energy analysis of potentially innovative and alternative applications required by Appendix E.

2.2.2.3 Qualification of Technology as Innovative by Regional Administrator

2.2.2.3.1 General

In accordance with Paragraph 6(a) of the Innovative and Alternative Technology Guidelines (40 CFR Part 35, Appendix E), certain treatment systems may qualify as innovative technology because they: (a) incorporate unique design and operational features due to local variations in geographic or climatic conditions; or (b) because the design achieves significant public benefit through the advancement of technology that would not otherwise be possible.

Qualification by these mechanisms will be made by the regional administrator on a selective basis for those projects that exhibit high potential towards achieving the goals of the Clean Water Act of 1977 but due to the unique nature of the technology or system design may not strictly qualify under the cost, energy, or improved application criteria.

In all cases, the present worth cost of the proposed innovative designs must be within 115% of that for the least cost non-innovative alternative.

2.2.2.3.2 Unique Design Features Due to Climatic and Geographic Conditions

Qualification by this mechanism recognizes that some conventional and many newly developed alternative technologies, especially those that use natural processes, are dependent on both climatic and geographical conditions of the particular site or the more general conditions that prevail in a given region or local area.

For these systems, the present worth cost, overall annual performance, risk of system failure, and potential benefits are related to design and operational features that are governed by geographic and climatic factors. Technologies considered proven under certain physical constraints and natural conditions may exhibit increased risk when applied under more extreme or substantially different climatic or geographic conditions.

These technologies may be judged innovative by the regional administrator where increased risk is demonstrated and where the potential benefits derived from the wider applicability or translocation of the technology justifies the increased levels of risk on a regional or local basis. In making the above determination, the regional administrator will consider the overall applicability of the technology for cost effectively meeting water quality goals of the region as required by the Clean Water Act of 1977. In some cases, approval of moderate or low risk technology may be justified due to high potential benefits to the particular region or a potential for transference to other regions.

2.2.2.3.3 Advancement of the State of the Art and Significant Public Benefit

Projects qualifying under these criteria must fully document and quantify both the: (a) technological advancement; and (b) the achievable public benefit.

The description of the technology advancement must include the following:

1. Identification of project element(s) contributing to state-of-the art advancement

2. Description of advancement by comparison to the most cost effective non-innovative design

3. Relationship of technological advancement to one or more of the following national goals for innovative and alternative technologies.

    - Cost reduction
    - Increased energy conservation or recovery
    - Greater recycling and conservation of water resources
    - Reclamation or reuse of effluents and resources
    - Improved efficiency and/or reliability of municipal treatment processes
    - Beneficial use of sludge or effluent constituents
    - Improved management of toxic materials
    - Increased environmental benefit

To be considered significant, the public benefits derived from innovative technologies under this criteria must: (a) be specifically identified; with applicability and benefits extending beyond the proposed project.

This advancement of the state-of-the-art criteria may be applied to individual unit processes or other sub-system components that are a part of the eligible portion of treatment works as well as to total treatment systems.

The Agency intent in permitting qualification under this criteria is to encourage the development and use of all innovative methods of treatment including conceptional advances, unit process advances, and the integration of improved unit processes into innovative treatment systems.

In judging qualification of innovative technology under this criteria, priority consideration will be given to new process and total treatment concept development versus specific unit process, equipment, and individual component development.

It is recognized that for equipment intensive unit processes and other proprietary devices, advances in the state of the art are an integral part of competition in the market place. Although the use of improved equipment, devices, and unit processes is encouraged as a part of innovative design, qualification of these unit processes or proprietary equipment items individually will be given lower priority than their incorporation into new concepts of treatment or to the development of totally new treatment processes.

The following is recommended as a general priority guide in qualifying innovative technology under the state of the art advancement and significant public benefit criteria.

Technology Priority Class	Critical Factor Assessment
(1) Development of new concepts of treatment (1) Development of totally new treatment systems	• Novel approach • New solution to problem • Departure from conventional practices • Incorporates more than one stated EPA goal for innovative technology • Process advantage over conventional • Widely applicable • Recognized potential benefits • High potential for transference to other applications
(2) Development of proprietary processes (2) Development of unit processes	• Entire unit process but not a total treatment system • Advance in technology has market potential • Lower total treatment system cost or energy savings potential • Some potential for transference to other processes
(3) Development of unit process components or improved efficiency of existing processes	• Equipment or device improvement • Advance has market potential • Least total treatment system cost or energy savings potential • Limited potential for transference to other processes

NOTE: (1) to (3)--highest to lowest

Although any of the three technology priority classes may be determined innovative for a particular application by the regional administrator, a greater judgmental latitude is justified by the higher priority classes because of the greater inherent benefits that are potentially achievable through the use of conceptual innovation as opposed to retrofitting or modification of more conventional approaches with improved unit processes, equipment, or devices. In all cases, increased risks and benefits must be assessed and documented to the satisfaction of the regional administrator.

In conjunction with the above, the regional administrators shall use the following criteria as a guide in their decisions. These criteria are applicable to projects proposed for innovative technology on the basis of cost or energy reductions but which do not achieve the respective 15% or 20% cost or energy savings over the entire treatment works as specified in Appendix E of 40 CFR Part 35.

1. Unit processes or operations which contain proposed innovative components must, as a minimum, achieve 15% total present worth cost savings or 20% net primary energy savings when compared to the replaced unit processes in the most cost effective or least net primary energy non-innovative alternative, respectively.

2. The project shall contain two or more distinctly separate innovative components. Preferably, these components should be located in different unit processes or operations.

3. Any increase in the total present worth cost or net primary energy requirements in other parts of the plant (i.e., as a result of sidestreams, recycle flows within the treatment works, etc.) must be included in the net cost and energy calculations in No. 1 above. Preferably, energy-saving projects qualified in accordance with these criteria should also be the most cost effective without adding the 15% cost preference.

2.2.2.4 Cost Effectiveness Analysis

The Step C and D cost effectiveness analysis is the same as that normally used for facility plans and the same guidelines should be used except that all projects originating from the alternative technology category (upper portion of Figure 2-2) and projects originating from the conventional concepts of treatment category (lower portion) that meet the energy saving criteria (Step D) are granted a 115% cost preference in the analysis. The cost effectiveness analysis must be completed in accordance with the Cost Effectiveness Analysis Guidelines in Appendix F of this manual.

For those cases where innovative or alternative unit processes would serve in lieu of conventional unit processes in a conventional wastewater treatment plant, and the present worth costs of the non-conventional unit processes are less than 50% of the present worth costs of the treatment plant, multiply the present worth costs of the replaced conventional processes by 115% and add the cost of non-replaced unit processes. In cases where alternative energy sources are substituted for power derived from unrenewable energy sources, the present worth cost of the replaced conventional components may be taken as the present worth cost of the conventionally supplied power. The portion of the project eligible for the cost effectiveness preference noted above should not be confused with the portion of projects eligible for grant increases. Table 2-1 summarizes both the cost effectiveness and grant increase eligibilities.

Many proposed designs include a mix of conventional, alternative, and proposed innovative processes, components, and equipment. For these cases, the facility plan must clearly identify all cost components in each category indicating those eligible for the 115% cost effectiveness preference as described in Appendix E and shown in Figure 2-2.

For systems involving individual and on-site systems, only the publicly owned portion of the proposed project may be given the 115% cost effectiveness preference. Further information regarding the eligibility of these individual and on-site systems is provided in PRM 79-8 shown in Appendix B.

The cost effectiveness analysis of the proposed innovative or alternative components with other alternative designs contained in the application should be conducted as a part of Step C or D of the decision methodology shown in Figure 2-2. Another critical part of this analysis is the comparison of the estimated costs of the alternatives contained in the application to the best available state of the art cost estimates for the technologies under consideration. The Municipal Treatment Technology Fact Sheets in Appendix A of this manual have been prepared for this purpose. These cost estimates are general in nature but can be used for comparative analysis within the accuracy limits shown. They should not be used as an absolute cost standard. Care must be exercised in recognizing and accounting for the differences between the design basis of the alternatives under consideration and that used in the development of the fact sheets. Details of the fact sheet cost estimates are provided in Pages A-1 thru A-5 of Appendix A of this manual.

TABLE 2-1

COST EFFECTIVENESS AND GRANT INCREASE PROJECT PORTION ELIGIBILITY

Project Preference or Eligibility \ Project Portion	Portion of Total Project That Is Eligible (a)		Authority or Reference
	For Project Portion Less Than 50% of Total Project	For Project Portion Greater Than 50% of Total Project	
115% Cost Effectiveness Preference for Innovative and Alternative (I&A) Technology	Only I&A Portion	Entire Project	CEAG Paragraph 7 Appendix A
75% to 85% Grant Increase for Innovative or Alternative (I&A) Technology	Only I&A Portion	Only I&A Portion	202(a)2 202(a)4 §35.908(b) Preamble

(a) Project eligibility is based on present worth cost of total project eligible portions excluding sewer related costs except for projects qualifying as alternatives to small communities (a municipality with a population of 3,500 or less or a highly dispersed section of a larger community).

(b) Conventional concepts of treatment qualifying as innovative under the energy criteria must meet the overall 115% cost effectiveness criteria to be eligible for funding.

Appendix C of this manual has also been provided to permit easy indexing of construction and O&M cost data from differing time periods. This appendix further contains cost locality factors for construction labor and materials.

2.2.2.5 Partial Project Eligibility Based on Time

The decision methodology described thus far has dealt with the analysis of innovative and alternative plant components proposed for the entire project planning period as well as for specific project portions previously described.

For these latter cases, equivalent project eligibility for increased grant assistance may be determined by multiplying the fraction of the normal plant components eligible for a grant increase by the ratio of the total flow treated over the project planning period by the innovative or alternative technology to the total flow treated by the innovative or alternative technology plus that treated by non-innovative technology over the project planning period. For a phased project, the total flow treated is the average flow per phase times the length of each phase.

For a single phase project, the equivalent project eligibility is given by the following expression:

$$F_e = F_n \frac{Q_{I/A}}{Q_{I/A} + Q_{NI}}$$

where F_e = Equivalent fraction of plant components eligible for grant increase in percent

F_n = Fraction of plant components normally eligible as innovative or alternative technology for entire planning period in percent

$Q_{I/A}$ = Total flow treated by innovative or alternative technology over the project planning period

Q_{NI} = Total flow treated by non-innovative or alternative technology over the project planning period

The above procedure may be extended for any number of phases and for differing innovative and alternative eligible portions for each phase. A similar analysis for the equivalent fraction of eligible components may be used for innovative or alternative components used for treatment or disposal of residuals.

2.3 Other Considerations

2.3.1 Individual and On-Site Systems (Reader is also Referred to Program Requirements Memorandum 79-8 in Appendix B for Additional Information on Individual and On-Site Systems)

Along with promulgation of the Innovative and Alternative Technology Guidelines, the Clean Water Act of 1977 substantially extended the basic eligibility of the Construction Grants Program to include individual systems. Under the Individual System Regulations (35.918, 35.918-1, 35.918-2, and 35.918-3), 4% of the construction grant funds have been set aside exclusively for funding "alternatives to conventional treatment works" in communities having a population of 3,500 or less and in highly dispersed sections of larger communities. The population density qualifying as highly dispersed will be made by the regional administrator.

Individual systems are defined as privately owned alternative wastewater treatment works serving one or more principal residences or commercial establishments which are neither connected into nor a part of any conventional treatment works.

On-site systems may be publicly or privately owned and include all wastewater treatment alternatives for single family, multiple family, or clustered residential or commercial developments that are not connected to centralized wastewater collection systems. On-site technology may include treatment with surface or subsurface discharge, recycle and reuse, or evaporation systems. On-site systems characteristically provide treatment and disposal of wastewaters in the immediate locality of generation.

Commonly used on-site technology is listed as follows:

On-Site Technology

1. Septic Tank - Soil Absorption Systems
2. Aerobic Treatment - Soil Absorption Systems
3. Sand Filtration, Polishing and Disinfecting
4. Mound Systems
5. Evapotranspiration Systems
6. Evaporation Systems
7. Waterless Toilets/Greywater Systems (only the treatment and treatment residual disposal portion are grant eligible. See 35.918-2(a))
8. On-Site Recycle Systems
9. Combinations of 1 thru 8

In addition to the individual and on-site systems, alternative collection systems and septage treatment have been identified as alternative technology by the Appendix E guidelines and thereby are eligible for the grant increase and the 115% cost effectiveness preference if publicly owned, which would normally be the case. Alternative collection and septage treatment systems are listed below.

Alternative Collection Systems (also see PRM 79-8 in Appendix B)

1. Pressure Sewers (limited to small communities or highly dispersed sections of larger communities)
2. Vacuum Sewers (limited to small communities or highly dispersed sections of larger communities)

3. Small Diameter Gravity Sewers (except if used for conveyance of raw wastewater to a centralized plant)

Septage Treatment

1. Separate Septage Treatment
2. Septage Disposal

All individual and on-site systems, alternative collection systems, and septage treatment systems have been identified as alternative technology in the Innovative and Alternative Technology Guidelines and are, therefore, eligible for the 75% to 85% grant increase. These individual systems may also qualify as innovative technology by meeting any of the six Appendix E qualifying criteria. Publicly owned portions of the above alternative technologies are eligible for the 115% cost effectiveness preference. Land used for treatment purposes for publically owned on-site systems serving more than one principle residence or commercial establishment is grant eligible. Acquisition of easement and legal fees associated with such acquisitions for purposes of obtaining access to on-site technology components are not grant eligible.

Because much of the on-site technology is new and very site specific, the cost and energy data bases needed to judge conformance with the innovative technology qualifying criteria are not as well developed as with the more conventional technologies. Also, many planners and design engineers are unfamiliar with the formulation and development of facility plans incorporating this technology. Recognizing an increased need for the dissemination of information on the cost and applicability of on-site technology, the Office of Research and Development, in cooperation with the Office of Water and Waste Management, sponsored two intensive one-week training seminars: one in Cincinnati, Ohio, and one in Denver, Colorado, during August of 1978 to familiarize both state and federal review authorities with the use of this technology in future facility plans. This information has been used where applicable in the development of the fact sheet cost and energy curves and is appropriately referenced on the individual fact sheets.

Of particular importance in judging the overall cost effectiveness of on-site technologies is the provision for adequate system maintenance and management budgets. These systems which may include combinations of individual home treatment units, clustered units, small centralized treatment with surface or subsurface disposal, along with various combinations of pressure or vacuum sewer collection, are generally more widely dispersed than conventional treatment systems and therefore require greater than normal attention to operation and maintenance requirements, especially as related to large numbers of small mechanical equipment items. Complete documentation of expected equipment lifetimes and recommended preventative maintenance practices should be included in the facility plan.

CHAPTER 3

IMPROVED APPLICATION CRITERIA FOR ALTERNATIVE TECHNOLOGY

3.1 General

Alternative technologies such as land treatment and application of wastewater and sludge are encouraged as fully proven technologies (See Chapter 2). In order to be classified as innovative, these fully proven technologies must be analyzed in Step 2 of the screening process (See Section 2.2.2.2 on Page 2.6). In addition to the specific cost and energy criteria, alternative technology leading to: (a) improved operational reliability; (b) better management of toxic materials; (c) increased environmental benefits; or (d) new or improved joint treatment of municipal and industrial wastes qualifies as innovative technology. The intent of these four criteria is to encourage the use of new or improved applications of already proven alternative technologies such as reuse, reclamation, recycle, and energy saving systems that offer an advantage over the current state of the art in one or more of the above categories. As described in Chapter 2, the new or improved applications of alternative technology must include elements of increased risk.

These criteria differ from the cost and energy criteria in that no specific target levels have been provided to quantitatively judge conformance or level of conformance. The intent, however, is to encourage alternative system designs that maximize the above benefits over contemporary practice. Each of the improved application criteria is discussed in the subsequent sections. Subjective qualitative analyses will be required to demonstrate compliance with these criteria. In these analyses, comparisons must be made on a total treatment works or system basis including all appurtenant equipment and processes, sludge handling and disposal processes and techniques. The systems to be used as a basis of comparison must be functionally similar alternative processes that are potentially cost effective as defined by Paragraph 5(c) of the Cost Effectiveness Analysis Guidelines. The period of comparison is the project planning period.

3.2 Improved Operational Reliability

Alternative technology contributing towards improved operational reliability must meet one of the following conditions to qualify as innovative.

1. Provide decreased susceptibility to upsets or interference (Also see Section 3.3.2)

2. Result in reduced occurrence (frequency x duration) of inadequately treated discharges

3. Provide decreased levels of required operator attention and skills

In the comparative analysis, claimed advantages for decreased susceptibility to upsets or interferences must be fully documented. As a minimum, the specific reason(s) for reduced susceptibility must be identified. For example, greater system reliability due to reliability of mechanical components must be documented with evidence such as greater mean time between failure data. It must be clearly identified if the increased operational reliability is due to:

1. Greater mechanical reliability
2. Greater inherent physical, chemical, or biological process stability or reliability, including processes and transformations taking place in the soils of land application systems
3. Improved system design
4. Increased standby or backup facilities
5. Continuous monitoring alert or diversion systems
6. Combinations of 1 through 5

Upsets would include any reduction in the system ability to meet the design effluent quality requirements continuously at flows up to design capacity. Interferences include influent stream factors as well as the impact of all internally generated streams or environmentally imposed conditions within the treatment system leading to total system or system component failure. The comparative analysis must include a reasonable range of potential process upsets and interferences, including the probable frequency of these occurring and their relative magnitude. The basic level of reliability against which the improvement is judged is the greater of: (1) that required by EPA Reliability Guidelines (Report EPA 430-99-74-001); (2) the minimum level specified in the NPDES permit; or (3) that required to meet effluent quality or reuse/reclamation criteria for non-discharging systems.

Reduced occurrence of the discharge of inadequately treated effluent must be made on a mass pollutant basis accounting for the frequency and magnitude of the excessive discharge(s) of the pollutant(s) of concern. The pollutants of concern, unless otherwise identified, are those contained in the NPDES permit for discharging systems including the requirements of BPWWT where applicable.

For non-discharging systems, the pollutants of concern are the major pollutants that the system is designed to remove to meet a pollution control objective or the pollutant(s) that must be removed to insure reuse quality.

For systems employing land application or land utilization practices, criteria for groundwater protection are contained in Alternative Waste Management Techniques for Best Practicable Waste Treatment (BPWPT), (EPA-430/9-75-013). The objective of the BPWPT criteria for land application systems is to protect groundwater for drinking water purposes and other beneficial uses. In the case of groundwater protection for drinking water supplies, the pollutants of concern are those contained in the appropriate sections of the National Primary Drinking Water Standards.

Applications which claim reduction in process upsets or interferences, and/or reductions in the occurrences of inadequately treated discharges simply through use of increased equipment redundancy or abnormally low loading will not normally be considered innovative. Innovative technology may include use of unique operational procedures, land application schedules, materials, and/or equipment which meets the requirements of: (1) decreased susceptibility; or (2) reduced occurrence previously mentioned.

Alternative systems or system components that claim decreased levels of required operator attention and skills must clearly document the differences in system operating and/or maintenance procedures and characteristics that justify the savings. The system upon which the comparison is based must be a functionally similar alternative technology that is potentially cost effective in accordance with Section 5(c) of the Cost Effectiveness Guidelines.

Claims for reduced operator attention due to increased use of automation and instrumentation for alternative technologies must fully document in annual person hours and dollars the savings for all required operator functions including but not limited to:

1. Process monitoring
2. Routine process observations and control changes
3. Effluent quality monitoring
4. Unique process control changes
5. Preventative maintenance activities, including instrument calibration
6. Corrective maintenance activities, including instrument repair
7. Mechanical component maintenance
8. Operation management and supervision
9. Maintenance management and supervision

This trade-off analysis must include documentation of all automated equipment service lifetimes, and maintenance costs under the conditions of their anticipated use.

3.3 Improved Toxics Management

Alternative technology contributing toward better or improved management of toxic materials are those processes, techniques, and practices that reduce the direct or indirect exposure of known toxicants to man or his environment beyond that normally expected in contemporary practice. Better management can also be demonstrated through enhanced controls such as in improved monitoring. Reduction in exposure may be brought about by chemical, physical, or biological mechanisms that reduce or eliminate the recycling of toxicants within or between media. Reduction of recycling and exposure potential may be achieved by:

1. Isolation
2. Modification of the chemical form (detoxification)
3. Destruction by such methods as thermal or biological oxidation

Applications qualifying alternative technology as innovative due to improved toxics management must: (a) identify the significant exposure pathways for the specific system under consideration; (b) document the mechanism(s) of improved management; and (c) identify the specific toxic compound(s) or classes of organic compounds that are reduced or better controlled. Although the priority pollutants shown in Table 3-1 are of primary concern, the requirements (a), (b), and (c) above also apply to other known or identified toxic materials.

The intent of the improved management of toxic material criteria is to encourage the use of specific exposure reduction mechanisms that result in improvement over the current state-of-the-art wastewater management and disposal techniques. Generalized claims of improved toxics management not meeting the requirements of items (a), (b), and (c) will not be considered as meeting the criteria.

The more common pathways of toxics movement in urban areas are shown in Figure 3-1. Toxic substances originate from four sources: industrial, residential, commercial or institutional, and non-point. They can be disposed of in the air, on the land, or in surface or ground water. Man can be affected by inhalation or ingestion of affected water or food products, or by exposure. Controlling legislation is found in the Clean Air Act (CAA), Clean Water Act (CWA), and Resource Conservation and Recovery Act (RCRA), and any proposed technology would have to comply with applicable sections of these laws or regulations promulgated as a result of the laws.

Figure 3-1 is comprehensive in nature, covering all aspects of toxics movement, but alternative technology which provides for improved toxics management and that would be eligible for funding under the CWA excludes portions of this chart. Generally, only publicly owned treatment works and on-site systems would become involved in funding under the Construction Grants Program. For example, stormwater control projects are not innovative solutions to toxics mangement and are limited in eligibility. Also, bypasses are not allowed and would not be considered innovative.

Improved toxics management opportunities applicable to alternative technology are identified as major control points and are denoted by the darnkened dots. In general, better management of toxics can be found in improved source control, i.e., improved pretreatment of industrial wastes and improved removal at the plant prior to sludge treatment and disposal or prior to effluent disposal. As is apparent from the figure, once toxic materials reach the plant, the toxics management question usually involves a comparison of trade-offs because the toxic materials which are present will be found either in the sludge or effluent unless they are detoxified or destroyed.

While it is not currently possible to quantitatively describe all possible transformations of the priority pollutants in Table 3-1, it is possible to describe many of the physical, chemical, and biological characteristics of broad classes of toxic materials that permit qualitative prediction and

TABLE 3-1

HENRY'S LAW CONSTANTS FOR EPA PRIORITY POLLUTANTS

		H(1)	VP(2) (mmHg)	Solubility(3) (mg/ℓ)
1.	*acenaphthene	0.009(c)	3.0×10^{-2}	3.88
2.	*acrolein	0.0046 (b)	300.	200,000.
3.	*acrylonitrile	0.0030 (b)	100.	93,000.
4.	*benzene	0.22 (b)	95.2	1780.
5.	*benzidine			
6.	*carbon tetrachloride (tetrachloromethane)	1.2(c)	91.3	800.
	*chlorinated benzenes (other than dichlorobenzenes)			
7.	chlorobenzene	0.19(d)	15.	448.
8.	1,2,4-trichlorobenzene			
9.	hexachlorobenzene			
	*chlorinated ethanes (including 1,2-dichloroethane, 1,1,1-trichloroethane and hexachloroethane)			
10.	1,2-dichloroethane	0.050 (c)	82.	8700.
11.	1,1,1-trichloroethane	0.17(b)	100.	4400.
12.	hexachloroethane	0.05(c)	0.33	8.
13.	1,1-dichloroethane	0.24(c)	226.	5100.
14.	1,1,2-trichloroethane	0.037 (c)	25.	4420.
15.	1,1,2,2-tetrachloroethane	0.020 (c)	6.5	3000.
16.	chloroethane	0.73 (c)	1200.	5700.
	*chloroalkyl ethers (chloromethyl, chloroethyl and mixed ethers)			
17.	bis(chloromethyl) ether			
18.	bis(2-chloroethyl) ether			
19.	2-chloroethyl vinyl ether (mixed)			
	*chlorinated naphthalene			
20.	2-chloronaphthalene			
	*chlorinated phenols (other than those listed elsewhere; includes trichlorophenols and chlorinated cresols)			
21.	2,4,6-trichlorophenol			
22.	parachlorometa cresol			
23.	*chloroform (trichloromethane)	0.16 (c)	192.	7840.
24.	*2-chlorophenol	0.001 (b)	5.0	28,000.
	*dichlorobenzenes			
25.	1,2-dichlorobenzene	0.081 (b)	1.0	100.
26.	1,3-dichlorobenzene	0.13 (c)	2.0	123.
27.	1,4-dichlorobenzene	0.10 (c)	1.0	79.

TABLE 3-1(Continued)

		H(1)	VP(2) (mmHg)	Solubility(3) (mg/ℓ)
	*dichlorobenzidine			
28.	3,3'-dichlorobenzidine			
	*dichloroethylenes (1,1-dichloroethylene and 1,2-dichloroethylene)			
29.	1,1-dichloroethylene	7.80	598.	400.
30.	1,2-trans-dichloroethylene	0.27	326.	6300.
31.	*2,4-dichlorophenol	0.002	1.0	4500.
	*dichloropropane and dichloropropene			
32.	1,2-dichloropropane	0.095(b)	42.	2700.
33.	1,2-dichloropropylene (1,3-dichloropropene)	0.095(b)	43.	2700.
34.	*2,4-dimethylphenol			
	*dinitrotoluene			
35.	2,4-dinitrotoluene			
36.	2,6-dinitrotoluene			
37.	*1,2-diphenylhydrazine			
38.	*ethylbenzene	0.27(b)	7.	152.
39.	*fluoranthene			
	*haloethers (other than those listed elsewhere)			
40.	4-chlorophenyl phenyl ether			
41.	4-bromophenyl phenyl ether			
42.	bis(2-chloroisopropyl) ether	0.005	0.85	1700.
43.	bis(2-chloroethoxy) methane			
	*halomethanes (other than those listed elsewhere)			
44.	methylene chloride (dichloromethane)	0.12(c)	438.	16,700.
45.	methyl chloride (chloromethane)	0.38(c)	760.	5380.
46.	methyl bromide (bromomethane)	4.39(b)	760.	900.
47.	bromoform (tribromomethane)	0.030(d)	5.6	3190.
48.	dichlorobromomethane			
49.	trichlorofluoromethane	5.11(c)	760.	1100.
50.	dichlorodifluoromethane	98.8(c)	4250.	280.
51.	chlorodibromomethane			
52.	*hexachlorobutadiene			
53.	*hexachlorocyclopentadiene			
54.	*isophorone	0.0002(b)	0.38	12,000.
55.	*naphthalene	0.017(c)	0.87	30.
56.	*nitrobenzene	0.0005(b)	0.15	1900.
	*nitrophenols (including 2,4-dinitrophenol and dinitrocresol)			
57.	2-nitrophenol	0.0036(b)	1.0	2100.
58.	4-nitrophenol			
59.	*2,4-dinitrophenol			

TABLE 3-1 (Continued)

		H(1)	VP(2) (mmHg)	Solubility(3) (mg/ℓ)
60.	4,6-dinitro-o-cresol	$8x10^{-6}$(a)	$1x10^{-4}$	130.
	*nitrosamines			
61.	N-nitrosodimethylamine			
62.	N-nitrosodiphenylamine			
63.	N-nitrosodi-n-propylamine			
64.	*pentachlorophenol	0.0001(b)	$1.1x10^{-4}$	14.
65.	*phenol	$1.3x10^{-5}$(c)	0.20	82,000.
	*phthalate esters			
66.	bis(2-ethylhexyl) phthalate			
67.	butyl benzyl phthalate			
68.	di-n-butyl phthalate	0.0030(c)	0.1	500.
69.	di-n-octyl phthalate			
70.	diethyl phthalate			
71.	dimethyl phthalate	0.00002(b)	0.01	5000.
	*polynuclear aromatic hydrocarbons			
72.	benzo(a)anthracene (1,2-benzanthracene)			
73.	benzo(a)pyrene (3,4-benzopyrene)			
74.	3,4-benzofluoranthene			
75.	benzo(k)fluoranthane (11,12-benzofluoranthene)			
76.	chrysene			
77.	acenaphthylene			
78.	anthracene	0.067(c)	0.04	0.075
79.	benzo(ghi)perylene (1,12-benzoperylene)			
80.	fluorene	0.010(c)	0.012	1.90
81.	phenanthrene	0.006(c)	$3.4x10^{-3}$	1.18
82.	dibenzo(a,h)anthracene (1,2,5,6-dibenzanthracene)			
83.	indeno (1,2,3-cd)pyrene (2,3-o-phenylenepyrene)			
84.	pyrene			
85.	*tetrachloroethylene	1.1 (c)	18.6	150.
86.	*toluene	0.27(c)	28.	515.
87.	*trichloroethylene	0.48(c)	74.	1000.
88.	*vinyl chloride (chloroethylene)	301.(c)	2660.	60.
	pesticides and metabolites			
89.	*aldrin	0.10(c)	$1.4x10^{-4}$	0.027
90.	*dieldrin	$8.2x10^{-6}$	$5.4x10^{-6}$	0.19
91.	*chlordane (technical mixture & metabolites)			
	*DDT and metabolites			
92.	4,4'-DDT	0.0016(c)	$1.9x10^{-7}$	$3.1x10^{-3}$
93.	4,4'-DDE (p,p'-DDX)			
94.	4,4'-DDD (p,p'-TDE)			

TABLE 3-1(Continued)

		H(1)	VP(2) (mmHg)	Solubility(3) (mg/ℓ)
	*endosulfan and metabolites			
95.	a-endosulfan-Alpha			
96.	b-endosulfan-Beta			
97.	endosulfan sulfate			
	*endrin and metabolites			
98.	endrin			
99.	endrin aldehyde			
	*heptachlor and metabolites			
100.	heptachlor	0.11 (c)	$3x10^{-4}$	0.056
101.	heptachlor epoxide			
	*hexachlorocyclohexane (all isomers)			
102.	a-BHC-Alpha	0.094 (c)	0.06	10.
103.	b-BHC-Beta	0.53 (c)	0.17	5.
104.	r-BHC (lindane)-Gamma	$1.5x10^{-5}$(c)	$9.4x10^{-6}$	10.
105.	g-BHC-Delta			
	*polychlorinated biphenyls (PCB's)			
106.	PCB-1242 (Arochlor 1242)	0.023 (c)	$4.1x10^{-4}$	0.24
107.	PCB-1254 (Arochlor 1254)	0.11 (c)	$7.7x10^{-5}$	0.012
108.	PCB-1221 (Arochlor 1221)			
109.	PCB-1232 (Arochlor 1232)			
110.	PCB-1248 (Arochlor 1248)	0.14 (c)	$4.9x10^{-4}$	$5.4x10^{-2}$
111.	PCB-1260 (Arochlor 1260)	0.29 (c)	$4.1x10^{-5}$	$2.7x10^{-3}$
112.	PCB-1016 (Arochlor 1016)			
113.	*toxaphene	2.97(c)	.40	3.0
114.	*antimony (total)			
115.	*arsenic (total)			
116.	*asbestos (fibrous)			
117.	*beryllium (total)			
118.	*Cadmium (total)			
119.	*chromium (total)			
120.	*copper (total)			
121.	*cyanide (total)			
122.	*lead (total)			
123.	*mercury (total)			
124.	*nickel (total)			
125.	*selenium (total)			
126.	*silver (total)			
127.	*thallium (total)			
128.	*zinc (total)			
129.	2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)			

(1) H is calculated Henry's Law Constant
(2) VP is vapor pressure of compound
(3) Solubility is compound solubility in water

*Specific compounds and chemical classes as listed in the consent degree

TABLE 3-1 (Continued)

(a) = 288°K(15°C)
(b) = 293°K(20°C)
(c) = 298°K(25°C)
(d) = 303°K(30°C)

Henry's Law Constant Calculation:

$$H = \frac{16.04\ PM}{(S)(T)}$$

H = Henry's Law Constant (dimensionless)
P = vapor pressure of compound (mmHg)
M = molecular weight of compound
S = solubility of compound (mg/ℓ)
T = temperature °Kelvin

References

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Physical Chemistry (Textbook), Morrison & Boyd, Allyn and Bucan, Inc., Second Edition 1966.

"Rate of Evaporation of Low-Solubility Contaminants from Water Bodies to Atmosphere," Mackay and Leinonen, Environmental Science and Technology, Vol. 9, Number 13, December 1975, pp. 1178 - 1180.

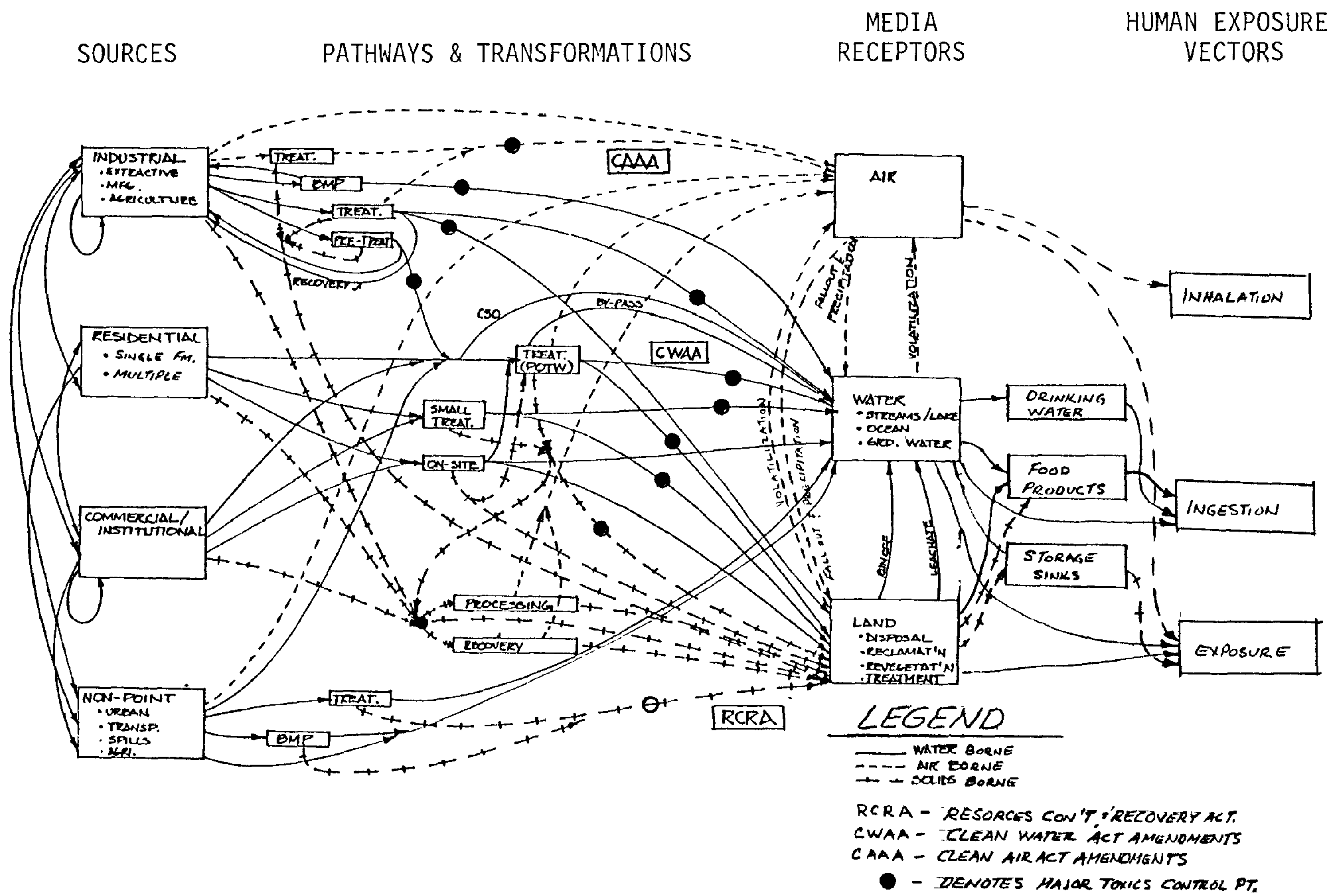
"Interphase Transfer Processes, II, Evaporation Rates of Chloromethanes, Ethanes, Ethylenes, Propanes, Propylenes from Dilute Aqueous Solutions Comparison with Theoretical Predictions," Wendell L. Dilling, Environmental Science and Technology, Vol. 11, Number 4, April 1977, pp. 405-409.

"Partition Coefficient and Bioaccumulation of Selected Organic Chemicals," Chiou, Freed, Schmedding, and Kohnert, Environmental Science and Technology, Vol. 11, Number 5, May 1977, pp. 475-478.

"Pesticide Manual," British Crop Protection Council, Fourth Edition, 1974.

FIGURE 3-1

PATHWAYS FOR TOXICS MOVEMENT IN URBAN AREAS



judgement of their behavior in the more common alternative technology processes and techniques. The loss of toxic organic compounds to the atmosphere during aeration of wastewater, the transformation of inorganic and organic toxicants by common biological treatment processes, the adsorbability of toxicants by activated carbon, and the transformation and effect on selected inorganic and organic toxicants by soil systems are discussed in the following sections of this chapter. The loss of toxic organic compounds to the atmosphere during aeration, the transformations during biological treatment and adsorbability are included since many land application and reclamation systems include these processes.

3.3.1 Loss of Toxic Organic Compounds to the Atmosphere During Conventional Wastewater Treatment or Application to Land

In any process of aeration, wherein air-liquid contact is provided, the opportunity exists for transfer of organic compounds from the liquid phase to the gas phase. Thus, in wastewater treatment processes such as aerated lagoons, activated sludge, fixed film contacting systems or spray irrigation application systems, the potential of stripping as a removal mechanism for certain toxic organic compounds should be recognized. Stripping may be caused by air-liquid contact due to bubble diffusion, mechanical aeration, spraying or any point where significant surface turbulence occurs.

In the proposed design, it must be shown that improvement by loss of toxics to the atmosphere is part of the design and not a happenstance occurrence. Also, the ultimate fate of the toxics in the atmosphere must be addressed.

The extent of removal of a compound by stripping is governed chiefly by two factors. One factor is the tendency of the compound to establish an equilibrium between the gas and liquid phases. This is the principle of Henry's Law which states that the partial pressure of the compound (a measure of the concentration in the gas phase) is equal to a constant (Henry's Law constant) times the concentration of the compound in the liquid phase. Henry's Law constant can be considered a partition coefficient which describes the relative tendency for the compound to partition between the gas and liquid at equilibrium in accordance with the following equation:

$$H = \frac{C_g}{C_e} \qquad (3\text{-}1)$$

where H = Dimensionless Henry's Law constant
C_g = Concentration in gas phase
C_e = Concentration in liquid phase

Henry's Law constant is a property of the compound which can be calculated by dividing the compound's vapor pressure (P) by its solubility (S). H can also be determined experimentally. The calculated values for H, vapor pressure, and solubility for 59 of the 129 priority pollutants are shown in Table 3-1. Recently published data on several organic compounds have shown fairly close agreement between calculated and experimentally determined values. Temperature obviously affects the value of H, since both solubility and especially vapor pressure are temperature dependent. The presence of electrolytes, surface active agents, lipids and particulate matter in sewage may all affect the equilibrium to some extent. Examples of calculated values of H at 25°C in clean water, taken from the literature are: chloroform - 0.16, carbon tetrachloride - 1.2, 1,2-dichloroethane - 0.05, benzene - 0.22, DDT - 1.6×10^{-3}, dieldrin - 8.2×10^{-6}, Arochlor 1260 - 0.29. Examining the values for dieldrin and Arochlor, both with very low vapor pressures, it is seen that the PCB is much more likely to be stripped than is the pesticide, because its extremely low solubility (in pure water) results in a fairly high Henry's Law constant. A more soluble PCB, Arochlor 1242, has a calculated H of 0.023. Laboratory experiments using Arochlor 1242 showed only minimal loss by stripping, in keeping with its low value of H. It should be remembered that very little data are available which experimentally verify the calculation of H from solubility and vapor pressure. Thus, the calculated values should be used with caution. However, this calculated value is at least a tool which can be used to provide an estimation of a compound's tendency to be stripped from solution in a given water or wastewater.

The air-liquid partition coefficient, H, can be determined by fairly simple laboratory equilibration tests providing analytical methods are available for the compound of interest in wastewater. Thus, the amenability of a compound to removal from any wastewater can be observed.

The removal of a strippable compound depends not only on its equilibrium partition ratio but also on the contact opportunity or the intensity and duration of the aeration. In a diffused air suspended growth system, the removal of a compound by stripping can be estimated assuming that the air leaving the process is saturated with the compound in accordance with Henry's Law with the process at steady state. The resulting expression is:

$$\frac{C}{C_i} = \frac{1}{1 + (Qa/Qi)\,H} \qquad (3\text{-}2)$$

where C is the effluent concentration, mg/l
C_i is the influent concentration, mg/l
Qa/Qi is the air to water ratio, $m^3/hr/m^3/hr$

As an example, if a suspended growth process is operated at one standard cubic foot of air per gallon of wastewater, and the partition coefficients at 25°C given above apply, the removal of chloroform would be estimated at 55%, carbon tetrachloride at 90% and 1-2-dichloroethane at 23%.

Transfer of compounds with high values of H (>0.1) is controlled by the resistance in the liquid film side of the air-water interface. Liquid film resistance also controls the rate of oxygen dissolution during aeration. Therefore, a reasonable assumption is that the more efficient the aeration device the more efficient will be the stripping of volatile compounds.

Aerated grit chambers, hydraulic jumps, overflow weirs, clarifier surfaces, turbulent flow in open channels all provide some air-wastewater contact opportunity and thus have potential for loss of volatile compounds from solution.

Very little data on removal of volatile compounds by alternative wastewater treatment processes or processes used as pretreatment for land application systems are available. There have been very few compounds for which Henry's Law constants have been experimentally determined. The best estimate for removal that can be made for most compounds now is based on calculated values of the partition coefficient from published solubility and vapor pressure data summarized in Table 3-1 and simple mathematical relationships based on mass balances at steady state.

The above methodology can be used for estimating the relative loss of organic compounds to the atmosphere from commonly used wastewater aeration systems. The same procedures may also be used for land application systems where air/water contact through aerosol formation may be significant. For these cases, equation 3-2 would be modified with a similar expression describing the air/water contact opportunity.

There could be another mechanism involved also, that is, loss of compound by discharge in the aerosol. This is probably not significant for the more volatile compounds but could be for other compounds, especially those that tend to accumulate at the air-water interface.

3.3.2 Transformation of Toxics Through Biological Treatment Processes Used as a Part of Alternative Technology Treatment Systems

In discussing the fate and effects of toxics during biological treatment, toxic materials can be arranged into two broad classes: one consisting of inorganics and the other synthetic organics.

3.3.2.1 Inorganics

Generally, inorganic toxics are represented by such elements as copper, nickel, zinc, chromium, lead, silver, arsenic, cadmium, and mercury. Also included in this class is the cyanide radical due to its association with metal plating operations.

Innovative suggestions for enhanced inorganic control should recognize that certain metals can cycle between several valence states that can influence removal or concentration of the element through the treatment process, depending on the prevailing oxidation-reduction level of the process. Chromium, for instance, exists in the soluble hexavalent form in aerobic processes and insoluble trivalent chromium in anaerobic environments. Additionally, elements such as mercury, can cycle between an inorganic form and a volatile organic form such as methyl mercury.

In the case of inorganics, as well as the inorganics to be discussed below, the phenomenon of acclimation in biological systems can be encountered. Upon the first introduction of a toxicant into a biological system, a deteriorated performance is noted; however, with continued dosage of the toxicant up to some upper concentration, the system gains the ability to tolerate the toxicant and normal performance returns. Response to the cyanide radical is typical of this type of toxicant stress.

Generally, biological secondary treatment processes can tolerate up to 5 mg/l of the inorganic toxicants without noticeable impairment of treatment efficiency. The composition of municipal wastewater and the chemistry of the inorganic toxics is such that re-allocation of the inorganics occurs during treatment and the materials are conservative in nature. Thus, if the inorganics enter the POTW at concentrations of 1 to 5 mg/l in the raw wastewater and removal occurs to yield low effluent residuals, the inorganics will be found in concentrated sidestreams such as primary sludge, waste biological sludge, digested sludge, digester supernatant, or lagoon bottom sediment. Mainly, the inorganics will exist as insoluble products in these sidestreams or sludge deposits. Assessment of potentially innovative technology to enhance inorganic toxics control must be based on the overall environmental trade-off of low final effluent residuals versus concentration of the inorganics in the sludge or sludge handling operations of municipal treatment systems and their subsequent fate during ultimate disposal practices in accordance with the overall requirements described in Section 3.1.

3.3.2.2 Organics

The situation with potentially innovative processes for enhanced control of organic toxics is more complicated than the inorganic class. In addition to loss to the atmosphere previously discussed, the organic toxics could yield the following type response upon introduction into either an aerobic or anaerobic treatment process:

1. Inhibition - the organic compound interferes with the proper functioning of the biological process and treatment efficiency deteriorates.

2. Non-biodegradability - the organic compound does not effect the treatment efficiency but passes substantially unchanged through the treatment system.

3. Primary degradation - the biological process transforms the organic compound into a different material which no longer responds to the specific analytical test procedure.

4. Ultimate degradation - the organic compound is mineralized into oxidized forms such as carbon dioxide and water and cellular mass.

5. Acclimation - initial introduction of the organic compounds does not show degradation but continued exposure causes a population shift which eventually results in degradation of the toxicant.

6. Sorption - the organic compound is removed from the mainstream by sorption onto soil particules, primary sludge, or mixed liquor particles without any biodegradation occurring.

Innovative suggestions will probably center on controlling one or more of the above type responses. Likely candidate process selections or modifications are as follows:

1. Inhibition Control - Aeration (previously described)

2. Chemical Oxidation Before the Secondary Process with Chemicals Like Ozone or Chlorine Dioxide - This approach is probably not cost effective due to the presence of high concentrations of competing organic materials in the wastewater.

3. Non-Degradable Control - Likely suggestions would be chemical oxidation before the secondary process. Probably not cost effective due to high concentrations of other organics. Pre-chemical oxidation might produce toxic compounds from innocuous materials. Laboratory documentation of specified approaches should be furnished.

4. Primary, Ultimate Degradation and Acclimation - Several control approaches can be considered for enhancing these reactions. Most will probably center on sludge age (solids retention time) control to encourage adaptive or constitute enzymatic population shifts. Also staged sequential reactors to manage the F/M ratios or environmental conditions for isolated biomass are a likely suggestion.

5. Proprietary Materials - There is an emerging interest in proprietary materials generically listed as biocatalytic additives. These are specifically prepared enzyme and/or microorganism cultures packaged in concentrated form for addition to treatment processes. To date there exists very little information on the real benefit of these type additives. Any suggested innovative process utilizing these type additives should be documented with results of pilot studies employing adequate controls. The diverse life forms in activated sludge and the huge mass of volatile solids under aeration make it unlikely that an additive could economically have a sustained beneficial impact upon treatment efficiency.

6. Sorptive Materials - Addition of sorptive materials such as activated carbon may be suggested for enhanced toxic control. The main decision point for these type approaches will be on the economics of replenishment of the sorptive agent and/or its regeneration to an active form. Comprehensive analytical documentation of the fate of toxics through the system would be necessary for evaluation.

7. Sorption - Primary sludge, soil particles, waste biological and activated sludges have very high surface areas which favor sorption of organics. Many toxic organics which are only slightly soluble can be sorbed to these surfaces and show removal through the treatment process even though there was no biodegradation. Pesticides in particular have been found to preferentially accumulate in fat and grease scum layers. Schemes for enhanced treatment of toxics should be documented by studies employing mass balances of complete treatment systems.

3.3.2.3 Analytical Considerations

The priority pollutants can be classified into five general groups (other than the inorganics and cyanide) as follows:

1. Carcinogenic, potentially carcinogenic and teratogenic compounds
2. Polycyclic aromatic hydrocarbons
3. Xenobiotics (new synthesized compounds such as pesticides)
4. Aromatic compounds and their halogenated and nitro derivatives
5. Halogenated alkyl compounds

Analytical procedures for mixtures of these materials in trace amounts is at the frontier stage of development. Highly specialized equipment such as gas chromatography and mass spectrography coupled with computer capability is necessary for coherent results. Any proposed innovative process for enhanced toxic control should be documented by comprehensive analytical data. The laboratory furnishing such data should be certified by the Environmental Monitoring and Support Laboratory as to its capability to perform such tedious analyses.

3.3.3 Activated Carbon Used as a Part of Alternative Technology Systems

It is possible that some reuse/reclamation projects could employ activated carbon for removal of organic materials including toxic compounds. The use of activated carbon has been shown to be a feasible unit process for removal of toxic organic compounds from water and wastewater. An additional benefit of the use of activated carbon is the safe ultimate disposal of the toxic compound when the exhausted carbon is thermally regenerated for recycle.

Activated carbon is a highly porous material having a surface area of approximately 1,000 square meters per gram. Adsorption is a phenomenon in which the molecules being adsorbed are attached to the surface of the carbon. A number of forces are involved in the adsorption process. These include:

1. Attraction of carbon for the solute
2. Attraction of carbon for the solvent
3. Solubilizing power of the solvent
4. Association
5. Ionization
6. Effect of solvent on orientation at the interface

7. Competition from other solutes in solution
8. Co-adsorption
9. Molecular size
10. Carbon pore size distribution of the carbon
11. Surface area of the carbon

More recently, it is recognized that biological activity plays a major role in the removal of organics by activated carbon.

Efficiency of adsorption of organic compounds depends on the relative adsorbability of the individual components. Based on the factors listed above, some generalizations can be made regarding the adsorbability of certain compounds. Solubility of the organic contaminant in water is a very important factor. As solubility decreases, adsorption capacity increases. Factors such as pH, concentration, temperature, and ionic strength which affect solubility will also affect adsorption. Molecular weight and polarity have a pronounced effect. Usually an increase in molecular weight improves adsorption. Non-polar molecules are more strongly adsorbed than polar molecules. Molecular structure is another important factor. The influence of substituent groups on adsorbability can be described in general terms. Hydroxyl usually reduces adsorbability because of increased polarity. Amino groups have a similar but greater effect than hydroxyl. Many amino acids are, in fact, not adsorbed to any appreciable extent. Carbonyl groups have a variable effect depending on the host molecule. Sulfonic groups are polar and decrease adsorbability. Nitro groups often increase adsorbability. Generalizations based on molecular structure can also be made. Aromatic and substituted aromatic compounds are, in general, more adsorbable than aliphatic compounds. Amines, ethers, and halogenated aliphatic compounds adsorb more efficiently than low molecular weight alcohols, glycols, or low molecular weight straight chain unsubstituted aliphatic compounds.

The quantitative effect of the factors discussed above can be expressed by the Freundlich adsorption equation:

$$X/M = KC_f^{1/n} \qquad (3\text{-}3)$$

where: $X = C_o - C_f$ which is the amount of compound adsorbed from a given volume of solution

M is the weight of carbon

C_o is the initial amount of compound in the untreated solution

C_f is the amount of compound remaining after carbon treatment

K and $1/n$ are empirical constants

Graphically, K is the X/M intercept of the isotherm plot at $C_f = 1$ and $1/n$ is the slope of the line when the equation is plotted on logarithmic paper. The intercept is roughly an indicator of adsorption capacity and the slope of adsorption intensity. The concentration of compound on the carbon in equilibrium with a concentration C_f is expressed by the X/M value. Since X/M values are dependent on the initial concentration of compound, comparisons among compounds must be made at similar concentrations.

The effect of substitutions on the benzene ring on adsorption capacity is illustrated in Table 3-2.

Many of the compounds identified as pesticides and herbicides on the Environmental Protection Agency's List of Priority Pollutants are chlorinated aromatic hydrocarbons. This group of compounds is readily adsorbed on activated carbon. Table 3-3 presents a summary of adsorption capacities at an initial concentration of 0.01 mg/l.

Adsorption capacities for several chemical carcinogens are summarized in Table 3-4. Polynuclear aromatic hydrocarbons, many of which are known carcinogens, are also strongly adsorbed on carbon.

Although activated carbon is very efficient for removal of many types of organic compounds from wastewater, it does not remove all classes of compounds. Table 3-5 lists some compounds which are not appreciably adsorbed by activated carbon.

Inorganic compounds also exhibit a wide range of adsorbability. Strongly dissociated salts, such as sodium chloride, are not adsorbed by activated carbon. Iodine, gold permanganates, dichromates, mercuric salts, molybdates, ferric salts, arsenates, and silver salts are adsorbed on activated carbon. Some of the metal salts are actually chemically reduced to elemental metal by activated carbon.

In summary, adsorption on activated carbon is an effective method for removal of many of the toxic compounds on the list of priority pollutants.

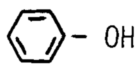
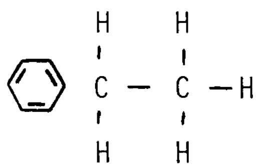
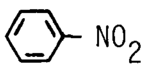
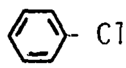
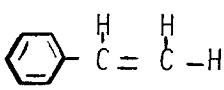
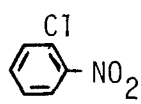
3.3.4 The Fate and Effects of Toxic Substances on Soil

3.3.4.1 General

Toxic substances which are present in wastewater can find their way into soil by means of land application of effluent, sludge, and septage after various stages of treatment. The regulations published on September 13, 1979, "Criteria for Classification of Solid Waste Disposal Facilities," do not affect land application of municipal effluents or location or operation of septic tanks but do affect in a major way the land application of sludges and septic tank pumpings/septage. The following discussion addresses both as sludge. Also, discussion is on sludge application rather than application of effluents since many of the same principles are applicable to both practices. For more information on land treatment and disposal of wastewater, refer to the process design manual for Land Treatment of Municipal Wastewater, October 1977.

TABLE 3-2

ADSORPTION CAPACITIES FOR BENZINE AND SUBSTITUTED BENZENES (2)

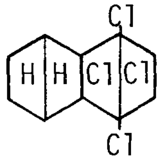
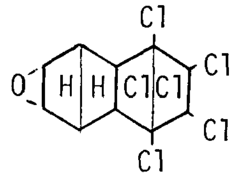
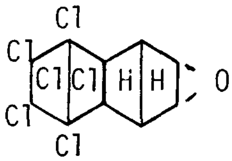
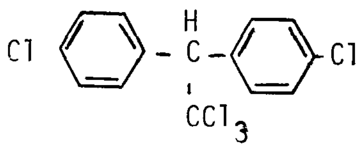
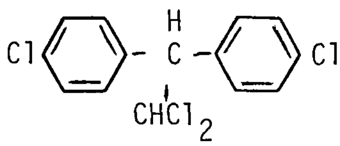
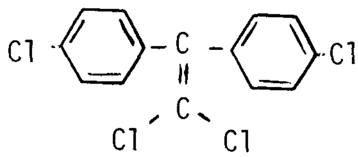
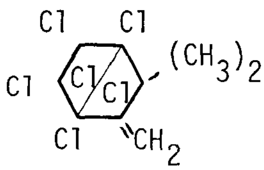
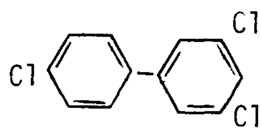
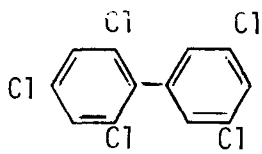
COMPOUND	STRUCTURE	ADSORPTION CAPACITY (mg/g)(1)
BENZENE		0.7
PHENOL		21
ETHYLBENZENE		53
NITROBENZENE		68
CHLOROBENZENE		93
STYRENE		120
1-CHLORO-2-NITROBENZENE		130

(1) Measured at 1 mg/l initial concentration

(2) R. A. Dobbs, R. J. Middendorf and J. M. Cohen "Carbon Adsorption Isotherms for Toxic Organics," Municipal Environmental Research Laboratory U.S. Environmental Protection Agency Cincinnati, Ohio 45268 (May 1978).

TABLE 3-3

ADSORPTION OF PESTICIDES AND RELATED COMPOUNDS ON ACTIVATED CARBON (2)

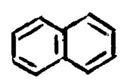
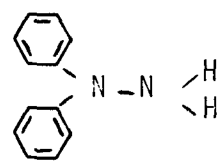
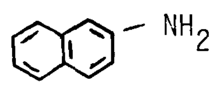
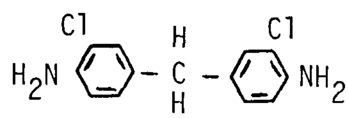
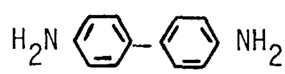
COMPOUND	STRUCTURE	ADSORPTION CAPACITY (mg/g)(1)
ALDRIN		3.5
DIELDRIN		9.3
ENDRIN		24
DDT		7.3
DDD		27
DDE		4.8
TOXAPHENE		21
AROCLOR 1242		19
AROCLOR 1254		6

(1) Measured at 0.01 mg/l initial concentration

(2) F. Bernandin, Jr., and E. M. Froelich, "Practical Removal of Toxicity by Adsorption," Presented 30th Annual Purdue Industrial Waste Conference, Purdue University, Lafayette, Indiana, May 8-9, 1978

TABLE 3-4

ADSORPTION CAPACITIES FOR CHEMICAL CARCINOGENS

COMPOUND	STRUCTURE	ADSORPTION CAPACITY (mg/g)(1)
NAPHTHALENE		169
1, 1-DIPHENYLHYDRAZINE		150
β-NAPTHYLAMINE		10
4-4'-METHYLENE-BIS (2-CHLOROANILINE)		240
BENZIDINE		173

(1) Measured at 1.0 mg/l initial concentration

TABLE 3-5

COMPOUNDS NOT ADSORBED BY ACTIVATED CARBON (1)

Dimethylnitrosamine
Acetone Cyanohydrin
Butylamine
Choline Chloride
Cyclohexylamine
Diethylene Glycol
Ethylenediamine
Triethanolamine
Ethanol

(1) R. A. Dobbs, R. J. Middendorf and J. M. Cohen "Carbon Adsorption Isotherms for Toxic Organics," Municipal Environmental Research Laboratory U.S. Environmental Protection Agency Cincinnati, Ohio 45268 (May 1978).

Application of sludge to land, especially agricultural lands, must be examined in terms of protection of human health and future land productivity. This is due to the present limited knowledge as to the full extent to which this practice could result in the entry of toxics substances in toxic amounts into the human food chain. There is strong potential for improved toxics management of alternative technologies in these areas. Better management of the toxic substances listed in Table 3-1 would qualify as innovative; however, the September 13, 1979 regulations establish maximum acceptable levels of two toxic substances--cadmium and PCB's. These should be addressed as minimum requirements. Better management of toxic substances could be an improved method of meeting these minimum criteria.

Significant quantities of potentially toxic substances can be applied to soil without developing phytotoxicity, producing crops with harmful concentrations or causing ground or surface water pollution or contamination if municipal sewage sludge is applied at fertilizer rates and good crop and soil management practices are followed. Proper sludge disposal practice has the benefit of providing a soil conditioner and conserving and recycling organic matter, N, P, and trace elements. In recent years, the intentional application of persistent pesticides and the incidental application of industrial compounds and elements that are potentially toxic to plants, animals, or man have occurred without adequate research to define the ultimate effects. Municipal wastewater sludge can be applied to soil, but it should be done in a way that will preserve the present and future integrity of soils and protect them from impairment of their capacity to produce a wide variety of adapted crops and protect public health. Beneficial use of sludge will require careful sludge and site selection and site management. Following the requirements of the September 13, 1979 regulations and the guidance provided in the Sludge Management Bulletin ("Municipal Sludge Management: Environmental Factors, EPA 430/9-77-004; October 1977; MCD-28 and various Agency technical reports) will help to insure that sludge is applied in a safe and beneficial manner.

3.3.4.2 Site Selection for Improved Toxics Management

A soil performs many functions that are important to its role as an assimilator of wastes. It transforms wastes by chemical, physical, and biological means. It filters, buffers, and adsorbs. The efficiency with which the soil accepts and transforms toxic wastes into innocuous or beneficial compounds and elements is determined by its physical and chemical properties. The soil is a natural body at the earth's surface that supports or is capable of supporting plant growth. It consists of a complex mixture of organic and mineral matter, air, and water. Optimum conditions for plant growth exist when pore space constitutes about half of the soil. The soil is inhabited by a heterogenous population of organisms including bacteria, actinomycetes, fungi, protozoa, algae, micro and macro animals, and higher plants.

Careful site selection can prevent many of the problems that can result from an improperly designed and managed system. Soil properties vary widely, so it is important to manage wastewater and sludge utilization sites according to soil characteristics.

An ideal site for improved management of sludge borne toxicants would have the following soil, geologic, and landscape characteristics: (Careful engineering design and site management can compensate for some undesirable characteristics):

1. Gentle slopes that are short with a closed drainage system
2. Moderate infiltration rate
3. Permeable to water and roots
4. Thick soil with no zones that remain saturated for extensive time periods, and no highly porous material within a depth of five feet
5. High cation adsorption capacity. Soils high in organic matter and cation exchange capacity have substantial capacity to adsorb cations and prevent increases of available metals in the soil solution.

6. Neutral to moderately alkaline pH.
7. Well-drained soil with high moisture-carrying capacity

The steepness, length, and shape of slopes influence the rate of runoff and thus the risk of erosion from a tract of land. Slopes of less than 3% are desirable. Those of 3% to 8% present some risk of erosion and require some soil erosion control conservation practices. Slopes steeper than 8% should be used only with a carefully designed system to control runoff and erosion.

In addition to the above, an ideal site would be remote from public access or water supply. Also, the future use of the site beyond the expected life for application purposes would be considered.

3.3.4.3 Effect of Soil Properties on Fate of Organic and Inorganic Toxicants

Physical, chemical, and biological properties of soils help determine their capacity to assimilate wastewater and sludge constituents and attenuate their pollution potential. The following basic properties determine water intake and movement; moisture-air relationships; availability, adsorption, and movement of some nutrients and other elements; and plant root distribution under given climatic and land use conditions.

Texture is an important consideration for selection of a site for sludge spreading. The proportion of sand, silt, and clay strongly influences moisture holding capacity, permeability, infiltration rates, and adsorption capacity. Clay has a much greater surface area than the silt or sand, so it gives to a soil the capacity to adsorb ions and hold moisture. Most physical and chemical reactions in soils are determined by the amount and kind of clay and organic matter present.

Bulk density, porosity, and soil structure strongly influence water and air movement, moisture-holding capacity, and plant root distribution. Cation exchange capacity, pH, the percentage of cation exchange sites occupied by bases, and the kinds of ions adsorbed influence the acceptable application rate and the effects of many sludge components when they are added to soil.

The rate at which soils will take in water is a function of the size, shape, and number of their pores. Fine-textured soils have many pores, but they are usually small and disconnected and transmit water slowly, whereas coarse-textured soils have fewer pores that are larger and may be continuous, thus water can infiltrate more readily. Infiltration in fine and medium-textured soils is influenced by tillage and soil management practices. Proper tillage will help break crusts and create a roughness and porosity of the soil surface that favors infiltration. A dense vegetative cover protects the soil surface from sealing due to direct impact of water droplets. Organic matter in the surface soil promotes aggregation, increases infiltration, and provides slow release nitrogen for plant growth.

The permeability of subsoils varies with texture, structure, density, and porosity. Restricted permeability in a subsoil layer may cause poor drainage and saturated zones above the restrictive layer which may result in runoff and/or erosion. Temporary anaerobic conditions have a potential for causing odors and plant toxicity. Drainage systems may be needed if sludge is applied to poorly drained soils. If soils with poor natural drainage are used, adverse effects can be minimized by applying sludge when the soil is dry. Coarse, sandy, and gravelly soils are usually rapidly permeable; however, they generally transmit water very rapidly and may not remove all of the suspended materials before they reach groundwater. Adsorption of nutrients, metals, and organisms is generally limited. The available moisture-holding capacity of these soils is low.

Depth of soil that is favorable for adsorption of elements, pathogenic organisms, and organic substances is an important consideration. The distribution of plant roots in the soil is also important. With nearly neutral pH and no inhibiting chemical conditions, many plants extend their roots to a depth of three feet or more in well aerated, permeable soils. Soils that inhibit root penetration may cause greater plant uptake of metals. The most severe limitations of soil depth are caused by bedrock, coarse sand and gravel, or a high water table.

Soil cation exchange capacity (CEC) is a measure of the net negative charge and is expressed as milli-equivalents (meq) per 100 g of soil. Soil CEC has been proposed as a measure for controlling metal applications to soil, although it is a nonspecific sorption reaction. The general consensus is that only a small proportion of the metals (Cd, Cr, Cu, Pb, Hg, Ni, and Zn) take part in cation exchange reactions between soil and soil solution.

Additionally, sorption studies with intact soil and soil components indicate that sorption sites with higher activation energies than that of cation exchange are involved. Further, it has been shown that removal of metals by soil materials in greater quantities than the CEC does occur. It becomes evident then that the CEC itself is not the controlling factor in metal retention in soil. However, the CEC of the soil may permit a first approximation of the soil's ability to retain metals in insoluble forms because it acts as a temporary storage system for soluble ions and represents a rough indicator of the clay and organic matter content of the soil (which are important in precipitation and sorption of metals).

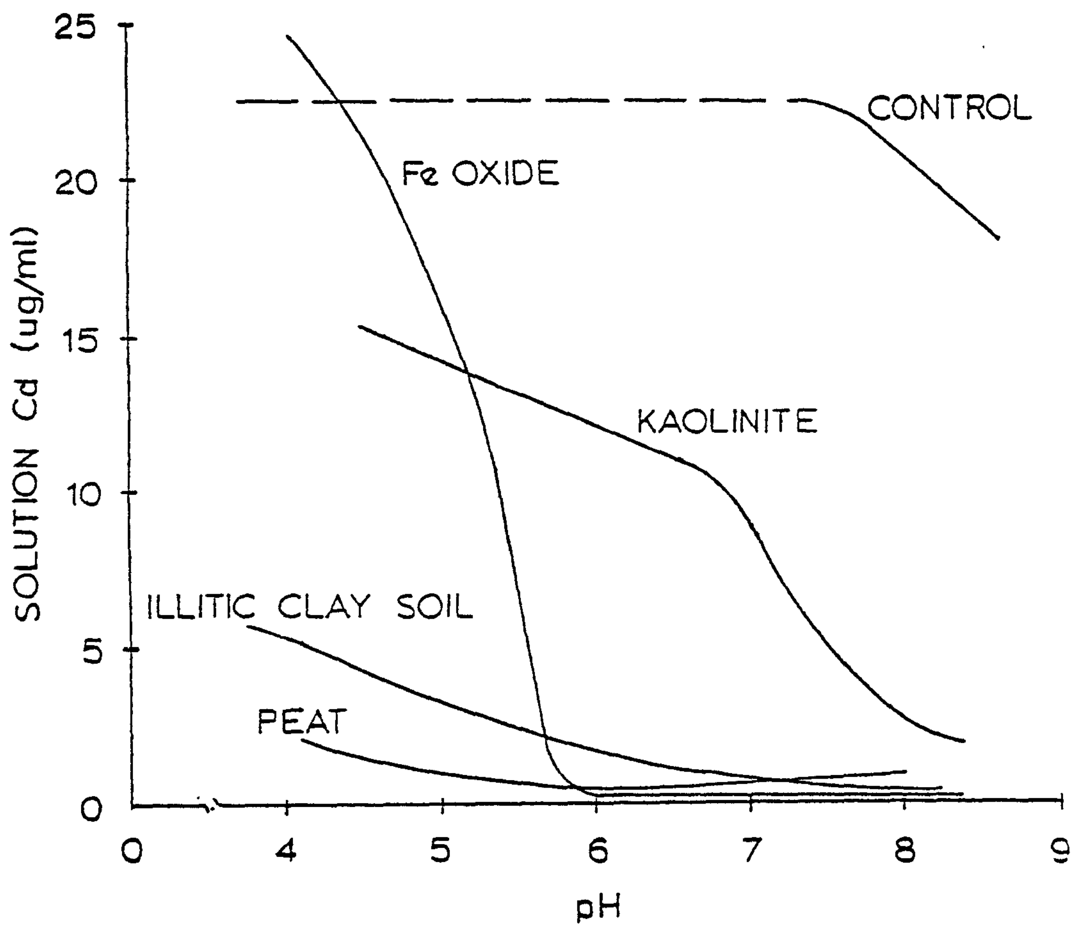
The organic fraction of soils has a significant effect on the solubility of heavy metals and organics in soils. This conclusion is the result of the observations that: (a) humic and fulvic acids (the complex heterogenous mixture which is the nucleus of soil organic matter) and plant extracts exhibit chelation tendencies; (b) biochemical compounds having chelating characteristics are continuously produced and degraded in soils; and (c) sorption of heavy metals and organics is often related to the organic matter content of soils.

The management of soil organic matter is important because of its involvement in the chemistry of metals and organic toxicants in soil. Production practices (crop rotation, manure crops, organic matter addition, etc.) which maintain or add organic matter to soil should reduce the solubility of metals.

Superimposed on the aforementioned soil variables is the soil pH. Soil pH has a significant effect on the other variables. It has been demonstrated numerous times that soil pH has a significant effect on heavy metal adsorption and uptake by plants. This pH effect could be the result of the decrease in solubility of metals as the pH increases. Figure 3-2 which shows the effect of solution pH on soluble Cd concentration in the presence of various solid phases and demonstrates the interaction between soil material and pH on sorption of Cd. These data provide an understanding for the observations that the Cd content of crops is a function of pH in that as the pH is increased, the concentration of Cd in the plant tissue decreases. Soil pH can also affect virus removal. As a general rule, viruses are readily desorbed by a high pH. Virus absorption and removal by soil is therefore reduced as the pH increases above 7.0. The optimum pH for soil treatment and disposal systems must include both toxics management and public health considerations. Disease control requirements are described in the 9/13/79 RCRA and BPT regulations.

FIGURE 3-2

DISTRIBUTION OF Cd BETWEEN SOIL MATERIAL AND EQUILIBRIUM SOLUTION AS A FUNCTION OF pH



3.3.4.4 Addition of Inorganic Elements in Sludge to Soils

Many elements are not of much environmental significance because of their low concentrations in sludge, low solubility, strong adsorption by soils, low tendency to be taken up by plants, or low toxicity to plants and animals. Unusually high concentrations of elements in sludge, poor site selection, and poor site management could render the application of less significant elements hazardous. Elements of most concern are cadmium, copper, molybdenum, nickel, and zinc. Copper, nickel, and zinc are of concern because when added at high levels to soil, they can become available to plants in concentrations that are toxic to the plant. Cadmium is of concern because it is taken up by plants and may increase the dietary cadmium intake of animals and man. Cadmium accumulates in the kidney and liver of humans and may constitute a health risk. Cadmium is controlled by the 9/13/79 (RCRA) regulations. Lead is an accumulative poison that is strongly adsorbed by soils, but could be a problem from direct ingestion of surface contaminated crops.

The principal pathways of the toxic substances are the contamination of soil causing: (a) plant uptake or uptake of soil directly by animals and transmission through the food chain to humans; (b) runoff and contamination of surface water; or (c) leaching and contamination of groundwater. Metals in sewage sludge added to soil generally have not leached significantly.

The complexity of the reactions of metals in soil and the difficulty in making precise predictions of their fate is illustrated in Figure 3-3. Mechanisms for removal of the metals from the soil include plant uptake, leaching, and volatilization.

The form of the metal added (sulfide, hydroxide, carbonate, phosphate, etc.) will have a significant effect on its initial solubility in soil and therefore its initial impact on plant growth. Crop yields have been affected more by inorganic metal additions than by the addition of an equivalent amount of metals from a sewage sludge.

The adverse effects of potentially toxic constituents of sludge can be controlled by good management practices such as: (a) controlling the rate and amount of sludge application; (b) controlling soil pH; (c) maintaining organic matter at high levels; (d) selecting crops that exclude the elements of concern; and (e) using soil conservation practices to control runoff and erosion.

In terms of recycling, the rate of sludge application that has been historically recommended is based on supplying the nitrogen needs of the crop. Sludges vary in nitrogen content and crops vary in nitrogen requirement, but the annual sludge application to supply the available nitrogen that would be supplied by mineral fertilizer usually ranges between 5 and 40 metric tons per hectare. However, the rate and amount of applied sludge cannot violate the 9/13/79 regulations, i.e., cadmium and PCB controls are needed. Other toxic substances should also be controlled as appropriate.

Total accumulative metal loadings based on a cation exchange capacity of soils, and controlled soil pH 6.5 is shown in Table 3-6. For pH 6.5, the limits are different. Lower rates are preferred.

FIGURE 3-3

PATHWAYS OF TOXIC SUBSTANCES IN SOIL

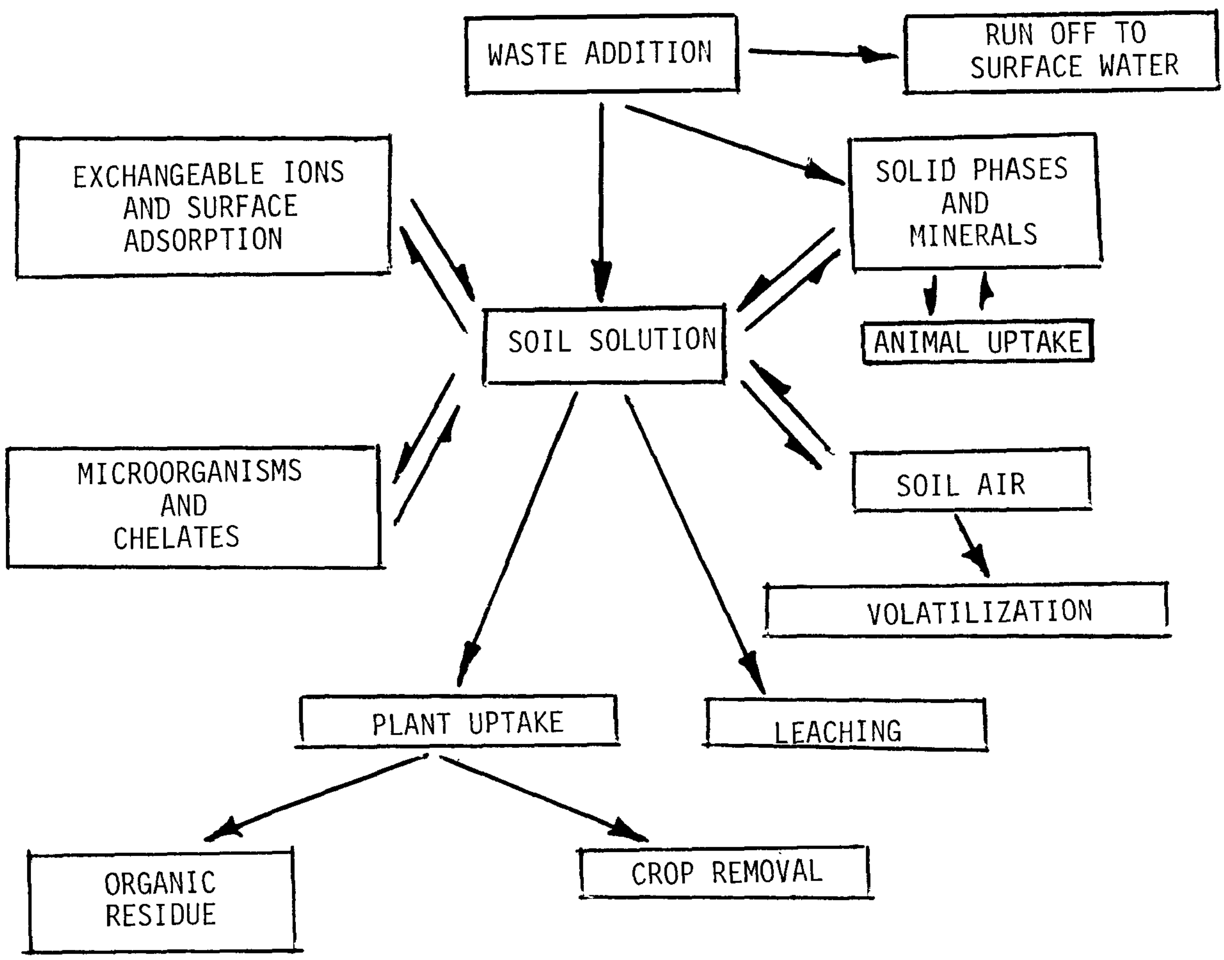


TABLE 3-6

ACCUMULATIVE METAL LOADINGS BASED ON CATION EXCHANGE CAPACITY OF SOILS FOR SLUDGE APPLICATION TO LAND

Metal	Soil cation exchange capacity (milliequivalent per 100 g) (a)		
	0-5	5-15	15
	Amount of metal (kilogram per hectare)		
Pb	500	1,000	2,000
Zn	250	500	1,000
Cu	125	250	500
Ni	50	100	200

Note: For information on land disposal and treatment of wastewater refer to the EPA Process Design Manual for Land Treatment of Municipal Wastewater, October, 1977

Cadmium (Cd) is specifically controlled by regulation, and in this respect, the new (9/13/79) RCRA requirements update all previous recommended limits for Cd. The regulation includes two approaches for the control of Cd. Under the first approach, controls are placed on both annual application rates and the maximum cumulative loadings. The pH must be at 6.5 or more at the time of each application (unless Cd is <2 mg/kg in the sludge). The annual application rate for accumulator crops (tobacco, leafy, or root crops for human consumption) shall not exceed 0.5 kg/ha. The annual rate for other crops will be phased until, by 1/1/87, the rate limit will also be 0.5 kg/ha.

Limits on cumulative loadings depend on pH of the soil. If the background pH of the soil is ≥ 6.5, or where natural soil background is pH < 6.5 but safeguards exist at the site which will assure pH will be maintained ≥ 6.5 for as long as food chain crops are grown, the maximum limits vary from 5 to 20 kg/ha. depending on the soil cation exchange capacity. In all other situations, the maximum cumulative loading may not exceed 5 kg/ha.

The second approach allows unlimited application of Cd provided that: the crop is only grown for use as animal feed; the pH must be maintained at ≥ 6.5 as long as food chain crops are grown; an operating plan must be developed describing how the feed will be distributed to prevent human ingestion and describing measures to prevent Cd from entering the human food chain from alternate future land uses; future homeowners must be provided notice that there are high Cd levels in the soil and that food chain crops should not be grown.

3.3.4.5 The Fate and Effects of Toxic Organic Wastes Added to Soils

A great number of organic pesticides have been used in agriculture with great advantage to society. Organic substances used in industries, many of which are recognized toxicants, are discharged into sewers and find their way into municipal sludge and ultimately are applied to soils. Only recently have aggressive studies been initiated to identify the toxic organic substances in sludge. Some of the known organic constituents of sludge that are potentially toxic include: (a) phenolic compounds (b) chlorinated hydrocarbons (c) chlorinated biphenyls (d) detergent residues, and (e) petroleum residues (3). Many of the organic compounds are reduced during wastewater treatment by biologic activity, volatilization or adsorption as previously described.

The pathways by which organic substances in sludge applied to cropland could reach animals and man includes:

1. Volatilization and rainout on land or water
2. Plant uptake from soils by food chain crops or direct ingestion of soil
3. Contamination of soil leading to phytotoxity
4. Leaching into aquifers used for water supply

The soil may adsorb, precipitate, transport, or decompose toxic organic substances. The degree of adsorption depends upon the characteristics of the soil and the adsorbate. Some of the most important soil properties favoring adsorption are large surface area, high organic content, and high cation exchange capacity. Some characteristics of the organic substance that affect it's adsorption are molecular size and structure, pH, water solubility, and polarity (4). The organic substances may be degraded photochemically, chemically, or microbially. Photochemical decomposition occurs while the chemical is at the soil surface and may play a minor role in degradation of sludge born toxic organics. Chemical decomposition is an important and widespread phenomenon. It is a complex process that is influenced by soil properties and properties of the organic substance. Microbial decomposition plays an important role in soil attenuation of toxic organic substances. Extensive research on pesticides has shown that soil microbes can degrade even those considered to be persistent and relatively non-biodegradable. Some of the important soil factors determining rate of degradation include soil moisture, pH, temperature, organic matter content, redox potential and nutrient availability. The chemical nature of the organic substances also determines the decomposition rate. Of most concern for sludge applications are the persistent organics which resist degradation and accumulate in the soil when they are applied at high rates. Phenolic compounds are rather stable, but they have been shown to decompose biologically when the soil adsorbs the compound and allows sufficient time for microbial activity (3). Chlorinated hydrocarbon pesticides also degrade biologically when present in soils at low concentrations.

Persistent pesticides and PCBs are relatively stable and strongly adsorbed by soils. They are sorbed by plant roots and transmitted to areal portions at negligible rates. Organics present more of a hazard from direct ingestion than from plant uptake, so direct ingestion of sludges by dairy animals should be avoided (5).

The application of sewage sludge containing low levels of pesticides or PCBs and other toxic organic substances from industrial discharges should not pose a reasonable probability of adverse effects on health or the environment when sludge is applied according to the 9/13/79 RCRA regulations and the EPA Sludge Technical Bulletin. There is not enough experimental data to justify applying sludges high in toxic organics, to poor sites, or under poor management. The 9/13/79 RCRA regulations control the application of sludge containing PCBs. Sludge containing concentrations of PCB $\geq$10 mg/kg (dry weight) must be incorporated into the soil when applied to land used for producing animal feed including pasture crops for animals raised for milk. Incorporation is not required if the PCB content $\leq$ 0.2 mg/kg (actual weight) in animal feed or less than 1.5 mg/kg (fat basis) in milk.

3.4 Increased Environmental Benefits

3.4.1 General

Projects or subsystems identified as alternative technology may be determined to be innovative as a result of increased environmental benefits. Unlike the cost and energy criteria, Agency regulations do not provide specific numerical comparisons between the environmental impacts of the alternative approaches and baseline technology.

The inclusion of the "increased environmental benefits" criteria for alternative technologies recognizes the need to consider the trade offs between environmental effects and other evaluation criteria. The analysis of improved environmental benefits for proposed innovative portions of alternative projects should be done at the same time and within the context of the overall environmental assessment and analysis activity.

The level of detail must be increased and reporting format modified specifically to compare the benefits of potentially innovative to non-innovative processes. Added benefits attributed to innovative designs must be separately identified and documented.

Environmental effects should be considered in alternatives design, evaluation, and plan selection (7, 13). Such environmental assessments should include not only the relative contribution to water quality enhancement, but also other related primary and secondary environmental impacts such as: (a) air quality; (b) public health; (c) water supply; (d) land use (including induced growth); (e) aesthetics; (f) housing availability; and (g) sensitive areas. Socio-economic considerations such as changes in employment and population characteristics should also be included in the analysis (8, 9). Environmental effects that occur: (a) during construction; (b) under normal facility operations; and (c) under various system failure conditions should be identified and evaluated. The expected frequency and duration of such failure conditions should also be estimated. The identification of potential environmental effects should be used to improve system design and to develop emergency control and other methods to mitigate adverse environmental impacts.

In general, environmental impacts may be associated with project siting, sizing, phasing, construction methods and materials, treatment and disposal options, and proposed methods of operation and maintenance. Only those impacts which are deemed to be relevant to the total project comparison of potentially innovative and non-innovative alternative systems or system components should be highlighted. These factors will vary significantly among proposed innovative projects. Therefore, as appropriate during Step 1 and 2 preparation, the design engineer should identify relevant criteria for the consideration of environmental benefits of the potentially innovative portion of specific projects. Similar criteria may be developed for other alternatives. The state and EPA regional project engineers should review the appropriateness of the identified environmental criteria and assessment techniques for the individual applications submitted.

Appendix E of the regulations lists five specific examples of potential environmental benefits that could be derived: (a) water conservation; (b) more effective land use; (c) improved air quality; (d) improved groundwater quality; and (e) reduced resource requirements for facility construction and operation. Each of these potential benefits should be assessed in addition to other potential environmental impacts outlined in more comprehensive Agency environmental assessment guidelines.

Water conservation practices should include consideration of methods or techniques over that required in the Cost Effectiveness Analysis Guidelines where these approaches are practicable. More effective land use should include:

1. Growth management and other regulatory measures to minimize induced growth and adverse secondary impacts of development (i.e., more efficient land development patterns)

2. Increased agricultural productivity (increased yields through nutrient additions)

3. Protection of environmentally sensitive areas (e.g., floodplains, aquifers, prime agricultural areas, historic and cultural areas, wetlands, habitats, recreation areas)

4. Relative consumption of land for the wastewater system

5. Erosion control

6. Potential off site "nuisance" factors for land uses abutting the facility (e.g., odor, noise, dust, glare, traffic)

Air quality impacts should normally consider potential discharges resulting from evaporation, stripping, volatilization, incineration, and aerosol effects, as well as automotive air pollutants associated with resultant development patterns and more specific transport requirements of alternative treatment and disposal practices. Consideration of groundwater should include estimation of relative expected changes in quantity, quality, and flow characteristics resulting from contamination from landfill leachate, infiltration from land application, as well as replenishment benefits (e.g., water supply, prevention of salt water intrusion, subsidence protection). Relative resource requirements should be considered both for construction and operation, including chemicals, construction materials, energy, and manpower.

Potential environmental impacts are generally identified on the process fact sheets in Appendix A in this manual. The design engineer should identify in more detail relevant environmental impacts. The reader should be aware, however, that the estimated impacts from a particular project will depend upon specific design characteristics and various local conditions. The state and EPA regional reviewers should very carefully examine the specific process and site designs proposed. With regard to many of the potential environmental effects described above, proper siting and design of an installation is far more important than a non-site specific comparison of generic technologies.

Although an alternative may rate high in one or more environmental effect categories, it may, at the same time, rate low in others (10). Therefore, it is necessary to determine the "net environmental benefits" (15). The user may find appropriate the use of a scalar rating system with both positive and negative values (benefits and costs) (11). In addition, to reflect the relative importance of various factors, varying weights may be assigned (12, 14). The design engineer should clearly identify and justify his selected technique for comparing the innovative and non-innovative application of the alternative technology. (Note that the engineer will have previously conducted a broader environmental assessment for all alternatives considered during Step 1.) For each relevant environmental criteria, the design engineer should document the environmental impacts for both the baseline alternative technology and the proposed innovative application(s) using a comparison matrix similar to that shown in Table 3-7.

3.5 Improved Joint Treatment of Municipal and Industrial Wastes

3.5.1 General

Alternative technology that provides for new or improved methods of joint treatment and management of municipal and industrial wastes discharged into municipal systems may qualify as innovative technology.

Improved joint treatment refers to: (a) treatment of industrial wastes discharged into municipal wastewater collection systems for treatment at Publicly Owned Treatment Works; and (b) the joint treatment and disposal of municipal and industrial residuals resulting from the joint or independent

TABLE 3-7

IMPROVED ENVIRONMENTAL IMPACT COMPARISON MATRIX

	Control Alternatives (1)							
	Baseline			Innovative "A"		Innovative "B"		Etc.
Environmental Impacts (2)	Weight (3)	Score (4)	Weighted Score (5)	Score	Weighted Score	Score	Weighted Score	
A. Water Conservation								
Criteria 1								
Criteria 2								
Etc.								
B. Effective Land Use								
Criteria 1								
Criteria 2								
Etc.								
C. Air Quality								
Criteria 1								
Criteria 2								
Etc.								
D. Groundwater								
Criteria 1								
Criteria 2								
Etc.								
E. Resource Requirements								
Criteria 1								
Criteria 2								
Etc.								
F. Other								
Criteria 1								
Criteria 2								
Etc.								
TOTAL NET SCORE								

Notes:

(1) The innovative applications of the alternative technology being considered must be clearly described in the facilities plan text. There may be more than one proposed innovative application for a specific subsystem. If there are several different innovative proposals, each should be compared separately with the appropriate baseline alternative technology.

(2) The five environmental impact categories listed in Appendix E should be considered as a minimum. The relevant aspects of each of these impact categories for the specific alternative technology should be identified by the design engineer.

(3) The relative importance of this environmental impact criteria should be assigned by the design engineer. Weights are best set by allocating a given number of points (e.g., 100) over the entire set of impact categories. The engineer may first want to determine the relative importance of the impact categories and then distribute those points within each category.

(4) Different scoring systems are possible. Recommended is the following:

- +2 very positive benefit
- +1 positive benefit
- 0 little or no impact
- -1 negative effect
- -2 very negative effect

(5) Product of the raw score and the associated criteria weight.

treatment of liquid wastes.

Facility plans qualifying for innovative technology under this criteria must meet EPA's General Pretreatment Regulations,40 CFR, Part 403, for existing and new sources of pollutants promulgated under Section 307 of the CWA of 1977, and must document the specific improved joint treatment benefit compared to non-innovative alternative wastewater management approaches.

Improved joint treatment efficiency may result from the use of industrial waste or waste products to improve municipal collection, treatment, or residual disposal efficiency as well as the use of municipal residuals for improved industrial waste processing and residual disposal.

Examples of the more common potential beneficial industrial/municipal recycling and joint treatment opportunities are listed below:

1. Use of industrial waste heat to improve liquid or solids processing efficiency.

2. Use of high nutrient industrial waste to supplement nutrient deficient municipal wastes or vice versa.

3. Addition of industrial liquid wastes or residuals to control or alleviate corrosion of municipal collection systems.

4. Use of industrial wastes or by-products as organic supplements or treatment aids for biological treatment processes.

5. Use of industrial waste products as source of chemical additives or bulking agents for physical, chemical, or biological liquid or residual processes.

6. Co-mixing or neutralization of combinations of industrial and municipal wastes to improve treatment efficiency or reduce the need for auxiliary sources of energy.

7. Industrial use of municipal treatment residuals.

8. Use of industrial waste products to alleviate municipal treatment process operating problems or improve treatment efficiency.

The above list is intended to illustrate potential beneficial joint treatment opportunities and in no way should be considered inclusive. The overall objective is to encourage joint industrial/municipal wastewater management facilities that maximize cost effectiveness of treatment, equitably distributes the cost, and achieves improved management and control of toxic materials and industrial wastes.

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CHAPTER 4

INNOVATIVE TECHNOLOGY CONCEPTS AND APPLICATIONS

4.1 General

The methodology and criteria presented in previous chapters of this manual have described a stepwise procedure for screening and classification of facility plans as well as a discussion of the criteria to be used in the final analysis. The appended information summarized the legislation, regulations, and guidelines to be followed in the analysis along with the best available information on the cost and energy utilization of commonly employed municipal treatment technology.

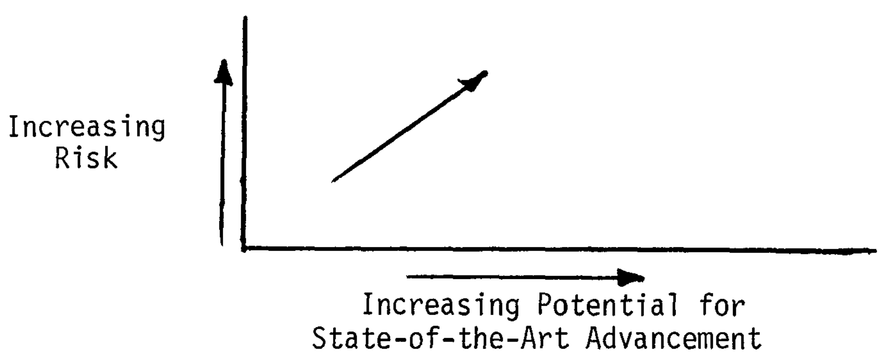
The intent of this chapter is to provide additional insights into the conception, development, and formulation of innovative municipal treatment system designs that satisfy the regulatory requirements while also demonstrating accelerated progress toward meeting the national goals of greater cost effectiveness, energy conservation, reclamation of water and wastewater constituents, and improved management of toxic materials.

4.2 Risk Versus Potential State-of-the-Art Advancement

Both the Congressional and Agency intent in administering the innovative and alternative technology provisions of the Act is to encourage the design and construction of more efficient municipal treatment technology by advocating departure from the traditional engineering and design practices. Implicit in this objective is a willingness to accept a greater degree of risk in order to achieve a greater potential for a significant advancement in the state of the art as evidenced by lower cost, greater reliability, or other similar design objectives. This trade off in the two objectives is illustrated in Figure 4-1.

FIGURE 4-1

RISK-POTENTIAL BENEFIT OF MUNICIPAL TREATMENT FACILITY DESIGNS



Under the new Innovative and Alternative Technology Guidelines, first quadrant designs (moving toward the right and upward, i.e., greater potential advancement with greater risk) are encouraged whereas the past traditional design and engineering practices tended to discourage this acceptance of greater risk with potentially greater benefit. Although definitive quantification of the risk/technology advance relationship has not been provided, the 15% cost savings and 20% energy savings, as well as the improved application criteria, may be viewed as a measurement of the advance or benefit expected, while the 100% two year replacement provision § 35.908(e) may be viewed as a measure of the increased risk that will be tolerated.

In addition to shifting the traditional risk benefit balance point to encourage process design innovation, the innovative and alternative regulations have also provided added incentive for the development and use of innovative equipment.

4.3 Innovative Planning and Design Approach

4.3.1. Innovative Processes

While it is difficult to explicitly define the boundaries or to prescribe universal guidelines leading to innovative processes or system designs, it is possible to outline and categorize successful approaches based on the history of past development efforts in the wastewater treatment field.

Innovative designs may originate in a number of ways, the most common of which are listed below.

1. Greater integration and use of natural processes.
2. Maximum consideration and beneficial use of available physical surroundings.
3. New process invention or development.
4. New equipment invention or development.
5. Modification, adaptation, or improvement of fundamental biological, chemical, or physical processes.
6. Improved efficiency or control of known processes.
7. The application of proven processes or equipment originally developed for another purpose for the treatment of municipal wastewater.
8. Unique combinations of processes and techniques that recognize and maximize inter-process compatability or synergistic effects.

The above elements of innovative designs are not inclusive, nor are the elements completely exclusive of one another. The degree to which they may be included in a particular project depends on such factors as design objectives, physical constraints, etc.

A major emphasis of innovative systems under the CWA of 1977 is the greater attention placed on multi-objective planning, inter-media impact considerations, and total systems design. Satisfaction of these objectives requires a higher level of discipline in the systematic screening and evaluation of alternatives than has been generally employed in the past. More important, however, is the much greater effort needed in concept development and the formulation of innovative alternatives.

4.3.2 Innovative Concept Development

Past experience with the review of facility plans has indicated a strong tendency for contemporary designers to consider a narrow range of alternatives, both with respect to liquid processing technology and also for residual treatment and disposal. Innovative design concepts should include a broad range of reuse, beneficial recycling, and energy conservation and recovery opportunities, as well as the specific methods or technologies of treatment. A partial list of recycling, reclamation, and energy recovery opportunities that might be incorporated into an innovative concept of treatment is shown in Table 4-1.

Conceptually, innovative designs may embody a number of the above mentioned recycle/reclamation or reuse opportunities depending on the particular site variables and design objectives. Maximum consideration should be given to the identification of all potential conceptual approaches early in the Step 1 planning process, especially those system designs incorporating alternative technologies that exhibit significant recycle, reclamation, energy recovery, or revenue generating potential.

Specific questions regarding state and regional policies and priorities on innovative concepts should be discussed with the appropriate review authorities during the Step 1 pre-application conference. Current Agency policy regarding the eligibility of multiple purpose projects is described in Program Requirements Memorandum No. 77-4.

4.3.3 Innovative Equipment

Equipment incorporated into the construction of wastewater treatment facilities under the CWA of 1977 will be considered innovative based on its application in a particular facility system design. Specific equipment items or classes of equipment will not be given a blanket qualification as innovative based on inherent characteristics. The intent of the above determination is to encourage the integrated use of the most efficient equipment in an overall system design that meets one or more of the innovative technology qualifying criteria. Systems may meet either the cost or energy criteria due to unique design features using standard equipment, novel equipment, or any combination that provides the required system cost or energy savings. The equipment so used may be developed specifically for municipal wastewater or residual treatment in conjunction with an innovative process design or may be originally

TABLE 4-1

EXAMPLES OF REUSE, RECLAMATION AND ENERGY RECOVERY OPPORTUNITIES

Effluent Reuse Recycling

1. Irrigation for nutrient or water value
2. Industrial recycle for nutrient, water, or heat value
3. Commercial recycle for nutrient, water, or heat value
4. Aquaculture uses including all farming and production operations
5. Groundwater injection as supplemental source, intrusion barriers, subsidence prevention

Beneficial Sludge Use

1. Land spreading of municipal sludges
2. Joint treatment, blending and disposal of municipal sludge, solid wastes and industrial sludges
3. Use of municipal sludges as new material(s) for industrial or commercial production of saleable products

Energy Conservation, Reclamation and Recycle

1. Use of solar energy to accelerate temperature sensitive processes
2. Use of solar energy for space heating
3. Use of heat pumps to extract heat from effluents
4. Use of digester gas for in-plant or off-plant uses including sale for industrial or commercial use
5. Gas recovery from landfill operation
6. Accelerated plant growth and harvesting for energy recovery
7. Waste heat recovery and reuse for thermal and combustion processes

Industrial and Commercial Reuse or Reclamation

1. Industrial use of wastewater
2. Industrial use of waste heat from municipal treatment systems
3. Municipal use of waste industrial heat
4. Commercial use of wastewater effluents
5. Joint industrial municipal disposal of effluents or residuals
6. Use of industrial waste products, including off gases for beneficial municipal use
7. Use of municipal waste products, including off gases, for beneficial industrial uses

developed for use in another industry and modified for use in an innovative municipal treatment plant design.

The non-restrictive specifications § 35.936-13(a)(1) presented in Appendix B prohibits the use of proprietary, exclusionary, or discriminatory bid specifications other than those based on performance or those necessary to demonstrate a specific thing or provide for necessary interchangeability...The above reference to...demonstrate a specific thing...recognizes the possibility of permitting the use of unique equipment items when incorporated into an overall system design meeting the innovative technology qualifying criteria. Sufficient justification for use of such proprietary specifications must be prepared and approved on a case by case basis.

The decision to allow exclusion will normally be made at the Step 1 review stage by state or federal review authorities and will be subject to confirmation during the Step 2 review stage. If the innovative qualifying criteria is based on cost savings, verification will take place as a part of the Step 3 interim and final audits. If the savings is based on the energy criteria, post construction verification and documentation may be requested as a part of the general requirement of Section 202(a)(3) of the CWA of 1977 as specified in § 35.908(c).

Equipment used in the context of the innovative and alternative provision includes the following:

1. All equipment used for liquid stream processing (includes pumping facilities that are a part of the treatment works)

2. All equipment needed for the treatment and disposal of residuals including energy recycling or reuse.

3. All automation and instrumentation equipment needed for equipment or process control.

For Item 3 above, the use of plant instrumentation and automation equipment to achieve greater cost or energy savings must clearly document the cost effectiveness of the automated level of control over manual control. Judgements regarding conformance with the qualifying innovative cost and energy criteria will be based on the overall system cost or energy savings including all processes and equipment items. For systems judged to have met the innovative qualifying criteria; the portion of the project qualifying for increased grant assistance must be explicitly identified by the applicant as previously discussed.

APPENDIX A

MUNICIPAL TREATMENT TECHNOLOGY FACT SHEETS

A.1 General

This appendix provides a series of two-page capsule summaries of processes and techniques commonly used in the United States for treatment and disposal of wastewater and its residuals. While it is expected that these fact sheets will be used extensively for the non-innovative cost and energy analysis and evaluation, the technologies contained in this appendix should not be used as an inclusive list of non-innovative or baseline technology. The inclusion or exclusion of processes and techniques in Tables A-3 and A-4 is not a direct indication of whether the technology is innovative or alternative in a particular application. Those processes employed to a more limited extent are identified with an asterisk. The cost and energy data presented in the appendix are generalized rather than site specific and are intended primarily for comparative analysis. The accuracy of the cost and energy estimating curves and information have been noted on the fact sheets where available. The user of the appendix is cautioned against considering the estimates as absolute. The estimates are to be used for comparative estimating purposes during the Step 1 review process and as a general guide for determining the adequacy of proposed cost and energy values.

The fact sheets also serve to provide basic information on a number of commonly used technologies which have been identified in the Innovative and Alternative Technology Guidelines (Appendix E of the Construction Grant Regulations) as alternative technology for the purpose of increased construction grant funding and other incentives provided under the Clean Water Act of 1977. These processes and systems are indicated by an "A" in parenthesis.

Portions of other systems may be considered alternative technology depending on the method of ultimate sludge disposal, degree of energy recovery, or other special design considerations.

The bibliography for this appendix contains numerous publications which are readily available to the manual user from EPA and other sources. The user should consider obtaining copies of selected material as a supplement to the fact sheet information.

A.2 Fact Sheet Format

The first of two sheets of the fact sheet sets has been designed to provide the following information for each process:

- Description
- Common Modifications
- Technology Status
- Applications
- Limitations
- Typical Equipment/No. Mfrs.
- Performance
- Design Considerations
- Reliability
- References

In addition, the following information has been included when applicable to the process under consideration:

- Chemicals Required
- Residuals Generated
- Potential of Improved Toxics Management
- Potential for Increased Environmental Benefits
- Joint Treatment Potential

The second page of each fact sheet set contains the following information:

- Flow or Schematic Diagram
- Energy Notes
- Construction Costs
- Operation and Maintenance Costs

Design criteria and assumptions used to develop the energy and cost estimates have been fully described on each fact sheet to provide the user with a base to adjust the information to specific project designs where required.

The information provided under Typical Equipment/No. Mfrs. has been supplied to provide the user an understanding of the relative availability of equipment for the process. The heading refers to well-known directories of equipment for manufacturers' names and numbers. These directories are annual publications and, therefore, become a renewable resource of information describing the state of the art.

Reference listings on the fact sheets have been shown in two forms; namely, general listings at the lower part of each page, and in parentheses where applicable to a particular subject being discussed.

Toxics management has been addressed in the fact sheets in several ways, depending on the characteristics of the progress and the contribution the process makes to toxics management. This information is supplementary to the discussion and tabular information presented in Chapter 3. If a process is passive with respect to improved toxics management opportunities, no statement has been made concerning the subject. On the other hand, if the process provides toxic management in the form of incidental removal, a statement has been made concerning this effect in the description of the process.

When applicable and where data is available, comments have also been made showing concentrations of toxics in the process sidestreams. A specific toxics management statement has been provided for those processes providing high levels of toxic control.

Energy information has been developed for each of the processes from published information or by derivation for the process being discussed. In certain cases, curves of energy requirements per year versus treatment plant flow have been provided. In these cases, the efficiencies of energy-using devices have been shown to permit adjustment where needed. In other cases, particularly where pumping energy is involved, a simple equation has been used to show the energy requirements at a given pumping head for an annual flow rate. The user can then, by simple correction to his conditions of flow and head, determine the energy needs for his specific design. Curves have also been provided in Appendix D to aid in this analysis.

The energy information presented has been based on the assumption that the process will be operated as proposed and that equipment used will be maintained in a representative good operating condition. In certain cases, wide variations in energy consumption can be expected to occur due to equipment wear or corrosion, changes in flow rate, heat transfer efficiency, poor operation techniques, inadequate controls or other factors influencing operation at the optimum conditions. The impact of these off-design operating conditions can be expected to vary widely with the process and the type of equipment being used. Additional energy information for specific alternative technology processes along with often needed conversion factors and equivalent fuel and energy values is presented in Appendix D.

Cost data presented in the fact sheets have been derived from EPA publications, open literature, construction grant files, and manufacturers' information. These data exhibit a level of accuracy dependent upon the degree of usage of the process. Therefore, processes using well-known types of equipment, facilities and operating methods can be expected to have a higher level of accuracy. Those processes with few examples of usage beyond the demonstration stage must be considered as individual cases with the potential for wider variation in costs when applied in a generalized fashion.

A large number of the construction and operation and maintenance curves used in the development of the fact sheets have been obtained or derived from the Areawide Assessment Procedures Manual (3). This information is the result of cost estimates developed over a period of years by several contractors from detailed conceptual designs, process and equipment layouts in accordance with standard estimating techniques plus verification using normalized "as built" costs where available. Fact sheets for processes having limited "as built" cost data bases contain single or multiple case history costs as available. In some cases costs have been tabulated rather than displayed graphically.

All cost curves are based on cost elements described in Table A-1 unless specifically noted otherwise in a given fact sheet. Conversion of the construction costs shown in the fact sheets may be made to capital cost by use of the outline in Table A-2. Construction and O&M costs for Appendix A curves have been indexed to September 1976 (ENR 2475) unless otherwise noted. Appendix C provides information for adjusting the costs to other time and regional bases.

TABLE A-1

GENERAL COST AND DESIGN BASIS FOR COST CURVES
(Used for All Fact Sheets Unless Noted)

Basis of Costs

1. ENR = 2475, September 1976

2. Labor rate, including fringe benefits = $7.50/hr

   Note: Labor costs are based on a man-year of 1,500 hours. This represents: a 5-day work week; an average of 29 days for holidays, vacations, and sick leave; and 6 1/2 hours of productive work time per day.

3. Energy Costs

a.	Electric Power		= $0.02/KwH
b.	Fuel Oil		= $0.37/gallon
c.	Gasoline		= $0.60/gallon

4. Land = $1,000/acre

5. Chemical Costs

a.	Liquid Oxygen		= $65/Ton
b.	Methanol		= $0.50/gallon
c.	Chlorine	150-lb cylinder	= $360/Ton
		1-ton cylinder	= $260/Ton
		Tank Car	= $160/Ton
d.	Quicklime		= $25/Ton
e.	Hydrated Lime		= $30/Ton (as CaO)
f.	Polymer (Dry)		= $1.50/lb
g.	Ferric Chloride		= $100/Ton
h.	Alum		= $72/Ton
i.	Activated Carbon (Granulated)		= $0.50/lb
j.	Sulfuric Acid (66° Be)		= $50/Ton
k.	Sodium Hexametaphosphate		= $0.25/lb
l.	SO_2	150-lb cylinder	= $450/Ton
		1-ton cylinder	= $215/Ton
		Tank Car	= $155/Ton

Design Basis

1. Construction costs and operation and maintenance costs are based on design average flow unless otherwise noted.

2. Operation and maintenance costs include:

   a. Labor costs for operation, preventive maintenance, and minor repairs.
   b. Materials costs to include replacement parts and major repair work (normally performed by outside contractors).
   c. Chemical costs.
   d. Fuel costs.
   e. Electrical power costs.

3. Construction costs do not include external piping, electrical, instrumentation, land costs, site work, miscellaneous structures, contingency, or engineering and fiscal fees.

TABLE A-2

DEVELOPMENT OF CAPITAL COSTS

Conversion from construction costs to capital costs can be made by using the following tabulation.

Component Installed Construction Costs				
Unit Processes			$ 250,000	
			$	
			$	
			$	
Miscellaneous Structures (administrative offices, laboratories, shop and garage facilities)			$	
Subtotal 1				$ 250,000
Non-Component Costs	Avg.*	Range*		
Piping	10%	8-15%	$ 25,000	
Electrical	8%	5-125%	$ 20,000	
Instrumentation	5%	3-10%	$ 12,500	
Site Preparation	5%	1-10%	$ 12,500	
Subtotals 2 & 1			$ 70,000	$ 320,000
Non-Construction Costs				
Engineering and Construction Supervision @ 15%**			$ 48,000	
Contingencies @ 15%**			$ 48,000	
Subtotals 3, 2, & 1			$ 96,000	$ 416,000
Total Capital Cost				$ 416,000

* Range due to level of complexity, degree of instrumentation, subsoil conditions, configuration of site, etc., percentage of Subtotal 1

** Percentage of Subtotals 1 plus 2

TABLE A-3

LIST OF FACT SHEETS

TABLE A-3 (Continued)

TABLE A-3 (Continued)

TABLE A-3 (Continued)

NOTE: (A) Denotes process and systems identified in the Innovative and Alternative Guidelines as Alternative Technology for incentives under the Clean Water Act of 1977.

* Denotes processes which have had limited use as of 10/79.

TALBE A-4

ALPHABETIZED LIST OF FACT SHEETS

Title	Fact Sheet No.
Activated Carbon Thermal Regeneration	4.4.2
Activated Sludge, Conventional, Diffused Aeration	2.1.1
Activated Sludge, Conventional, Mechanical Aeration	2.1.2
Activated Sludge, High Rate, Diffused Aeration	2.1.3
Activated Sludge, Pure Oxygen, Covered	2.1.4
Activated Sludge, Pure Oxygen, Uncovered	2.1.5
Activated Sludge with Nitrification	2.1.6
Aerobic Treatment and Absorption Bed	7.1.1
Aerobic Treatment and Surface Discharge	7.1.2
Alum Addition	5.1.1
Ammonia Stripping	4.1.1
Aquaculture - Water Hyacinth	1.2.1
Aquaculture - Wetlands	1.2.2
ARRP (Ammonia Removal and Recovery Process)	4.1.2
Bio-Filter, Activated (with Aerator)	2.1.7
Biological Contactors, Rotating (RBC)	2.2.1
Breakpoint Chlorination	4.1.3
Centrifugal Dewatering	6.3.1
Centrifugal Thickening	6.3.8
Chlorination (Disinfection)	4.5.1
Clarifier, Primary, Circular with Pump	3.1.1
Clarifier, Primary, Rectangular with Pump	3.1.2
Clarifier, Secondary, Circular	3.1.3
Clarifier, Secondary, High Rate Trickling Filter	3.1.5
Clarifier, Secondary, Rectangular	3.1.4
Co-Disposal by Starved Air Combustion	6.2.7
Co-Incineration of Sludge, Sludge Incinerator	6.2.1
Co-Incineration of Sludge, Solid Waste Incinerator	6.2.2
Composting Sludge, Static Pile	6.2.3
Composting Sludge, Windrow	6.2.4
Contact Stabilization, Diffused Aeration	2.1.8
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Dechlorination (Sulfur Dioxide)	4.5.2
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Denitrification Separate Stage, with Clarifier	2.1.9
Dewatered Sludge Transport (Rail)	6.1.1
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Digestion, Aerobic	6.4.1
Digestion, Autothermal Thermophilic Aerobic (Air)	6.4.2
Digestion, Autothermal Thermophilic Oxygen (Oxygen)	6.4.3
Digestion, Two Stage Anaerobic	6.4.4

TABLE A-4 (Continued)

Title	Fact Sheet No.
Digestion, Two Stage Thermophilic Anaerobic	6.4.5
Disinfection (Heat)	6.4.6
Disinfection for On-Site Surface Discharge	7.1.3
Dissolved Air Flotation	3.1.6
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Evaporation Lagoons	7.1.4
Evapotranspiration Systems	7.1.5
Extended Aeration, Mechanical and Diffused Aeration	2.1.10
Ferric Chloride Addition	5.1.2
Filter, Belt	6.3.3
Filter Press, Diaphragm	6.3.4
Filtration, Dual Media	3.1.7
Flow Equalization	3.1.9
Force Mains, Transmission	1.1.1
Heat Treatment of Sludge	6.4.7
Incineration of Sludge, Fluidized Bed Furnace (FBF)	6.2.5
Incineration of Sludge, Multiple Hearth Furnace (MHF)	6.2.6
Independent Physical/Chemical Treatment	4.3.1
Intermittent Sand Filtration, Lagoon Upgrading	2.2.4
In-the-Home Treatment and Recycle	7.2.1
Ion Exchange (for Ammonia Removal)	4.1.4
Lagoons, Aerated	2.1.11
Lagoons, Anaerobic	2.1.12
Lagoons, Facultative	2.1.13
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Land Treatment, Slow Rate, Gravity, Not Underdrained	1.2.7
Land Treatment, Slow Rate, Gravity, Underdrained	1.2.8
Land Treatment, Slow Rate, Sprinkler, Not Underdrained	1.2.6
Land Treatment, Slow Rate, Sprinkler, Underdrained	1.2.5
Lift Stations, Raw Wastewater	1.1.2
Lime Clarification of Raw Wastewater	5.1.5
Lime Recalcination	4.2.1
Lime Stabilization	6.4.8
Liquid Sludge Transport (Pipeline)	6.1.5
Liquid Sludge Transport (Rail)	6.1.6
Liquid Sludge Transport (Truck)	6.1.7
Mixing/Chlorine Contact, High Intensity	3.1.10
Nitrification, Separate Stage, with Clarifier	2.1.14
Non-Water Carriage Toilets	7.2.2
Overland Flow, Gravity, Not Underdrained	1.2.9
Oxidation Ditch	2.1.15
Ozone Disinfection (Air and Oxygen)	4.5.3
Ozone Oxidation (Air and Oxygen)	4.4.3
Phostrip	2.1.17
Polishing Filter for Lagoon, Rock Media	2.2.5
Polymer Addition	5.1.6
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Powdered Carbon Addition	5.1.7

TABLE A-4 (Continued)

Title	Fact Sheet No.
Preliminary Treatment	3.1.12
Pump Stations, In-Plant	3.1.13
Rapid Infiltration, Not Underdrained	1.2.4
Rapid Infiltration, Underdrained	1.2.3
Screen, Horizontal Shaft Rotary	3.1.16
Screen, Wedge Wire	3.1.17
Septage Treatment and Disposal	7.1.9
Septic Tank Absorption Bed	7.1.6
Septic Tank Mound Systems	7.1.7
Septic Tank Polishing, Surface Discharge	7.1.8
Sewers, Gravity	1.1.3
Sewers, Pressure	1.1.4
Sewers, Vacuum	1.1.5
Sludge Drying	6.2.9
Sludge Lagoons	6.1.11
Sludge Landfilling - Area Fill	6.1.4
Sludge Landfilling - Sludge Trenching	6.1.10
Sludge Pumping	6.1.8
Sludge Storage	6.1.9
Starved Air Combustion of Sludge	6.2.8
Tertiary Granular Activated Carbon Adsorption	4.4.1
Thickening, Dissolved Air Flotation	6.3.6
Thickening, Gravity	6.3.7
Trickling Filter, High Rate, Rock Media	2.2.7
Trickling Filter, Low Rate, Rock Media	2.2.8
Trickling Filter, Plastic Media	2.2.6
Two-Stage Tertiary Lime Treatment, without Recalcination	4.2.2
Vacuum Filtration, Sludge	6.3.9

FACT SHEETS

FORCE MAINS, TRANSMISSION

FACT SHEET 1.1.1

Description - A force main conveys wastewater under pressure from the discharge side of a pump or lift station to a point of gravity flow downstream. The purpose of the force main (also referred to as rising main or pressure main) is to convey the wastewater from a low level area to a high level system. Energy for movement of the wastewater is provided by a pumping system. Wastewater often first enters a storage well which serves as a suction well for the pump(s). The size of the force main is a compromise between the most cost effective pipe and pump size and the need to provide suitable wastewater velocity to insure proper scouring of the pipe during operation.

Common Modifications - Mains may be aerated or the wastewater chlorinated to maintain freshness or prevent septicity. Installation of wye cleanouts on longer lines. Various pipe materials are used.

Technology Status - Widespread use, fully demonstrated.

Typical Equipment(23) - Pipe/18.

Applications - To convey wastewater from a low level area to a high level system where a gravity sewer is not feasible.

Limitations - Often the dissolved oxygen content of the wastewater is depleted in the storage well and the subsequent passage through the force main results in the discharge of septic wastewater which is not only devoid of oxygen but often contains sulfides. Frequent cleaning and maintenance of force mains is required to remove slimes and solids buildup.

Design Criteria - Desirable force main velocities are from 3.5 to 5 ft/s to assure adequate scouring. Under certain circumstances, velocities as low as 2 ft/s can be used, provided precautions are used to increase the velocity from time to time. This increased velocity for scouring is commonly obtained by operating the spare and active pump simultaneously on at least a weekly basis. Pipe of 4-inch diameter is commonly used for small ejector stations, and pipe of 6-inch or larger is used for installations fed by a pumping station.

Force main design is intimately tied to pump station selection to insure a cost effective design. Wetwell size must be coordinated with the force main size and length to determine the methods needed for sulfide control.

Force Main Capacity

Diameter, inches	V = 2 ft/s		V = 3.5 ft/s		V = 5.0 ft/s	
6	176 gpm	.25 Mgal/d	308 gpm	.44 Mgal/d	440 gpm	.63 Mgal/d
8	313 gpm	.45 Mgal/d	548 gpm	.79 Mgal/d	780 gpm	1.12 Mgal/d
10	490 gpm	.71 Mgal/d	860 gpm	1.24 Mgal/d	1,230 gpm	1.77 Mgal/d

A peaking factor allowance ranging from 3 for average flows of 1 Mgal/d and less, to 2 for average flows in excess of 10 Mgal/d, should be used in sizing the force main pipe diameter.

If continuous pumping is desired it may be necessary to have two or three sizes of pumps, some of which may be constant-speed units and some variable-speed units.

Force mains should be designed with proper provision for the release of air and/or gases and should enter the gravity sewer system at a point not more than 2 ft above the flow line of the receiving manhole. Special design consideration must be given to valve and pump selection and the elevation and slope of the force main to avoid water hammer problems.

Characteristics of some of the more common pipe materials are given below.

Material	Application	Advantages	Disadvantages	C Values
Cast or ductile iron, unlined	General use; high pressures	Less expensive than most	Undergoes corrosion, grease build-up	100
Cast or ductile iron, cement-lined	General use; high pressures	No corrosion, slow grease build-up	More expensive than unlined	120
Steel, cement-lined	General use; high pressures	No corrosion, slow grease build-up	More expensive than unlined steel	120
Cement-asbestos	General use, moderate pressures	No corrosion, slow grease build-up	Relatively brittle	120
Fiberglass-reinforced epoxy pipe	General use; moderate pressures	No corrosion, slow grease build-up	As expensive as glass-lined pipe	140
Plastic	General use; lower pressures	No corrosion, slow grease build-up		140

Reliability - Very reliable if properly designed and maintained.

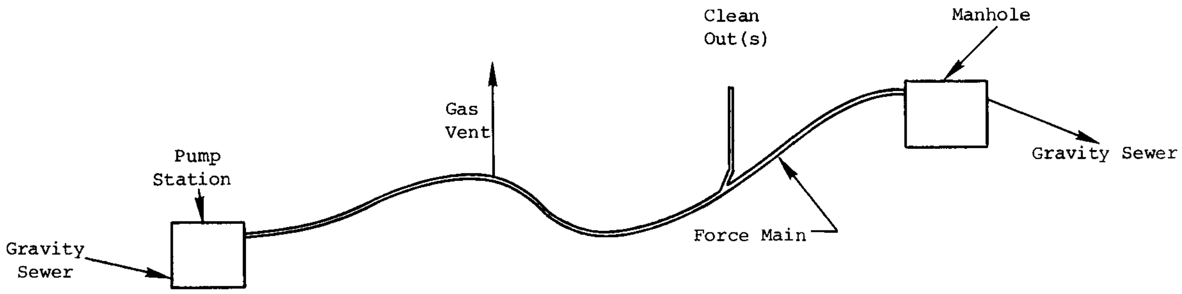
Environmental Impact - Subject to odors, especially during service interruptions. Involves less land use disruption and capital expenditures than excessively deep sewering in many areas.

References - 7, 20, 30, 229

FORCE MAINS, TRANSMISSION

FACT SHEET 1.1.1

FLOW DIAGRAM



ENERGY NOTES - The energy required to convey wastewater through the force main is derived from the pump station.

COSTS - Assumptions: Costs have been adjusted to third quarter 1977 dollars; ENR Index = 2611.

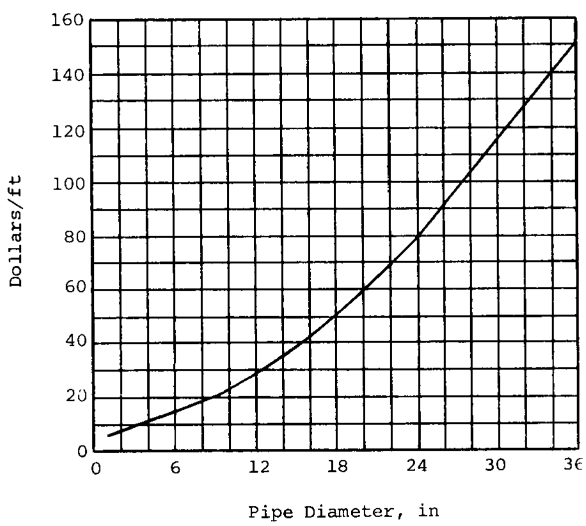
1. Capital costs* have been derived from reference 228. Operating and maintenance costs have been obtained from reference 3.

2. Capital costs include construction costs for force main in-place (including materials and labor) and non-construction costs (administrative/legal costs; land, structures and right-of-way costs; architect/engineer fees; bond interest, contingency and indirect costs). Because of the wide variety of construction conditions under which force mains are built, capital costs shown here do not include allowances for appurtenances, or site-specific requirements such as stream or thoroughfare crossings, extensive rock excavation, etc. Also not included is the cost of pump station.

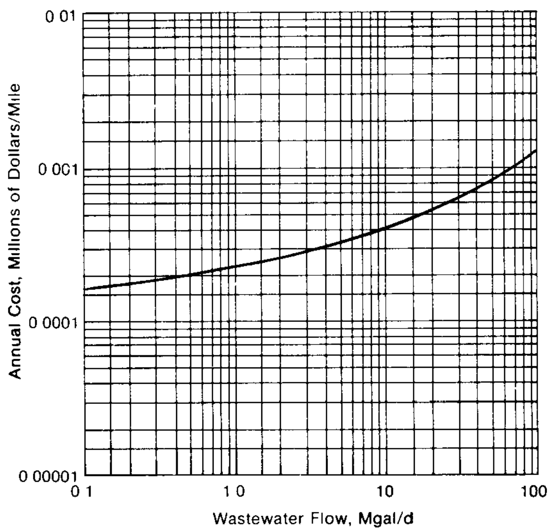
3. If adequate information about pipe size is not available, the following table can be used to approximate the pipe size, assuming a velocity of 3.5 ft/s and a peaking factor of 3.

6 inch diameter - .15 Mgal/d	12 inch diameter - .59 Mgal/d	24 inch diameter - 2.37 Mgal/d
10 inch diameter - .4 Mgal/d	18 inch diameter - 1.35 Mgal/d	30 inch diameter - 3.7 Mgal/d

CAPITAL COST



OPERATION & MAINTENANCE COST



REFERENCES - 3,228

*Capital (rather than construction) costs are shown since the development of capital costs shown in Table A-2 is not readily applicable to force mains.

LIFT STATIONS, RAW WASTEWATER FACT SHEET 1.1.2

Description - An arrangement of pumps, electric motor sets, piping, valves, strainers, controls, and alarms, usually with ventilation fan, sump pump, dehumidifier, lights, and space heater, assembled in an enclosed structure which consists of a wet well (wastewater receiver, equipped with a screen and sometimes also a comminutor) and a dry well (pump and motor room). The pump station can be field-installed or factory pre-fabricated or packaged. The capacities range from 20 gal/min and over. The packaged unit generally has a capacity up to 10,000 gal/min. The total dynamic head varies.

Common Modifications - When separate wet and dry wells are not provided as described above, the following pump configurations may be used: pump set submersible; liquid end of pump is submersible, with extended shaft for motor drive and controls outside of wet well but in weather-proof enclosure; liquid end of pump, piping, and valves are above wastewater level but pump has extended, submerged suction pipe, with motor drive and controls outside of wet well but in weather-proof enclosure.

Pneumatic ejector, with separate or integral collection chamber acting as a wet well when connected to sanitary line, can be substituted for pumps in a dry well configuration and are economically feasible for capacities up to 300 gal/min. Above 300 gal/min space requirements and equipment and power costs become excessive.

Use of various pump capacities in a multiple unit system to match diurnal flow characterisitcs.

Provision for emergency power supply.

Oxygenation, aeration, or chemical feeding equipment is sometimes included for the stated purpose of reducing H_2S at force main discharge.

Technology Status - Widespread use in wastewater application.

Application - Lifts wastewater to a higher elevation when the continuance of the gravity flow line at reasonable slopes would involve excessive depths of trench; lifts wastewater from areas too low to drain into an available sanitary sewer line; boosts wastewater elevation where there is insufficient head in the incoming gravity flow line for gravity flow through a treatment plant.

Limitations - Potential exists for odor problems and H_2S generation when wastewater flow conditions are not properly controlled. Need for emergency power under certain conditions. Single pump units are not recommended. Wet well mounted units may have inspection and maintenance problems in the wet well.

Typical Equipment/No. of Mfrs. (23) - Pump sets/34; valves/39; screens/20; comminutors/12; heaters/7; ventilating fans/7; controls and alarms/29.

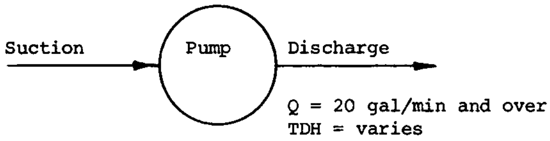
Design Criteria - Wet well maximum detention time 10 to 30 min; minimum slope wet well bottom 2:1; dry well and wet well must be ventilated; effective volume of the wet well may include incoming sewerlines; wet well floor should always remain covered with liquid to reduce odor problems; bar screens should be provided; pump suction and discharge nozzle velocities should range between 10 and 14 ft/s; minimum solid capacity of pump, 3 inch diameter; high water alarm; minimum number of pumps, 2; suitable water level controls for pump motor operation; emergency power provisions; pumping capacity must equal the maximum flow condition with the largest pump unit out of service.

Reliability - Reliable with a 10 to 20 year life expectancy consistent with cost effective guidelines provided manufacturer's maintenance procedures are followed. Reliability highly dependent upon power source and number of pumps. Regular operation and maintenance required.

Environmental Impact - Low impact on air and water. Moderate impact on land during installation. Potential for water pollution and health risk under failure conditions. Potential for noise, odor.

References - 3, 7, 22, 23, 30, 195, 196, 197, 198

FLOW DIAGRAM -



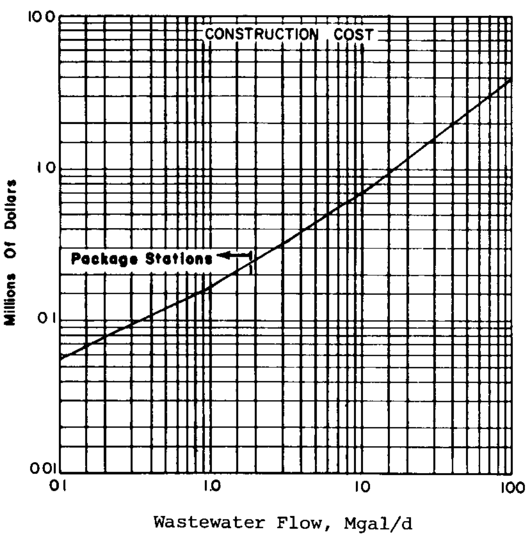
ENERGY NOTES - Primary energy consumption for a lift station is related to the pumping requirements. Pumping energy can be computed from the following equation:

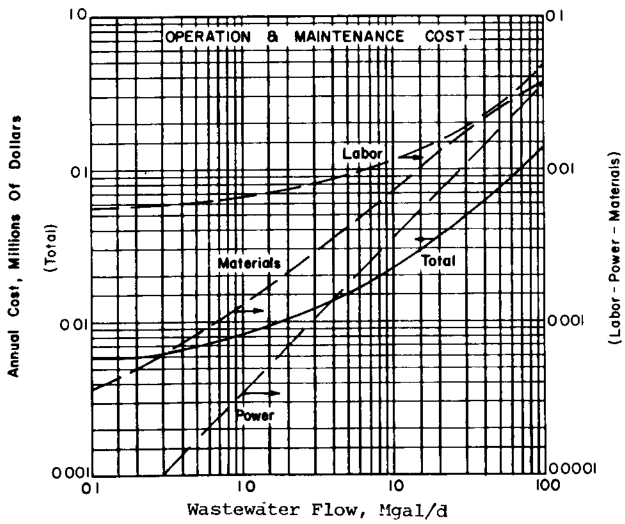
$$kWh/yr = \frac{1140\ (Mgal/d \times TDH)}{\text{Wire to Water Efficiency}}$$

Assuming a wire to water efficiency of 67 percent, a power consumption of 17,500 kWh/Mgal/d/yr would be expected at a TDH of 10 feet. Small additional energy needs are required for controls, lights, and mechanical screening (if used).

COSTS* - Assumptions: ENR Index = 2475

1. Construction cost includes fully enclosed wet well/dry well pit structure; pumping equipment capable of meeting the peak flow with largest unit out of service; standby pumping facilities; piping and valves within structure; bar screens - mechanically cleaned. TDH = 10 ft.
2. Power costs based on $0.02/kWh.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

SEWERS, GRAVITY | FACT SHEET 1.1.3

Description - Gravity sewers are used for the transport of sanitary and industrial wastewater, stormwater and any combination of wastewaters by proper slope design, which results in a flow due to gravity. Access to a gravity sewer is made by manholes every 300 to 500 ft or at changes in slope or direction.

Common Modifications - Addition of corrosion protection coatings (coal based tar, PVC based tar), chemical grouting and slip-in liners (for pipes with diameters of less than 12") for rehabilitation of in-place sewers, inverted syphons, lift stations for hilly or excessively flat terrain, diversion regulators for combined sewers. Drop manholes. Various types of joint materials are used, such as rubber, lead, plastic and various forms of masonry.

In rural communities where topography is favorable, small diameter gravity sewers which transport septic tank effluent to central treatment works have been employed in Australia and, to a limited extent, in the United States. Generally, these sewers have a minimum pipe diameter of 4 in. All installations to date have employed PVC pipe, owing to its light weight, long lengths and ease of laying. Curvilinear alignments in the vertical and horizontal planes are allowable, and manholes or meter boxes (depending on line depth) may be kept to a minimum (400 to 600 ft spacing).

Applications - Gravity sewers are used for the transport of wastewater wherever gravity flow is cost effective.

Technology Status - Oldest and most common wastewater transport system existing. Technology advancement limited principally to improvement in materials and methods of construction. Small diameter systems are undergoing design improvements with applications. Present gradient and size requirements are conservative.

Limitations - High capital cost in rural areas, in areas requiring removal of ledge rock and where depths greater than 15 feet are required. Possible explosion hazard due to production of gas or improper discharge of combustibles into the system. Severe internal corrosion of piping materials can occur due to improper hydraulic design of a sewer. Stoppage due to grease, sedimentation, tree root development and, in the case of combined sewers, debris. Excessive infiltration and inflow are the most common problems for both old and new systems.

Material	Diameters Available	Favorable	Unfavorable
(1) Asbestos Cement	4" to 42"	light weight, ease of handling, long laying lengths, tight joints	Subject to corrosion where acids and hydrogen sulfide are present
(2) Clay Pipe	4" to 42"	Resists corrosion from acids and alkalies, resists erosion and scour	Limited range of sizes and strength, brittle, short lengths, many joints.
(3) Concrete (Reinforced) (Non-reinforced)	 12" to 144" 4" to 24"	Strength, availability of sizes, widely used	Subject to corrosion where acids or hydrogen sulfide are present. Short pipe lengths. Large number of joints.
(4) Cast Iron	2" to 48"	Long laying lengths, tight joints, withstands high external loads, corrosion resistant in neutral soils	Corrosion by acid, highly septic wastewater or corrosive soils
(5) Solid Wall (Plastic Pipe) Truss Pipe	Up to 12" 8" to 15"	Light weight, tight joints, long laying lengths, some cases - corrosion resistant	Thin walls, susceptibility to sunlight and low temperature which affect shape and strength, limited sizes, limited experience, continuous lateral support is essential.

Design Criteria - Size: Dependent upon flow, minimum 6 inch inside diameter for all laterals in collection systems. Slope: Dependent upon size and flow. Velocity: Minimum of 2.0 ft/sec at full depth. Material: Must meet service application requirements. Additional Requirements: Adequate ground cover, minimum scouring (self-cleaning) velocity; infiltration shall not exceed 200 gal/d/in diameter/mile (lower in certain jurisdictions). Small diameter gravity sewers transport septic tank effluent; have a minimum diameter of 4 in., and are designed for 1/2-full peak flow (corresponding to a gradient of 0.67 percent for a 4-in. sewer).

Unit Process Reliability - Highly reliable, with a long life expectancy. System is not dependent upon moving parts.

Environmental Impact - Low impact on air and water. Considerable impact on land during installation. The installation of sewers in roadways adjacent to vacant properties leads to an increase in the rate of development of the land. Small diameter gravity sewers in rural areas would result in a reduction in the magnitude of the land and secondary development impacts for conventional gravity sewers, and they may also reduce the land requirements for subsequent treatment processes where organic loading is the principal design parameter.

References - 3, 7, 103, 228

ENERGY NOTES - Since, by definition, the process is gravity operated, no energy is consumed in its operation.

COSTS-

1. Capital costs* are third quarter 1977 dollars (based on EPA Complete Urban Sewer System Cost Index) and have been derived from reference 228. Operating and Maintenance costs represent September 1976 Figures (ENR=2475), and have been obtained from reference 3.

2. Capital costs include: construction costs for in-place sewer pipe; appurtenances and non-pipe costs; and non-construction costs. Construction costs for in-place pipe include material and labor. Appurtenances and non-pipe costs include manholes, thoroughfare crossings, pavement removal and replacement, rock excavation (minimal), special pipe bedding and miscellaneous appurtenances. Non-construction costs include administrative/legal costs; land, structures & right-of-way costs; architect/engineer fees, bond interest, contingency, indirect and miscellaneous costs.

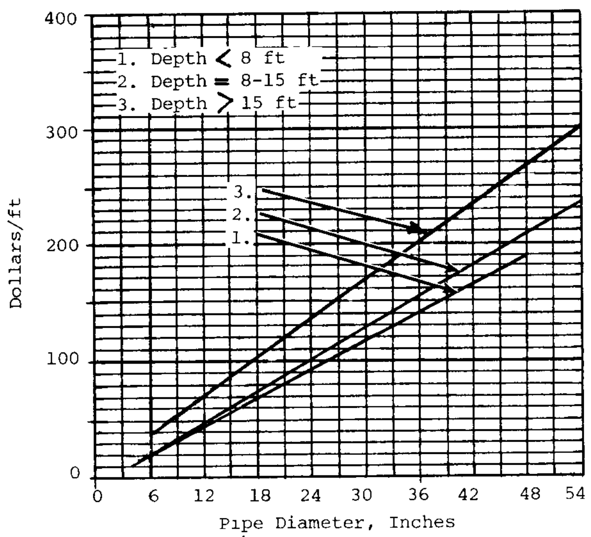
3. Data base for capital costs consisted of over 13,000 bid items for 455 construction projects. Pipe materials used on these projects included PVC, asbestos cement, vitrified clay, cast iron, reinforced concrete and ductile iron. Typical capital costs shown here do not include costs for special or site specific requirements such as extensive rock excavation, dewatering, shoring, or local cost indices.

4. **If adequate information** about pipe diameters is not available, the following table may be used as a guide to convert a given design wastewater flow to pipe diameter.

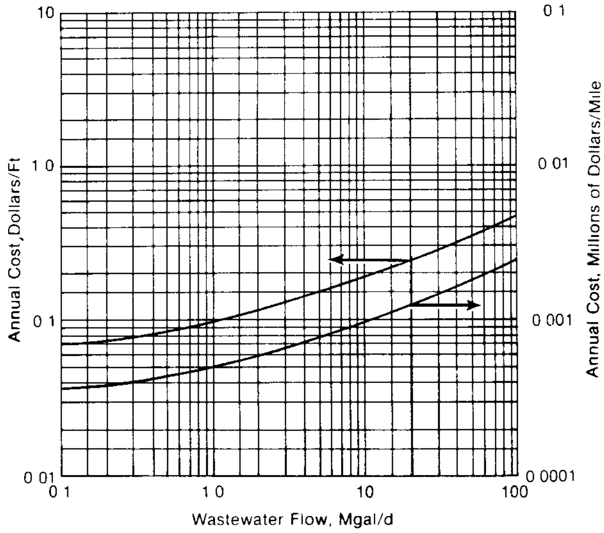
Sizing of Collector and Interceptor Sewers

Pipe Diameter (Inches)	Minimum Slope for Pipe Velocity of 2 ft/sec	Minimum Slope for Pipe Velocity of 8 ft/sec	Design Wastewater Flow (Mgal/d) with Pipe Flowing Full, Velocity, ft/sec: 2	3	4	8
6	0.0060	0.075	0.26	0.36	0.47	0.91
8	0.0038	0.045	0.48	0.69	0.91	1.76
10	0.0030	0.035	0.72	1.04	1.37	2.54
12	0.0022	0.026	1.04	1.46	1.94	3.51
15	0.0015	0.020	1.69	2.47	3.25	5.84
18	0.0012	0.016	2.41	3.45	4.42	9.43
21	0.0010	0.013	3.38	4.94	6.37	12.35
24	0.00078	0.011	4.10	6.24	8.13	15.28
27	0.00065	0.0095	5.20	7.80	10.08	18.85
30	0.00058	0.0080	6.50	9.75	13.00	24.05
36	0.00045	0.0060	9.75	14.63	18.20	37.05
42	0.00038	0.0050	13.00	19.50	25.36	48.10
48	0.00032	0.0045	16.25	24.70	31.85	59.80
54	0.00026	0.0039	20.80	31.85	39.65	84.50

CAPITAL COST



OPERATION & MAINTENANCE COST



REFERENCES - 3, 228, 261

*Capital rather than construction costs are provided since Table A-2 is not readily applicable to gravity sewers.

SEWERS, PRESSURE

FACT SHEET 1.1.4

October 1978

Description (38) - Pressure sewers are used to reduce costs relative to gravity sewer systems in less populated areas. The pressure sewer embodies a number of pressurizing inlet points and a single outlet to a treatment facility or to a gravity sewer, depending on the application.

The two major types of pressure sewer systems are the grinder pump (GP) system and the septic tank effluent pump (STEP) system. The major differences between the alternative systems are in the on-site equipment and layout. Neither pressure sewer system alternative requires any modification of household plumbing.

In both designs household wastes are collected in the sanitary drain and conveyed by gravity to the pressurization facility. The on-lot piping arrangement includes at least one check valve and one gate valve to permit isolation of each pressurization system from the main sewer. GP's can be installed in the basement of a home to provide easier access for maintenance and greater protection from vandalism.

In STEP systems, wastewater receives intermediate treatment in a septic tank. The septic tank effluent then flows to a holding tank which houses the pressurization device, control sensors, and valves required for a STEP system. Normally, small centrifugal pumps are employed for the STEP systems. These pumps are submersible and range in size from 1/4 to 2 hp. Pump total head requirements generally range from 25 to 90 ft. Impellers can be made of plastic to reduce corrosion problems. Also included within the holding tank are level controls, valves and piping. The effluent holding tank can be made of properly cured precast or cast-in-place reinforced concrete, or they may be made of molded fiberglass or reinforced polyester resin. Tank size is based on accessibility for repairs and maintenance.

Pump control switches are either a pressure sensing type, or the mercury float switch type.

Service connection lines between the pump and the pressure main are generally made of 1 to 2 inch PVC pipe (Schedule 40, SDR-21, or SDR-26) with PVC drain, waste, and vent fittings. Pressure mains are usually 2 to 12 in diameter PVC pipe, depending on hydraulic requirements. Pipes must only be buried deep enough to avoid freezing. Head loss due to pipe friction generally is in the range of 1 to 4 ft H_2O/100 ft of pipe.

Common Modifications (38) - On GP systems an emergency (i.e., power failure, etc.) overflow tank may be provided. Measures such as standpipes and pressure control valves are sometimes used to maintain a positive pressure on the system. Air release valves are also provided to eliminate gas pockets in the system. Polyethylene pipe, pneumatic ejectors, and mainline check valves have been used in some designs.

Technology Status - More than 30 pressure sewer systems have been operated in the United States to date. At least 70 more are either being designed or constructed.

Applications - Pressure sewers are most applicable where population density is low, severe rocky conditions exist, high ground water or unstable soils prevail, and/or where undulating terrain predominates.

Limitations - High operation and maintenance costs related to the use of mechanical equipment at each point of entry to the system. In GP systems, the wastewater conveyed to the treatment facility may be more concentrated than normal wastewater. In STEP systems, a weaker, more septic waste is generated. Therefore, both systems require special care in system design and in treatment facility design.

Typical Equipment/No. of Mfrs. (10, 38) - Pressurization pumps/27; Septic tanks and distribution piping/locally supplied; air release valves/8; pressure sustaining valves/9; grinder pumps/8.

Design Criteria - Dendriform systems are generally used instead of grids. Pump requirements vary with the type of pump employed and its location in the system. Flushing provisions are necessary. Pipe design is based on Hazen-Williams friction coefficient of 130 to 140. For GP systems a minimum velocity of about 3 ft/s at least one time per day is used to prevent deposition of solids. Meter boxes generally suffice in place of manholes.

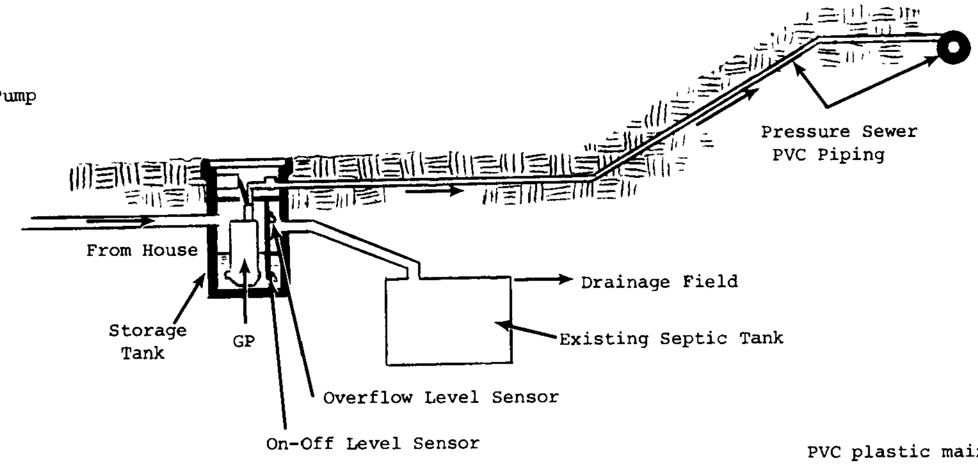
Process Reliability (38) - Severe corrosion can cause mechanical and electrical problems. Accumulations of grease and fiber can cause reductions in pipe cross-sectional areas of GP systems during partial flow conditions. Estimated life of current pump designs exceeds ten years. Centralized maintenance is generally required for optimum service.

Environmental Impact - During construction, there is potentially less noise impact, fugitive dust problems and erosion than with conventional sewers because of smaller equipment and less excavation requirements. In aquifer areas, the smaller and shallower trench and water tight piping will minimize the trench draining effect that is normally associated with sewer pipes in aquifer areas. Fewer pumping station requirements improve aesthetics. Some odor potential is inherent in pressure sewers, but judicious design has been successful in controlling it. Pressure sewers generally run along road right-of-ways, resulting in less traffic disruption during construction and repair operations. Without proper emergency backup and warning systems, in-house overflows may occur.

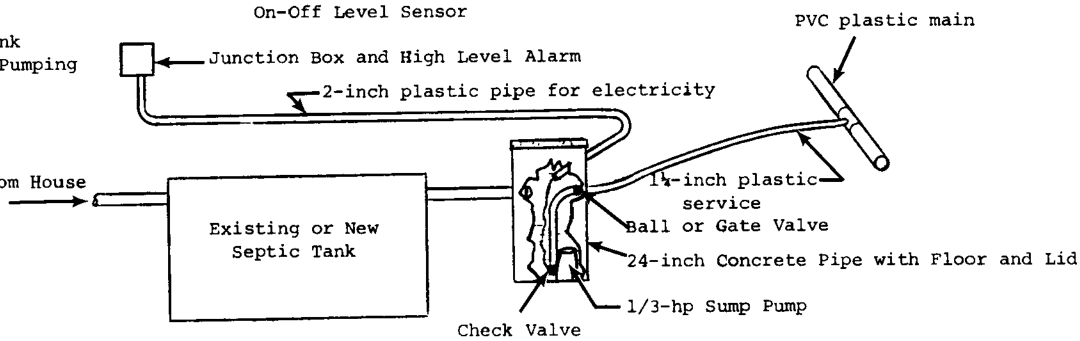
References - 10, 38, 103

FLOW DIAGRAM -

Grinder Pump



Septic Tank
Effluent Pumping



ENERGY NOTES - Required kWh/yr/home = 50 to 200

COSTS* (1978 dollars) ENR Index = 2776

Components**	Construction Cost	Operation & Maintenance Cost
1. Mainline Piping (PVC)		$100-200/year/mile
a. 1-3 in diameter	$3.00/lin ft	
b. 4 in	$3.50/lin ft	
c. 6 in	$4.65/lin ft	
TOTAL		$100-200/year/mile
2. On-lot Septic Tank Effluent Pumping (STEP)		
a. Pump, controls, etc.	$ 900-1,500	$40/year
b. Service line (100 ft @ $2/ft)	200	
c. Corporation cocks, valves, etc.	50	
d. Septic tank (optional)	250	$10/year
e. Connection fee	50-100	
TOTAL	$1,200-2,100	$50/year
3. On-lot Grinder Pump (GP)		
a. GP unit, controls, etc.	$1,300-2,000	$75/year
b. Service line (100 ft @ $2/ft)	200	
c. Cocks, valves, etc.	50	
d. Connection fee	50-100	
TOTAL	$1,600-2,350	$75/year

* To convert construction cost to capital cost, refer to Table A-2.

** Local economics, climate, geology, soils, etc. make any such effort to give specific, accurate costs for these components extremely difficult. The above costs are considered typical for gross estimating purposes only.

REFERENCES - 38, 103

SEWERS, VACUUM

FACT SHEET 1.1.5

Description - Vacuum sewers employ a central vacuum source which is maintained at 15 to 25 in Hg vacuum. A gravity vacuum interface valve separates atmospheric pressure in the home service line or toilets from the vacuum in the collection mains. When the interface valve opens, a volume of wastewater enters the main, followed by a volume of atmospheric air. After a preset interval, the valve closes. The packet of liquid, called a slug, is propelled into the main by the differential pressure of vacuum in the main and the higher atmospheric pressure air behind the slug. After a distance, the slug is broken down by shear and gravitational forces, allowing the higher pressure air behind the slug to slip past the liquid. With no differential pressure across it, the liquid then flows to the lowest local elevation and vacuum is restored to the interface valve for the subsequent operation. When the next upstream interface valve operates, identical actions occur, with that slug breaking down and air rushing across the second slug. That air then impacts the first slug and forces it further down the system. After a number of operations, the first slug arrives at the central vacuum station. When sufficient liquid volume accumulates in the collection tank at the central vacuum station, a sewage pump is actuated to deliver the accumulated sewage to a treatment plant.

There are significant differences in the designs of the four types of currently installed systems: Liljendahl-Electrolux, Colt Envirovac, AIRVAC, and Vac-Q-Tec. The major differences lie in the extent to which each system uses separate black (toilet) and gray (the balance) water collection mains. Electrolux uses separate systems for these sources; Colt uses vacuum toilets and only one main, and AIRVAC and Vac-Q-Tec take the normal household combined waste. Other differences relate to the location of the gravity/vacuum interface (i.e. in the house or outside) and to the design of pumps and vacuum valves.

Wastewater piping in all four designs is 3 to 6 inches in diameter PVC except where separate black and gray lines are used, which are 1½ to 3 inches. Joints are made with solvent welds or special "O" ring seals. Piping profiles vary in each system depending on terrain. Traps are located where the designer wishes to reform a slug of water for transport purposes or to gain elevation within the limits available; i.e., 15 to 25 in Hg.

Vacuum toilets are flushed after each use, while a vacuum valve opens automatically when a predetermined volume of water has accumulated behind it, provided there is adequate vacuum available. The valve is actuated by a pneumatic or electrical controller, depending on the design.

Vacuum pump construction has been both sliding vane and liquid ring. Liquid ring pumps have been used more frequently. The contents in the vacuum collection tank are transferred to a treatment facility by non-clog wastewater pumps. It is important to use pumps whose shaft seals close against vacuum. The Vac-Q-Tec system utilizes a pneumatic ejector for this service.

Common Modifications - Vacuum reserve tanks are often installed to reduce vacuum pump cycling thereby extending pump life. On-lot tanks can be used to hold accumulated liquid or the existing building sewer can be used.

Technology Status - Vacuum sewage systems are in limited commercial use (15 to 20 systems have been installed), and many designs and component fabrication improvements have been made in recent years to improve their performance.

Applications - Vacuum sewers are most applicable in areas with scarce water supply, high ground water, impermeable soil, rocky conditions, and low population density.

Limitations - Vacuum systems are limited in the lift available and are therefore more suitable to flat terrain. These systems may be adversely affected by low initial use/design use ratio because of inefficient operation and high cost/unit volume of sewage transported. Generally, all system malfunctions result in on-lot wastewater accumulation.

Typical Equipment/No. of Mfrs. (38, 23) - Vacuum valves/4, vacuum toilets/2, pumps/34.

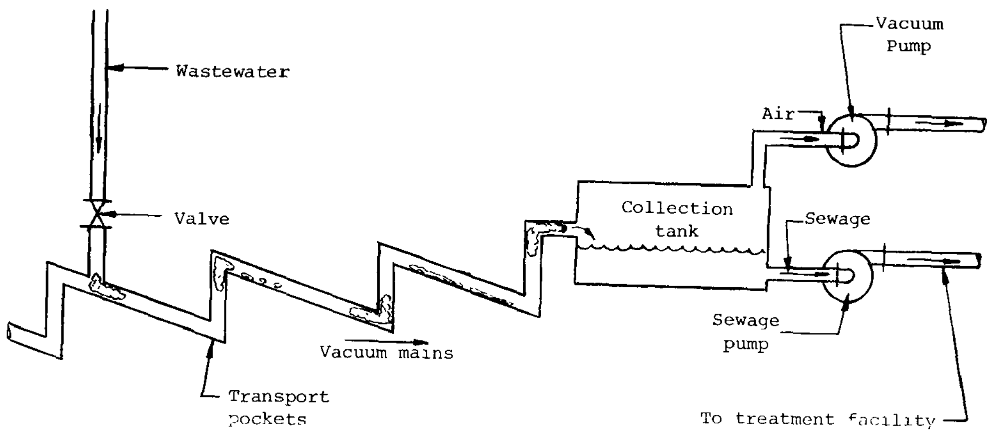
Design Criteria- Trap spacing = 200 to 400 ft(max.). Minimum line velocity = 2 ft/s at 0.7 of full pipe flow. Wastewater flow = 50 to 75 gal/d/capita. Vacuum receiver pressure 15 to 25 in Hg. Air flow volume into system equals the wastewater volume, but expansion under vacuum increases the air/wastewater ratio.

Process Reliability - Valves will generally require a yearly inspection, scheduled major maintenance every 6 years and unscheduled repair every four to eight years. Vacuum and discharge pumps will require major repair or replacement every ten years. Vacuum system malfunctions have occurred in the valves, piping system and collection stations. Moisture in sensor lines and valve boot ruptures have been major sources of valve problems.

Environmental Impact - There is potentially less noise impact, fewer problems with fugitive dust, and less erosion potential than conventional sewers during construction because of smaller equipment requirements. There is potentially less chance of disturbing natural areas, such as streambeds and low-lying wetlands, because of lack of gravity flow requirements. In aquifer areas, the smaller and shallower trench will minimize the trench draining effect that is normally associated with sewer pipes in aquifer areas. Less growth inducement potential because of considerably less reserve capacity in sewer lines. Air pollution potential at vacuum stations due to exhaust air has not been quantified.

References - 23, 38, 103

FLOW DIAGRAM -



ENERGY NOTES - Electrical power requirements have been shown to vary from 0.0024 to 0.44 kWh/gal of wastewater transported (103). Elevation head loss per trap = 1.5 ft H_2O (varies with design); Dynamic head loss = 1 to 5 ft H_2O/1000 ft of pipe length; vacuum valve head loss = 5 ft H_2O.

COSTS* (1978 dollars); ENR Index = 2776.

Estimated Construction Costs per Home

(Flat terrain; design population 500; 3.5 persons/home; one valve/home) (Ideal Conditions)

	Cost	Approximate Range
Valve and Appurtenances	$1,000	$ 800-1,100
Service Line (100 ft)	200	150- 300
Mainline (120 ft)	660	600-1,200
Pocket and Cleanouts (@ $100 each)	50	30- 100
Vacuum Station (@ $85,000)	595	400-2,000
Discharge Pipe	15	10- 50
TOTAL	$2,520	$1,990-4,750

Estimated Operation and Maintenance Costs per Home

Preventive Maintenance (4 h @ $10/h)	$40/year
Power (175 gal/d @ $0.02/kWh and 13.2 gal/kWh)	26
Repair and Replacement	14
Mainline Operation and Maintenance	2-5
TOTAL	$82-85/year

REFERENCES 38, 103

*To convert construction cost to capital cost, refer to Table A-2.

AQUACULTURE - WATER HYACINTH FACT SHEET 1.2.1

Description - Aquaculture, or the production of aquatic organisms (both flora and fauna) under controlled conditions has been practiced for centuries, primarily for the generation of food, fiber and fertilizer. The water hyacinth (Eichhornia crassipes) appears to be the most promising organism for wastewater treatment and has received the most attention. However, other organisms are being studied. Among them are duckweed, seaweed, midge larvae, alligator weeds and a host of other organisms. Water hyacinths are large fast-growing floating aquatic plants with broad, glossy green leaves and light lavender flowers. A native of South America, water hyacinths are found naturally in waterways, bayous, and other backwaters throughout the South. Insects and disease have little effect on the hyacinth, and they thrive in raw, as well as partially treated, wastewater. Wastewater treatment by water hyacinths is accomplished by passing the wastewater through a hyacinth-covered basin, where the plants remove nutrients, BOD_5, suspended solids, metals, etc. Batch treatment and flow-through systems, using single and multiple cell units, are possible. Hyacinths harvested from these systems have been investigated as a fertilizer/soil conditioner after composting, animal feed, and a source of methane when anaerobically digested.

Common Modifications - Generally used in combination with (following) lagoons, with or without chemical P removal. Artificial and natural wetlands are also being studied (see Fact Sheet 1.2.2).

Technology Status - Developmental stage. A number of full-scale experimental and demonstration systems are in operation; exact design and economic data have not been developed.

Applications - Most often considered for nutrient removal and additional treatment of secondary effluent. Also, research is being conducted on the use of water hyacinths for raw and primary treated wastewater or industrial wastes, but present data favor combination systems. Very good heavy metal uptake by the hyacinth has been reported. Hyacinth treatment may be suitable for seasonal use in treating wastewaters from recreational facilities and those generated from processing of agricultural products. Other organisms and methods with wider climatological applicability are being studied. The ability of hyacinths to remove nitrogen during active growth periods and some phosphorus and retard algae growth provides potential applications in the upgrading of lagoons, renovation of small lakes and reservoirs, pretreatment of surface waters used for domestic supply, storm water treatment, demineralization of water, recycling fish culture water and for biomonitoring purposes.

Limitations - Climate or climate control is the major limitation. Active growth begins when the water temperature rises above $10^{\circ}C$. and flourishes when the water temperature is approximately $21^{\circ}C$. Plants die rapidly when the water temperature approaches the freezing point; therefore, greenhouse structures are necessary in northern locations. Water hyacinths are sensitive to high salinity. Removal of phosphorus and potassium is restricted to the active growth period of the plants.

Metals such as arsenic, chromium, copper, mercury, lead, nickel and zinc can accumulate in hyacinths and limit their suitability as a fertilizer or feed material. The hyacinths may also create small pools of stagnant surface water which can breed mosquitoes. Mosquito problems can generally be avoided by maintaining mosquito fish in the system. The spread of the hyacinth plant itself must be controlled by barriers since the plant can spread and grow rapidly and clog affected waterways. Hyacinth treatment may prove impractical for large treatment plants due to land requirements. Removal must be at regular intervals to avoid heavy intertwined growth conditions. Evapotranspiration can be increased by 2 to 7 times greater than evaporation alone.

Typical Equipment - Ponds, channels or basins (in northern climates covers and heat would be required); harvesting equipment; processing (macerating, etc.) equipment; water hyacinths - locally acquired.

Performance - In tests on five different wastewater streams the following removals were reported:

Feed Source	BOD_5 Reduction	COD Reduction	TSS Reduction	N Reduction	Phosphate Reduction
Secondary Effluent	35%	-	-	44%	74%
Secondary Effluent	83%	61%	83%	72%	31%
Raw Wastewater	97%	-	75%	92%	60%
Secondary Effluent	60-79%	-	71%	47%	11%

There is some evidence that coliform, heavy metals, organics are also reduced, as well as pH neutralization.

Residuals Generated - Hyacinth harvesting may be continuous or intermittent. Studies indicate that average hyacinth production (including 95 percent water) is on the order of 1,000 to 10,000 lb/d/acre. Basin cleaning at least once per year results in harvested hyacinths.

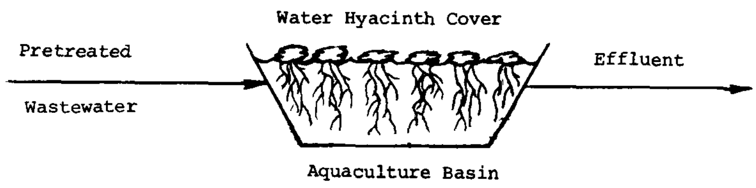
Design Criteria - Experimental data vary widely. Ranges below refer to hyacinth treatment as a tertiary process on secondary effluent. Depth should be sufficient to maximize plant rooting and plant absorption. Detention time: depends on effluent requirements and flow; 4-15 days average; phosphorus reduction: 10 to 75 percent; nitrogen reduction: 40 to 75 percent; land requirement: 2 to 15 acres/Mgal/d.

Overall Reliability - Additional data is required. Process appears reliable from mechanical and process standpoints, subject to temperature constraints.

Environmental Impact - Reduces the nutrient and contaminant levels of wastewater effluent and subsequent eutrophication potential. Land use is high. Metal uptake by hyacinths may limit the harvested culture's end use, but provide removal from wastewater effluent.

References - 57, 74, 174, 200, 209

FLOW DIAGRAM -

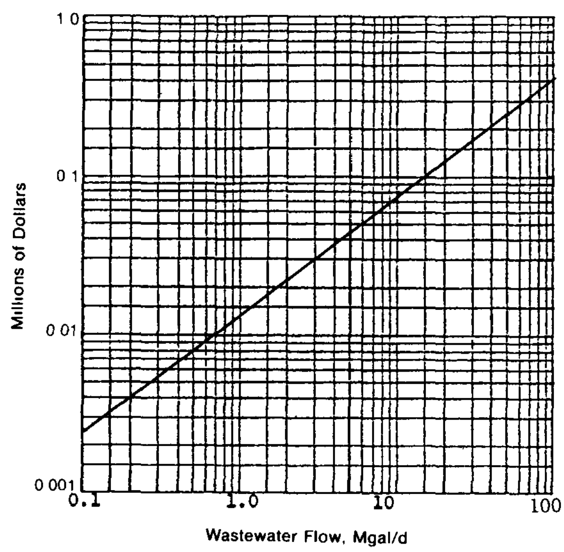


ENERGY NOTES - Operation is by gravity flow and requires no energy. Hyacinth growth energy is supplied by sunlight. All experimental data is from southern climates where no auxiliary heat was needed. Data is not available on heating requirements for northern climates, but it can be assumed proportional to northern latitude of location and to the desired growth rate of hyacinths.

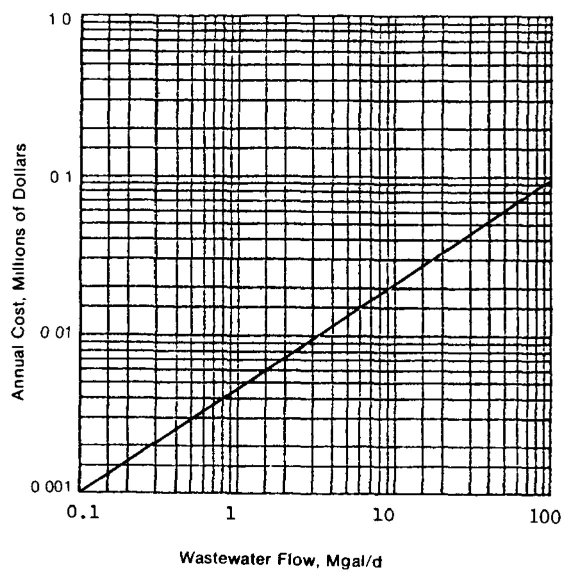
COSTS* - Assumptions:

1. Design basis: used as tertiary treatment; average detention time = 5 days, average depth = 4 ft. Costs based on September 1976 prices (ENR = 2475).
2. Construction costs include excavation, grading and other earthwork, service roads, hyacinth seeding. Costs do not include land, pumping, harvesting equipment or covers/auxiliary heat for northern climates.
3. Operation and maintenance costs include labor at $7.50/h, including fringe benefits. Does not include costs for harvesting, processing or disposal of hyacinths. No credit is indicated for value of harvested hyacinths.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES - 3, 174

*To convert construction cost to capital cost see Table A-2.

AQUACULTURE - WETLANDS FACT SHEET 1.2.2

Description - Aquaculture systems for wastewater treatment include natural and artificial wetlands as well as other aquatic systems involving the production of algae and higher plants (both submergent and emergent), invertebrates, fish and integrated polyculture foodchain systems. Natural wetlands, both marine and freshwater, have inadvertently served as natural waste treatment systems for centuries; however, in recent years marshes, swamps, bogs and other wetland areas have been successfully utilized as managed natural "nutrient sinks" for polishing partially treated effluents under relatively controlled conditions. Constructed artificial wetlands can be designed to meet specific project conditions while providing new wetland areas that also improve available wildlife wetland habitats and the other numerous benefits of wetland areas. Managed plantings of reeds (e.g., Phragmites spp.) and rushes (e.g., Scirpus spp. and Schoenoplectus spp.) as well as managed natural and constructed marshes, swamps, and bogs have been demonstrated to reliably provide pH neutralization and some reduction of nutrients, heavy metals, organics, BOD_5, COD, SS, fecal coliforms and pathogenic bacteria. Wastewater treatment by natural and constructed artificial wetland systems is generally accomplished by sprinkling or flood irrigating the wastewater into the wetland area or by passing the wastewater through a system of shallow ponds, channels, basins or other constructed areas where the emergent aquatic vegetation has been planted or naturally occurs and is actively growing. The vegetation produced as a result of the system's operation may or may not be removed and can be utilized for various purposes e.g., composted for use as a source of fertilizer/soil conditioner, dried or otherwise processed for use as animal feed supplements, or digested to produce methane.

Common Modifications- Tie-ins with cooling water from power plants to recover waste heat have potential for extending growing seasons in colder climates. Enclosed and covered systems are possible for very small flows.

Technology Status - Developmental stage. Several full-scale, demonstration, and experimental systems are in operation or under construction; a limited amount of tested design and economic data have been developed to date.

Applications - Useful for polishing treated effluents. Has potential as a low cost, low energy consuming alternative or addition to conventional treatment systems, especially for smaller flows. Has been successfully used in combination with chemical addition and overland flow land treatment systems. Wetland systems may also be suitable for seasonal use in treating wastewaters from recreational facilities, some agricultural operations, or other waste-producing units where the necessary land area is available. Potential application as an alternative to lengthy outfalls extended into rivers, etc. and as a method of pretreatment of surface waters for domestic supply, storm water treatment, recycling fish culture water and biomonitoring purposes.

Limitations - Temperature (climate) is a major limitation since effective treatment is linked to the active growth phase of the emergent vegetation. Herbicides and other materials toxic to the plants can affect their health and lead to poor treatment. Duckweeds are prized as food for waterfowl and fish and can be seriously depleted by these species. Winds may blow duckweeds to the shore if wind screens or deep trenches are not employed. Small pools of stagnant surface water which can allow mosquitoes to breed can develop, but problems can generally be avoided by maintaining mosquito fish or a healthy mix of aquatic flora and fauna in the system. Wetland systems may prove impractical for large treatment plants due to the large land requirements. May cause evapotranspiration increases.

Typical Equipment - Natural or artificial marshes, swamps, bogs, shallow ponds, channels, or basins. Irrigation, harvesting and processing equipment optional. Aquatic vegetation locally acquired.

Performance - In test units and operating artificial marsh facilities using various wastewater streams, the following removals have been reported for secondary effluent treatment (10 day detention): BOD_5, 80 - 95 percent; TSS, 29 - 87 percent; COD, 43 - 87 percent; nitrogen, 42 - 94 percent; (depending upon vegetative uptake and frequency of harvesting); Total P, 0 - 94 percent (high levels possible with warm climates and harvesting); coliforms, 86 - 99 percent; heavy metals, highly variable depending on species. There is also evidence of reductions in wastewater concentrations of chlorinated organics and pathogens, as well as pH neutralization without causing detectable harm to the wetland ecosystem.

Chemical, Physical and Biological Aids - Sunlight, proper temperature.

Residuals Generated - Dependent upon type of system and whether or not harvesting is employed. Duckweed, for example, yields 50 - 60 lb/acre/d (dry weight) during peak growing period to about half of this figure during colder months.

Design Criteria - Design criteria are very site and project specific. Experimental data are sparse and vary widely. Values below refer to one type of artificial system used as a tertiary process on secondary effluent:

Detention Time: 13 days
Land Requirement: 8 acres/Mgal/d
Depth may vary with type of system, generally 1 to 5 ft.

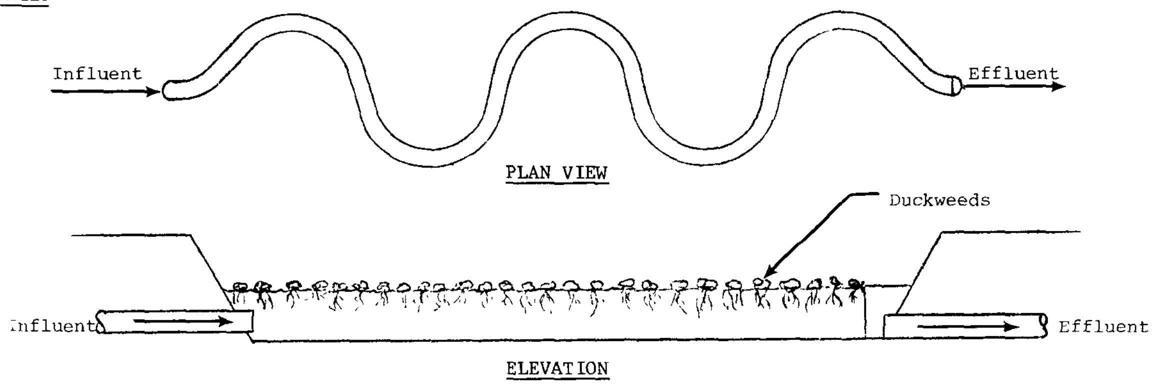
Overall Reliability - Additional data is required. Process appears reliable from mechanical and performance standpoints, subject to seasonality of vegetation growth. Low operator attention is required if properly designed.

Environmental Impact - Reduces pollutant levels of sewage effluent while enhancing available wetland wildlife habitat. Land use is high.

References - 214, 215, 216, 217, 218, 219, 220.

AQUACULTURE - WETLANDS FACT SHEET 1.2.2

FLOW DIAGRAM -

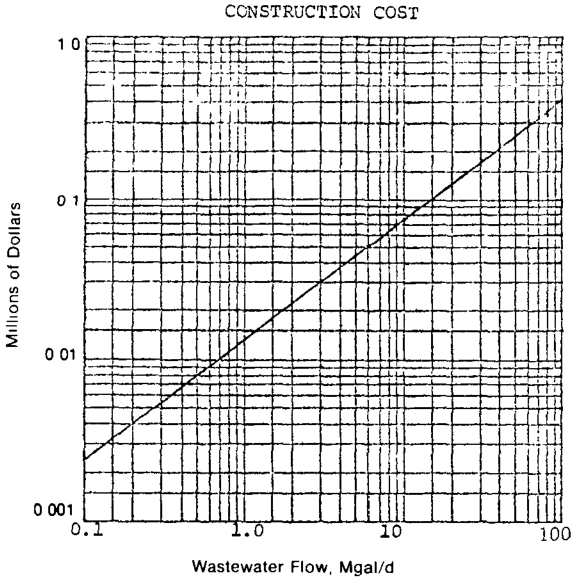


ENERGY NOTES - Operation by gravity flow and requires negligible energy due to minimal headloss. Growth energy supplied by sunlight. Enclosed systems in northern climates will require supplemental heating during cold months, but no data are available.

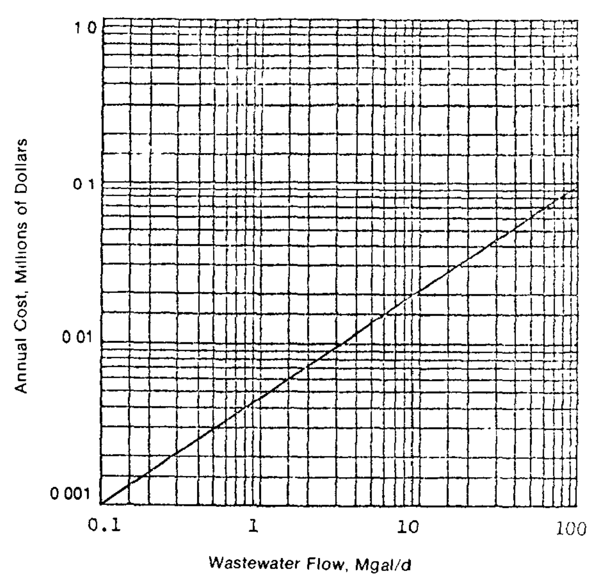
COSTS* - Assumptions:

1. Secondary effluent feed; nominal detention time = 5 days; average depth 4 feet; ENR = 2475
2. Construction costs include excavation, grading and other earth work, service roads, vegetation seeding. Costs do not include land, pumping, harvesting equipment, or covers/auxiliary heat for northern climates.
3. O/M costs include labor at $7.50/h, including fringe benefits, but do not include costs for harvesting, processing or disposal of vegetation. No credit is given for potential value of harvested vegetation

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES - 3, 174

*To convert construction cost to capital cost see Table A-2.

RAPID INFILTRATION, UNDERDRAINED FACT SHEET 1.2.3

Description - Wastewater is applied to deep and permeable deposits such as sand or sandy loam usually by distributing in basins or infrequently by sprinkling, and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange precipitation, and microbial action. Most metals are retained on the soil, many toxic organics are degraded or adsorbed. An underdrainage system consisting of a network of drainage pipe buried below the surface serves to recover the effluent, to control groundwater mounding, or to minimize trespass of wastewater onto adjoining property by horizontal subsurface flow. To recover renovated water for reuse or discharge underdrains are usually intercepted at one end of the field by a ditch. If groundwater is shallow, underdrains are placed at or in the groundwater to remove the appropriate volume of water. Thus, the designed soil depth, soil detention time and underground travel distance to achieve the desired water quality can be controlled. Effluent can also be recovered by pumped wells.

Basins or beds are constructed by removing the fine textured top soil from which shallow banks are constructed. The underlying sandy soil serves as the filtration media. Underdrainage is provided by using plastic, concrete (sulfate resistant if necessary), or clay tile lines. The distribution system applies wastewater at a rate which constantly floods the basin throughout the application period of several hours to a couple of weeks. The waste floods the bed and then drains uniformly away, driving air downwards through the soil and drawing fresh air from above. A cycle of flooding and drying maintains the infiltration capacity of the soil material. Infiltration diminishes slowly with time due to clogging. Full infiltration is readily restored by occasional tillage of the surface layer and, when appropriate, removal of several inches from the surface of the basin. Preapplication treatment to remove solids improves distribution system reliability, reduces nuisance conditions, and may reduce clogging rates. Common preapplication treatment practices include the following: primary treatment for isolated locations with restricted public access; biological treatment for urban locations with controlled public access. Storage is sometimes provided for flow equalization and for non-operating periods.

Common Modifications - Nitrogen removals are improved by establishing specific operating procedures to maximize denitrification, including adjusting application cycles, supplying an additional carbon source, using vegetated basins (at low rates), recycling portions of wastewater containing high nitrate concentrations and reducing application rates.

Technology Status - Was developed approximately 100 years ago and has remained unaltered since then. Has been widely used for municipal and certain industrial wastewaters throughout the world.

Application - A simple wastewater treatment system that is less land intensive than other land application systems and provides a means of controlling groundwater levels and lateral subsurface flow. Also provides a means of recovering renovated water for reuse or for discharge to a particular surface water body. Is suitable for small plants where operator expertise is limited. Is applicable for primary and secondary effluent and for many types of industrial wastes, including those from breweries, distilleries, paper mills, and wool scouring plants. In very cold weather the ice layer floats atop the effluent and also protects the soil surface from freezing.

Limitations - Process is limited by soil type, soil depth, the hydraulic capacity of the soil, the underlying geology, and the slope of the land. Nitrate and nitrite removals are low unless special management practices are used.

Typical Equipment/No. of Mfrs. (23) - Storage tanks/2, pipe/9, pumps/34.

Performance (9) - Effluent quality is generally excellent where sufficient soil depth exists and is not normally dependent on the quality of wastewater applied within limits. Well designed systems provide for high quality effluent that may meet or exceed primary drinking water standards. Percent removals for typical pollution parameters are: BOD_5 and TSS, 95 to 99 percent; Total N, 25 to 90 percent; Total P, 0 to 90 percent until flooding exceeds adsorptive capacity; Fecal Coliform, 99.9 to 99.99+ percent.

Chemicals Required - None

Residuals Generated - Occasional removals of top layer of soil are sometimes required. This material is disposed of on-site.

Design Criteria - Field area 3 to 56 acres/Mgal/d; application rate 20 to 400 ft/yr, 4 to 92 in/wk; BOD_5 loading rate 20 to 100 lb/acre/d; soil depth 10 to 15 ft or more; soil permeability 0.6 in/h or more; hydraulic loading cycle 9 h to 2 wks application period, 15 h to 2 wks resting period; soil texture - sands, sandy loams; basin size 1 to 10 acres, at least 2 basins/site; height of dikes 4 ft; underdrains 6 or more ft deep, well or drain spacing site specific; application techniques - flooding or sprinkling; preapplication treatment - primary or secondary.

Process Reliability - Extremely reliable, as long as sufficient resting periods are provided.

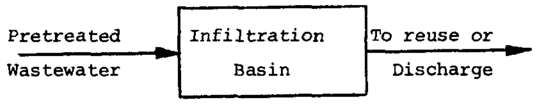
Environmental Impact - Potential for contamination of groundwater by nitrates. Heavy metals are eliminated by pretreatment techniques as necessary. Monitoring for metals and toxic organics is needed where they are not removed by pretreatment. Requires long term commitment of relatively large land areas, although small by comparison to other land treatment systems.

References - 6, 9, 23, 40, 41

RAPID INFILTRATION, UNDERDRAINED

FACT SHEET 1.2.3

FLOW DIAGRAM -

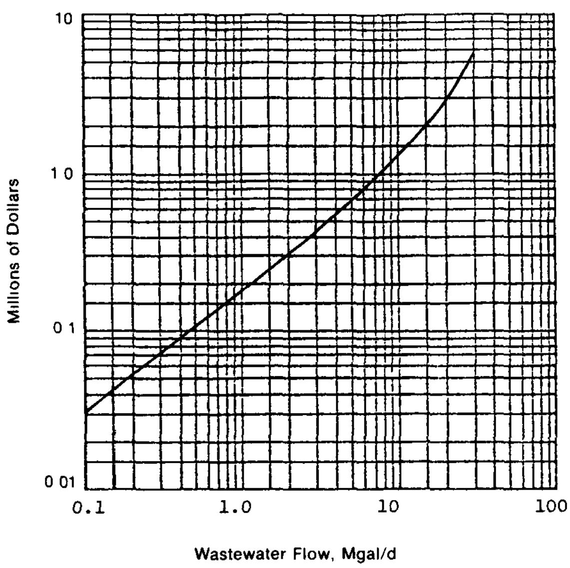


ENERGY NOTES - Gravity distribution methods consume no energy but do require head availability; sprinkler application energy requirements are included in 1.2.5 .

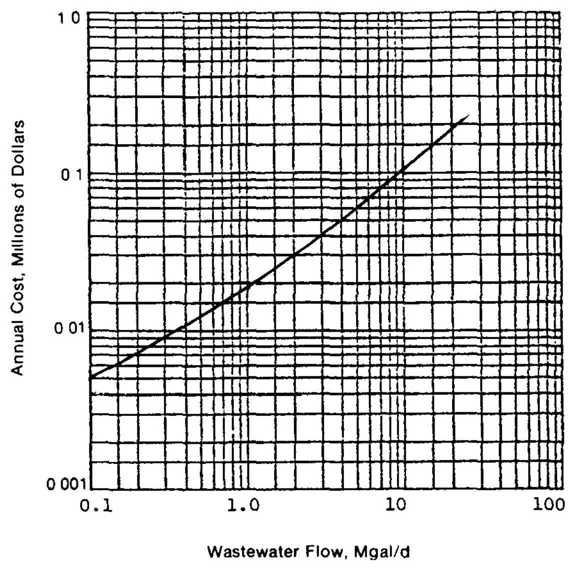
COSTS* - Assumptions:

1. Costs are based on February 1973 (EPA Index 194.2) figures. ENR Index = 1850
2. Labor rates including fringe benefits = $5/hr; application rate 182 ft/yr.
3. Construction costs include field preparations (removal of brush and trees) for multiple unit infiltration basins with 4 ft dike formed from native excavated material, and storage is not assumed necessary.
4. Drain pipes buried 6 to 8 ft with 400 ft spacing, interception ditch along length of field, and weir for control of discharge; gravel service roads and 4-ft stock fence around perimeter.
5. O&M cost includes inspection and unclogging of drain pipes at outlets; annual rototilling of infiltration surface and major repair of dikes after 10 years; high pressure jet cleaning of drain pipes every 5 yr, annual cleaning of interceptor ditch, and major repair of ditches, fences and roads after 10 yr.
6. Costs of pretreatment monitoring wells, land and transmission to and from pretreatment facility not included.

CONSTRUCTION COSTS



OPERATION & MAINTENANCE COST



REFERENCE - Curves derived from Reference 6.

*To convert construction cost to capital cost see Table A-2.

RAPID INFILTRATION, NOT UNDERDRAINED — FACT SHEET 1.2.4

Description - Wastewater is applied to deep and permeable deposits such as sand or sandy loam usually by distributing in basins or infrequently by sprinkling, and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange precipitation, and microbial action. Most metals are retained on the soil, many toxic organics are degraded or adsorbed. The treated effluent eventually reaches the groundwater.

Basins or beds are constructed by removing the fine textured top soil from which shallow banks are constructed and the underlying sandy soil serves as the filtration media. The distribution system applies wastewater at a rate which constantly floods the basin throughout the application period of several hours to a couple of weeks. The waste floods the bed and then drains uniformly away, driving air downwards through the soil and drawing fresh air from above. A cycle of flooding and drying helps maintain the infiltration capacity of the soil material. Infiltration diminishes slowly with time due to clogging. Full infiltration is readily restored by occasional tillage of the surface layer and, when appropriate, removal of several inches from the surface of the basin.

Preapplication treatment to remove solids improves distribution system reliability, reduces nuisance conditions, and may reduce clogging rates. Common preapplication treatment practices include the following: Primary treatment for isolated locations with restricted public access; biological treatment for urban locations with controlled public access. Storage is sometimes provided for flow equalization and for non-operating periods.

Common Modifications - Nitrogen removals are improved by establishing specific operating procedures to maximize denitrification including adjusting application cycles, supplying an additional carbon source, using vegetated basins (at low rates), recycling portions of wastewater containing high nitrate concentrations and reducing application rates.

Technology Status - Was developed approximately 100 years ago and has remained unaltered since then. Has been widely used for municipal and certain industrial wastewaters throughout the world.

Application - A simple wastewater treatment system that is less land intensive than other land application systems and provides a means of groundwater recharge. Is useful for temporary storage of renovated water in the aquifer. If groundwater quality is being degraded by salinity intrusion, groundwater recharge can help to reverse the hydraulic gradient and protect the existing groundwater. Process is useful for the reclamation of sterile or stripmined soil. Is suitable for small plants where operator expertise is limited. Is applicable for primary and secondary effluent and for many types of industrial wastes including those from breweries, distilleries, paper mills, and wool scouring plants. In very cold weather the ice layer floats atop the effluent and also protects the soil surface from freezing.

Limitations - Process is limited by soil type, soil depth, the hydraulic capacity of the soil, the underlying geology, and the slope of the land. Adverse conditions cause improper treatment results. Nitrate and nitrite removals are low unless special management practices are used. Crops grown and harvested from basins and groundwater below basins require monitoring for heavy metal content, unless metal removal practiced in pretreatment step.

Typical Equipment/No. of Mfrs. (23) - Storage tanks/2, pipe/9, pumps/34.

Performance (9, 40) - Effluent quality is generally excellent where sufficient soil exists and is not normally dependent on the wastewater applied (within limits). Well designed systems provide for high quality effluent that may meet or exceed primary drinking water standards. Percent removals for typical pollution parameters are: BOD_5 and TSS, 95 to 99 percent; Total N, 25 to 90 percent; Total P, 0 to 90 percent (until flooding exceeds adsorptive capacity); Fecal Coliforms, 99.9 to 99.99+ percent.

Chemicals Required - None

Residuals Generated - Occasional removal of top layer of soil is sometimes required. This material is disposed of on-site.

Design Criteria - Field area 3 to 56 acres/Mgal/d; application rate 20 to 400 ft/yr, 4 to 92 in/wk; BOD_5 loading rate 20 to 100 lb/acre/d; soil depth 10 to 15 ft or more, soil permeability 0.6 in/h or more; hydraulic loading cycle 9 h to 2 wks application period, 15 h to 2 wks resting period; soil texture - sands, sandy loams; basin size 1 to 10 acres, at least 2 basins/site; height of dikes 4 ft; application techniques - flooding or sprinkling; preapplication treatment - primary or secondary.

Process Reliability - Extremely reliable, as long as sufficient resting periods are provided.

Environmental Impact - Potential for contamination of groundwater by nitrates. Heavy metals are eliminated by pretreatment techniques as necessary. Monitoring for metals and toxic organics is needed where they are not removed by pretreatment. Requires long term commitment of relatively large land area, although small by comparison to other land treatment systems. Water resources are diverted to groundwaters. Crops grown and harvested from basins and groundwater below basins require monitoring for heavy metal content, unless metal removal practiced in pretreatment step.

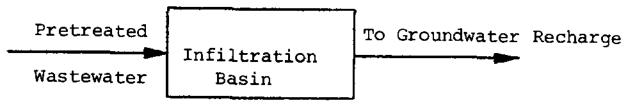
References - 6, 9, 23, 40, 41

RAPID INFILTRATION, NOT UNDERDRAINED

FACT SHEET 1.2.4

October 1978

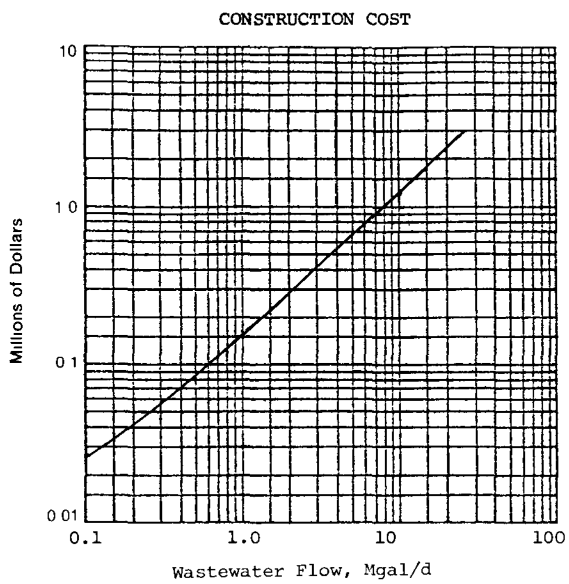
FLOW DIAGRAM --

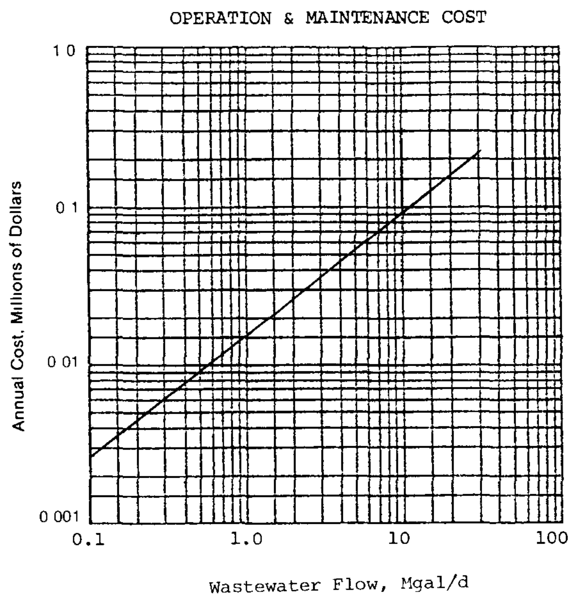


ENERGY NOTES - Gravity distribution methods consume no energy, but do require sufficient head availability; sprinkler application energy requirements are included in 1.2.5 .

COSTS* - Assumptions: ENR Index = 1850

1. Costs are based on February 1973 (EPA Index 194.2) figures; application rate 182 ft/yr; no storage required.
2. Labor rates, including fringe benefits = $5/hr.
3. Construction costs include field preparations (removal of brush and trees) for multiple unit infiltration basins with 4 ft dikes formed from native excavated material; gravel service roads; and 4-ft stock fence around perimeter.
4. Materials cost includes annual rototilling of infiltration surface and major repairs of dikes, fences and roads after 10 yr.
5. Costs of pretreatment, monitoring wells, land and transmission from treatment facility to application site not included.
6. Storage assumed unnecessary.





REFERENCE - Curves derived from reference 6.

*To convert construction cost to capital cost see Table A-2.

LAND TREATMENT, SLOW RATE, SPRINKLER, UNDERDRAINED — FACT SHEET 1.2.5

Description - Wastewater is applied by sprinkling to vegetated soils that are slow to moderate in permeability (clay loams to sandy loams) and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange, precipitation, microbial action and by plant uptake. An underdrainage system consisting of a network of drainage pipe buried below the surface serves to recover the effluent, to control groundwater, or to minimize trespass of leachate onto adjoining property by horizontal subsurface flow. To recover renovated water for reuse or discharge, underdrains are usually intercepted at one end of the field by a ditch. Underdrainage for groundwater control is installed as needed to prevent waterlogging of the application site or to recover the renovated water for reuse. Proper crop management also depends on the drainage conditions. Sprinklers can be categorized as hand moved, mechanically moved, and permanent set, the selection of which includes the following considerations: field conditions (shape, slope, vegetation, and soil type), climate, operating conditions, and economics. Vegetation is a vital part of the process and serves to extract nutrients, reduce erosion and maintain soil permeability. Considerations for crop selection include: (1) suitability to local climate and soil conditions; (2) consumptive water use and water tolerance; (3) nutrient uptake and sensitivity to wastewater constituents; (4) economic value and marketability; (5) length of growing season; (6) ease of management; (7) public health regulations. Common preapplication treatment practices include the following: primary treatment for isolated locations with restricted public access and when limited to crops not for direct human consumption; biological treatment plus control of coliform to 1000 MPN/100 ml for agricultural irrigation, except for human food crops to be eaten raw; secondary treatment plus disinfection to 200 MPN/100 ml fecal coliform for public access areas (parks). Wastewaters high in metal content should be pretreated to avoid plant and soil contamination.

Modifications - Forestland irrigation is more suited to cold weather operation, since soil temperatures are generally higher, but nutrient removal capabilities are less than for most field crops.

Technology Status - Has been widely and successfully utilized for more than 100 years.

Application - Slow rate systems produce the best results of all the land treatment systems. Advantages of sprinkler application over gravity methods include: more uniform distribution of water and greater flexibility in range of application rates, applicability to most crops, less susceptibility to topographic constraints, and reduced operator skill and experience requirements. Underdrainage provides a means of recovering renovated water for reuse or for discharge to a particular surface water body when dictated by senior water rights and a means of controlling groundwater. The system also provides the following benefits: (1) an economic return from the use of water and nutrients to produce marketable crops for forage; and (2) water and nutrient conservation when utilized for irrigating landscaped areas.

Limitations - Process is limited by soil type and depth, topography, underlying geology, climate, surface and groundwater hydrology and quality, crop selection and land availability. Crop water tolerances, nutrient requirements, and the nitrogen removal capacity of the soil-vegetation complex limit hydraulic loading rate. Climate affects growing season and will dictate the period of application and the storage requirements. Application ceases during period of frozen soil conditions. Once in operation, infiltration rates can be reduced by sealing of the soil. Limitations to sprinkling include adverse wind conditions and clogging of nozzles. Slopes should be less than 15 percent to minimize runoff and erosion. Pretreatment for removal of solids and oil and grease serves to maintain reliability of sprinklers and to reduce clogging. Many states have regulations regarding preapplication disinfection, minimum buffer areas, and control of public access for sprinkler systems.

Typical Equipment/No. of Mfrs. (23) - Pipe/9; pumps/34; valves/39; gates/9; spray nozzles/3; irrigation systems/1; plus farm equipment.

Performance (9) - Effluent quality is generally excellent and consistent regardless of the quality of wastewater applied. Percent removals for typical pollution parameters when wastewater is applied through more than 5 ft of unsaturated soil are: BOD_5 and TSS, 90 to 99 percent plus; Total N, 50 to 95 percent, depending on N uptake of vegetation; Total P, 80 to 99 percent, until adsorptive capacity is exceeded; Fecal Coliform, 99.99 percent plus when applied levels are more than 10^4 MPN/100 ml.

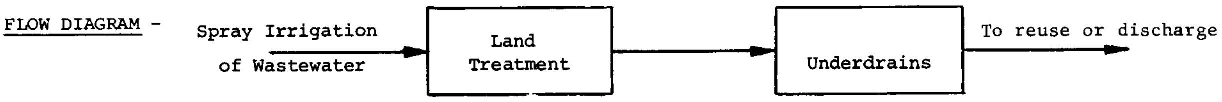
Chemicals Required, Residuals Generated - None

Design Criteria - Field area 56 to 560 acres/Mgal/d; application rate 2 to 20 ft/yr, 0.5 to 4 in/wk; BOD_5 loading rate 0.2 to 5 lb/acre/d; soil depth 2 to 5 ft or more; soil permeability 0.06 to 2.0 in/h; minimum preapplication treatment - primary; lower temperature limit 25°F; particle size of solids less than 1/3 sprinkler nozzle diameter; any common pressure pipe material is suitable. Further details on sprinkler system characteristics are included in 1.2.6. Underdrains 4 to 8 inch diameter, 4 to 10 ft deep, 50 to 500 ft apart, pipe material plastic, concrete (sulfate-resistant, if necessary), or clay.

Environmental Impact - Requires long term commitment of large land area; i.e., largest land requirement of all land treatment processes. N and P are conserved. Concerns with aerosol carriage of pathogens, potential vector problems, and crop contamination have been identified, but are generally controllable by proper design and management.

References - 6, 9, 23

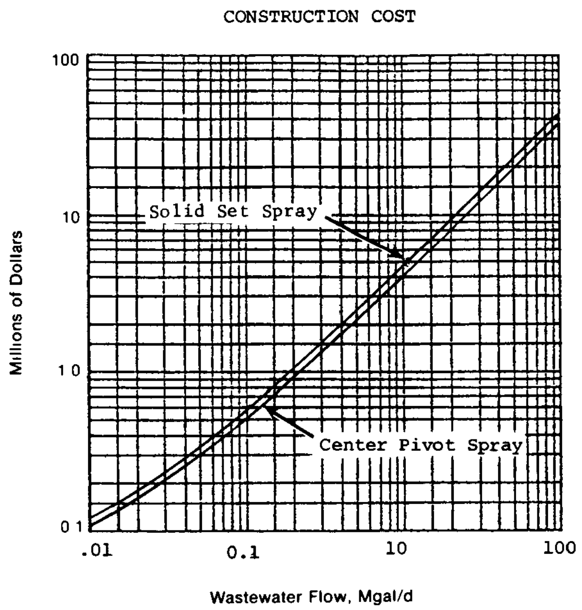
LAND TREATMENT, SLOW RATE, SPRINKLER, UNDERDRAINED — FACT SHEET 1.2.5

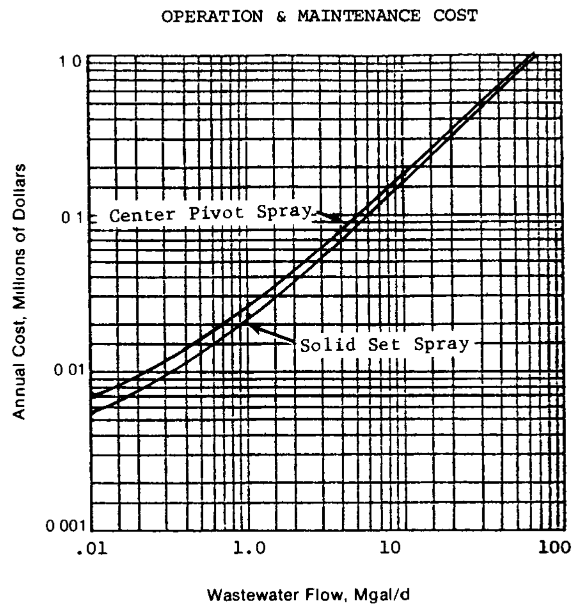


ENERGY NOTES - Solid set spray distribution requires 2,100 kWh/yr/ft of TDH/Mgal/d capacity. Center pivot spraying requires an additional 0.84 X 10^6 kWh/yr/acre (based on 3.5 d/wk operation) for 1 Mgal/d or larger facilities (below 1 Mgal/d, additional power = 0.84 - 1.35 X 10^6 kWh/yr/acre).

COSTS* - Assumptions: (EPA Index = 194.2) (Yearly average application rate = 0.33 in./d)

1. Costs are based on February 1973 figures; ENR Index = 1850; labor rates, including fringe benefits = $5/h.
2. Clearing costs are for brush with few trees using bulldozer-type equipment.
3. Solid set spraying construction costs include: lateral spacing, 100 ft; sprinkler spacing, 80 ft along laterals; 5.4 sprinklers/acre; application rate, 0.20 in/h; 16.5 gal/min flow to sprinklers at 70 psi; flow to laterals controlled by hydraulically operated automatic valves; laterals buried 18 in; mainlines buried 36 in; all pipe 4 in diameter and smaller is PVC; all larger pipe is asbestos cement (TDH = 150 ft).
4. Center pivot spraying construction costs include: heavy-duty center pivot rig with electric drive; multiple units for field areas over 40 acres; maximum area per unit, 132 acres; distribution pipe buried 36 in.
5. Underdrains are spaced 250 ft between drain pipes. Drain pipes are buried 6 to 8 ft deep with interception ditch along length of field and weir for control of discharge.
6. Distribution pumping construction costs include: structure built into dike of storage reservoir; continuously cleaned water screens; pumping equipment with normal standby facilities; piping and valves within structure; controls and electrical work.
7. Labor costs include inspection and unclogging of drain pipes at outlets and dike maintenance.
8. Materials costs include for solid set spraying: replacement of sprinklers and air compressors for valve controls after 10 yr; for center pivot spraying, minor repair parts and major overhaul of center pivot rigs after 10 yr; high pressure jet cleaning of drain pipes every 5 yr, annual cleaning of interceptor ditch, and major repair of ditches after 10 yr; distribution pumping repair work performed by outside contractor and replacement parts; scraping and patching of storage receiver liner every 10 yr.
9. Storage for 75 days is included; 15 ft dikes (12-ft wide at crest) are formed from native materials (inside slope 3:1, outside 2:1); rectangular shape on level ground; 12-ft water depth; multiple cells for more than 50 acre size; asphaltic lining; 9-in riprap on inside slope of dikes.
10. Cost of pretreatment, monitoring wells, land, and transmission to and from land treatment facility not included.





REFERENCE - Curves derived from Reference 6.

*To convert construction cost to capital cost see Table A-2.

LAND TREATMENT, SLOW RATE, SPRINKLER, NOT UNDERDRAINED — FACT SHEET 1.2.6

Description - Wastewater is applied by sprinkling to vegetated soils that are slow to moderate in permeability (clay loams to sandy loams) and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange, precipitation, microbial action and also by plant uptake. Sprinklers can be categorized as hand moved, mechanically moved, and permanent set, the selection of which includes the following considerations: field conditions (shape, slope, vegetation, and soil type), climate, operating conditions, and economics. Vegetation is a vital part of the process and serves to extract nutrients, reduce erosion and maintain soil permeability. Common preapplication treatment practices include the following: primary treatment for isolated locations with restricted public access and when limited to crops not for direct human consumption; biological treatment plus control of coliform to 1000 MPN/100 ml for agricultural irrigation except for human food crops to be eaten raw; secondary treatment plus disinfection to 200 MPN/100 ml fecal coliform for public access areas (parks). Wastewaters high in metal content should be pretreated to avoid plant and soil contamination.

Modifications - Forestland irrigation is more suited to cold weather operation since soil temperatures are generally higher, but nutrient removal capabilities are less than for most field crops.

Technology Status - Has been widely and successfully utilized for more than 100 years.

Application - Slow rate systems produce the best results of all the land treatment systems. Advantages of sprinkler application over gravity methods include: more uniform distribution of water and greater flexibility in range of application rates, applicability to most crops, less susceptibility to topographic constraints, and reduced operator skill and experience requirements. Provides following benefits: water conservation when utilized for irrigating landscaped areas, marketable crops, or forage; reuse of nitrogen, phosphorus, and other plant nutrients.

Limitations - Process is limited by soil type and depth, topography, underlying geology, climate, surface and groundwater hydrology and quality, crop selection and land availability. Crop water tolerances, nutrient requirements, and the nitrogen removal capacity of the soil-vegetation complex limit hydraulic loading rate. Climate affects growing season and will dictate the period of application and the storage requirements. Application ceases during periods of frozen soil conditions. Once in operation, infiltration rates can be reduced by sealing of the soil. Limitations to sprinkling include adverse wind conditions and clogging of nozzles. Slopes should be less than 15 percent to minimize runoff and erosion. Pretreatment for removal of solids and oil and grease necessary to maintain reliability of sprinklers. Many states have regulations regarding preapplication disinfection, minimum buffer areas, and control of public access for sprinkler systems.

Typical Equipment/No. of Mfrs. (23) - Pipe/9; pumps/34; valves/39; gates/9; spray nozzles/3; irrigation system/1; plus farm equipment.

Performance (9) - Effluent quality is generally excellent and consistent regardless of the quality of the wastewater applied. Percent removals for typical pollution parameters when wastewater is applied through more than 5 ft of unsaturated soil are: BOD_5 and TSS, 90 to 99 percent plus; Total N, 50 to 95 percent, depending upon N uptake of vegetation; Total P, 80 to 99 percent until adsorptive capacity is exceeded; Fecal Coliforms, 99.99 percent plus, when applied levels are more than 10^4 MPN/100 ml.

Chemicals Required, Residuals Generated - None

Design Criteria - Field area 56 to 560 acres/Mgal/d; application rate 2 to 20 ft/yr, 0.5 to 4 in/wk; BOD_5 loading rate 0.2 to 5 lb/acre/d; soil depth 2 to 3 ft or more; soil permeability 0.06 in/h or more; minimum preapplication treatment - primary; lower temperature limit 25°F; particle size of solids less than 1/3 sprinkler nozzle diameter; any common pressure pipe material is suitable.

Sprinkler System Characteristics

	Application Rate, in/h	Outlets per Lateral	Nozzle P lb/in^2	Size of Area, acres	Shape of Field	Maximum Slope, %	Maximum Crop Height, ft
Hand moved							
Portable pipe	0.1-2.0	Multiple	30-60	1-40	Any shape	15	--
Stationary gun	0.25-2.0	Single	50-100	20-40	Any shape	15	--
Mechanically moved							
End tow	0.1-2.0	Multiple	30-60	20-40	Rectangular	5-10	--
Traveling gun	0.25-1.0	Single	50-100	40-100	Rectangular	Unlimited	--
Side wheel roll	0.10-2.0	Multiple	30-60	20-80	Rectangular	5-10	3-4
Center pivot	0.20-1.0	Multiple	15-60	40-160	Circular[a]	5-15	8-10
Permanent							
Solid set	0.05-2.0	Multiple	30-60	Unlimited	Any shape	Unlimited	--

a. Travelers are available to allow irrigation of any shape field.

Process Reliability - Extremely reliable.

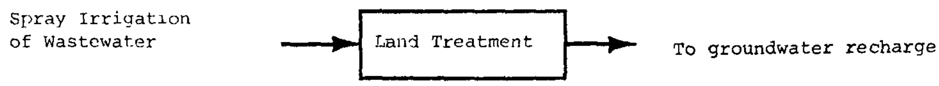
Environmental Impact - Water resources are diverted to groundwater. Requires long term commitment of large land area; i.e., largest land requirement of land treatment systems. Concerns with aerosol carriage of pathogens, vectors, and crop contamination have been identified, but are generally controllable by proper design and management.

References - 6, 9, 23

LAND TREATMENT, SLOW RATE, SPRINKLER, NOT UNDERDRAINED — FACT SHEET 1.2.6

October 1978

FLOW DIAGRAM -

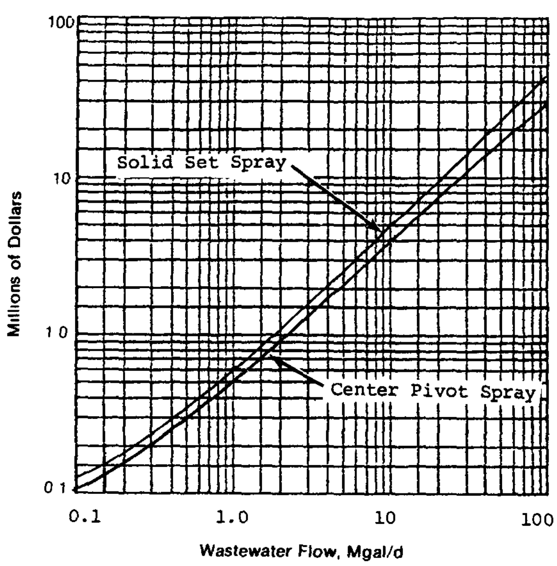


ENERGY NOTES - Solid set spray distribution requires 2,100 kWh/yr/ft of TDH/Mgal/d capacity. Center pivot spraying requires an additional 0.84×10^6 kWh/yr/acre (based on 3.5 d/wk operation) for 1 Mgal/d or larger facilities (below 1 Mgal/d, additional power = $0.84 - 1.35 \times 10^6$ kWh/yr/acre).

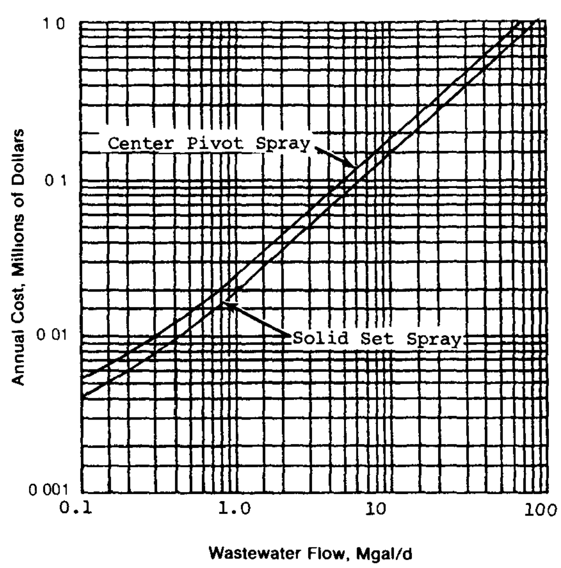
COSTS* - Assumptions: EPA Index = 194.2; ENR Index = 1850; Yearly average application rate = 0.33 in/d.

1. Costs are based on February 1973 figures; labor rates, including fringe benefits = $5/h.
2. Clearing costs are for brush with few trees using bulldozer-type equipment.
3. Solid set spraying construction costs include: lateral spacing, 100 ft; sprinkler spacing, 80 ft along laterals; 5.4 sprinklers/acre; application rate, 0.20 in/h; 16.5 gal/min flow to sprinklers at 70 psi; flow to laterals controlled by hydraulically operated automatic valves; laterals buried 18 in; mainlines buried 36 in; all pipe 4 in. diameter and smaller is PVC; all larger pipe is asbestos cement. (TDH = 150 ft)
4. Center pivot spraying construction costs include: heavy-duty center pivot rig with electric drive; multiple units for field areas over 40 acres; maximum area per unit, 132 acres; distribution pipe buried 36 in.
5. Distribution and storage costs are included as discussed in 1.2.5C;
6. O&M costs include: for solid set spraying-replacement of sprinklers and air compressors for valve controls after 10 yr; for center pivot spraying - minor repair parts and major overhaul of center pivot rigs after 10 yr; dike maintenance; and scraping and patching of storage reservoir liner every 10 yrs.
7. Cost of pretreatment, monitoring wells, land and transmission of pretreated waste to land treatment site are not included.

CONSTRUCTION COSTS



OPERATION & MAINTENANCE COST



REFERENCE - Curves derived from Reference 6.

*To convert construction cost to capital cost see Table A-2.

LAND TREATMENT, SLOW RATE, GRAVITY, NOT UNDERDRAINED — FACT SHEET 1.2.7

Description - Wastewater is applied by gravity flow to vegetated soils that are slow to moderate in permeability (clay loams to sandy loams) and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange, precipitation, microbial action and also by plant uptake. Part of the water is lost to evaporation and plant transpiration, part is stored in plant tissue, and the remainder percolates to groundwater. Organics are reduced substantially by biological oxidation, and most mineral components become part of the soil matrix or are extracted by plant uptake. Nitrogen is removed primarily by crop uptake which varies with the type of crop grown and the crop yield. Phosphorus is removed by soil adsorption, precipitation and crop uptake. Surface distribution employs gravity flow from piping systems or open ditches to flood the application area with several inches of water. Application techniques include ridge and furrow and surface flooding (border strip flooding). Ridge and furrow irrigation consists of running irrigation streams along small channels (furrows) bordered by raised beds (ridges) upon which crops are grown. Surface flooding irrigation consists of directing a sheet flow of water along border strips or cultivated strips of land bordered by small levees. The latter method is suited to close-growing crops such as grasses that can tolerate periodic inundation at the ground surface. A tailwater return system for wastewater runoff from excess surface application is usually employed. It consists of a small pond, a pump, and return pipeline. Flooding basins or furrows vary in size and shape depending upon the crops grown, slope and grade of the land, quantity of flow, soil permeability, compatibility with farm implements, and installation and operating costs. Once in operation infiltration rates can be reduced by sealing. Remedies include disking or harrowing of the soil every year and the use of normal or deep plowing (ripping) of heavier soils at 2 to 4 year intervals. High flotation tires are recommended for farm vehicles. Vegetation is a vital part of the process and serves to extract nutrients, reduce erosion and maintain soil permeability. Considerations for crop selection include: (1) suitability to local climate and soil conditions; (2) consumptive water use and water tolerance; (3) nutrient uptake and sensitivity to wastewater constituents; (4) economic value and marketability; (5) length of growing season; (6) ease of management; (7) public health regulations. Common preapplication treatment practices include the following: primary treatment for isolated locations with restricted public access and when limited to crops not for direct human consumption; biological treatment plus control of coliform to 1000 MPN/100 ml for agricultural irrigation except for food crops to be eaten raw; secondary treatment plus disinfection to 200 MPN/100 ml fecal coliform for public access areas (parks). Wastewater high in metal content should be pretreated to avoid soil and plant contamination.

Modifications - Forestland irrigation is more suited to cold weather operation since soil temperatures are generally higher, but nutrient removal capabilities are less than for most field crops.

Technology Status - Has been widely and successfully utilized for more than 100 years.

Application - Slow rate systems are capable of producing the best results of all the land treatment systems. Gravity distribution is less costly, better suited to heavy soils and less capable of uniform wastewater distribution than sprinkler application. It also provides the following benefits: (1) an economic return from the reuse of water and nutrients to produce marketable crops or forage; (2) water conservation when utilized for irrigating landscaped areas; and (3) groundwater recharge.

Limitations - Process is limited by soil type and depth, topography, underlying geology, climate, surface and groundwater hydrology and quality, crop selection and land availability. Crop water tolerances, nutrient requirements, and the nitrogen removal capacity of the soil-vegetation complex limit hydraulic loading rate. Graded land is essential; excessive slope increases runoff and erosion. Climate affects growing season and will dictate the period of application and the storage requirements. Application ceases during periods of frozen soil conditions. Regions where prolonged wet spells limit application include Gulf states and the Pacific Northwest coastal region. Border strip flooding has the following limitations: (1) It requires operator skill and experience to ensure uniform distribution and minimal runoff, and (2) Crop must be able to withstand periods of inundation. Many states have regulations regarding preapplication disinfection and minimum buffer areas.

Typical Equipment/No. of Mfrs. (23) - Pipes/9, pumps/34, valves/39, gates/9, plus farm equipment.

Performance (9) - Effluent quality is generally excellent and consistent regardless of quality of wastewater applied. Percent removals for typical pollution parameters when wastewater is applied through more than 5 ft of unsaturated soil are: BOD_5 and TSS, 90 to 99 percent plus; Total N, 50 to 95 percent, depending on N uptake of vegetation; Total P, 80 to 99 percent, diminishes when P uptake exhausted; Fecal Coliforms, 99.99 percent plus (when applied counts more than 10^4 MPN/100 ml).

Chemicals Required, Residuals Generated - None

Design Criteria - Field area 56 to 560 acres/Mgal/d; application rate 2 to 20 ft/yr, 0.5 to 4 in/wk; BOD_5 loading rate 0.2 to 5 lb/acre/d; soil depth 2 to 3 ft or more; soil permeability 0.06 in/h or more; minimum preapplication treatment - primary; lower temperature limit -25°F; tailwater return system capacity 10 to 50 percent applied surficial flow.

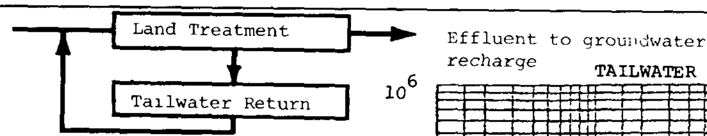
Process Reliability - Extremely reliable.

Environmental Impact - Requires long term commitment of large land area; i.e., largest land requirement of all land treatment systems. Water resources are diverted to groundwater. Concerns with vectors and crop contamination have been identified, but are generally controllable with proper design and management.

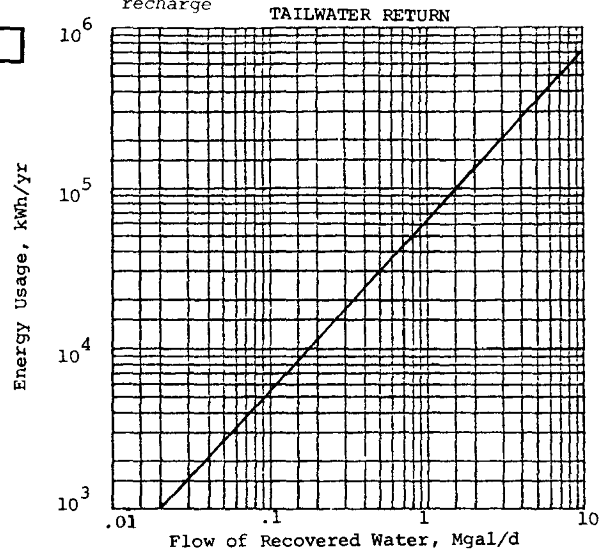
References - 6, 9, 23

LAND TREATMENT, SLOW RATE, GRAVITY, NOT UNDERDRAINED — FACT SHEET 1.2.7

FLOW DIAGRAM - Surface Flooding of Wastewater

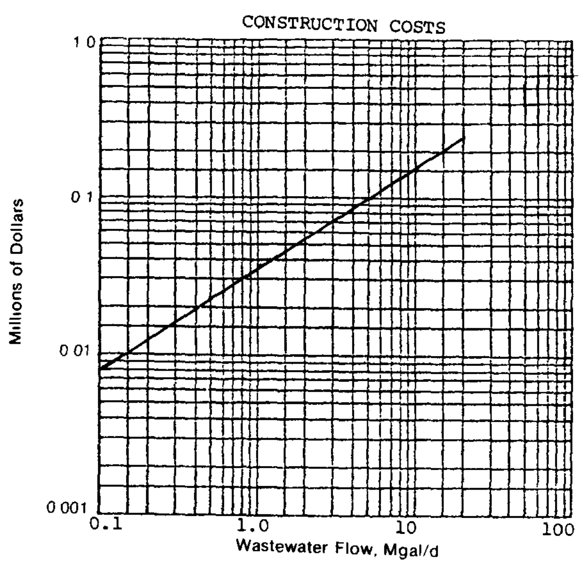


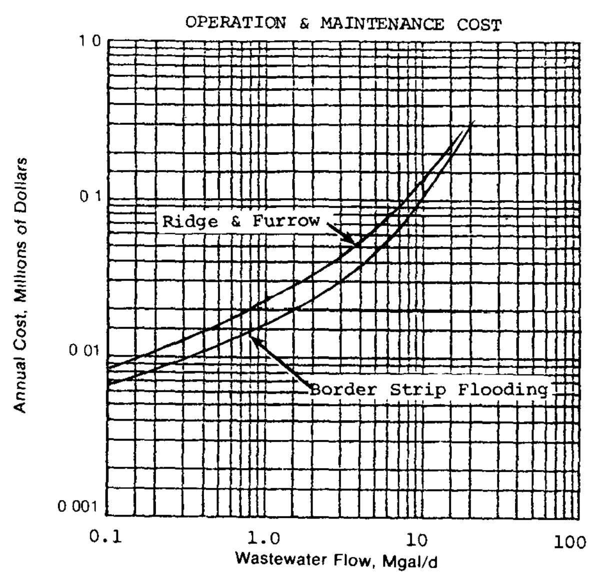
ENERGY NOTES - Gravity distribution methods consume no energy. Tailwater return energy usage is indicated assuming: pump efficiency (wire to water) = 60 percent, total head = 30 ft; operation 8760 h/yr. Energy cost = $.02/kWh.



COSTS*-Assumptions: ENR Index = 1850

1. Costs are based on February 1973 figures (EPA Index = 194.2) (Yearly average application rate = 0.33 in./d)
2. Labor rates, including fringe benefits = $5/hr.
3. Clearing costs are for brush with few trees using bulldozer-type equipment.
4. Levelling costs are for moving 500 yd^3/acre.
5. Distribution is by surface flooding using border strips or ridge and furrow methods. Border strips are 40 ft wide by 1150 ft long; have concrete lined trapezoidal distribution ditches with 2 slide gates per strip. Ridge and furrow-gated aluminum pipe distribution based on 1200 ft long furrows, rectangular shaped fields.
6. Tailwater return-construction costs include drainage collection ditches; pumping station forebay 1/3 acre; pumping station with shelter and multiple pumps, piping to nearest point of distribution mainline (230 ft); assumed rate of return = 20 percent of applied wastewater.
7. O&M cost (border strip) includes rebordering every 2 yr and major relining of ditches after 10 yrs. O&M cost (ridge and furrow) includes replacement of gated pipe after 10 yr.
8. O&M cost includes major repair of pumping station after 10 yr; dike maintenance; and scraping and patching of storage reservoir liner every 10 yrs.
9. Storage for 75 days included (See Fact Sheet 1.2.5).
10. Cost of pretreatment, monitoring wells, land and transmission of wastewater to land application site not included.





REFERENCE - Derived from figures in Reference 6.

*To convert construction cost to capital cost see Table A-2.

LAND TREATMENT, SLOW RATE, GRAVITY, UNDERDRAINED — FACT SHEET 1.2.8

Description - Wastewater is applied by gravity flow to vegetated soils that are slow to moderate in permeability and is treated as it travels through the soil matrix by filtration, adsorption, ion exchange, precipitation, microbial action and also by plant uptake. An underdrainage system consisting of a network of drainage pipe buried below the surface serves to recover the effluent, to control groundwater, or to minimize trespass of wastewater onto adjoining property by horizontal subsurface flow. To recover renovated water for reuse or discharge, underdrains are usually intercepted at one end of the field by a ditch. Underdrainage for groundwater control is installed as necessary to prevent waterlogging soils of the application site and to recover renovated water for further reuse. Proper crop management also depends on the drainage conditions. Surface distribution employs gravity flow from piping systems or open ditches to flood the application area with several inches of water. Application techniques include ridge and furrow and surface flooding (border strip flooding). Ridge and furrow irrigation consists of running irrigation streams along small channels (furrows) bordered by raised beds (ridges) upon which crops are grown. Surface flooding irrigation consists of directing a sheet flow of water along border strips or cultivated strips of land bordered by small levees. The latter method is suited to close-growing crops such as grasses that can tolerate periodic inundation at the ground surface. A tailwater return system for wastewater runoff from excess surface application is usually employed. It consists of a small pond, a pump, and return pipeline. Flooding basins or furrows vary in size and shape depending upon the crops grown, characteristics of the land, quantity of flow, soil permeability, compatibility with farm implements, and installation and operating costs. Once in operation, infiltration rates can be reduced by sealing. Sealing results from compaction from farm machinery, raindrops, or formation of a clay crust. Remedies include disking or harrowing of the soil every year and normal or deep plowing (ripping) of heavier soils at two to four year intervals. The use of high flotation farm equipment is recommended. Vegetation is a vital part of the process and serves to extract nutrients, reduce erosion and maintain soil permeability. Considerations for crop selection include: (1) suitability to local climate and soil conditions; (2) consumptive water use and water tolerance; (3) nutrient uptake and sensitivity to wastewater constituents; (4) economic value and marketability; (5) length of growing season; (6) ease of management; (7) public health regulations. Common preapplication treatment practices include the following: primary treatment for isolated locations with restricted public access and when limited to crops not for direct human consumption; biological treatment plus control of coliform to 1000 MPN/100 ml for agricultural irrigation except for human food crops to be eaten raw; secondary treatment plus disinfection to 200 MPN/100 ml fecal coliforms for public access areas (parks). Wastewaters high in metal content should be pretreated to avoid soil and plant contamination.

Modifications - Forestland irrigation is more suited to cold weather operation since soil temperatures are generally higher, but nutrient removal capabilities are less than for most field crops.

Technology Status - Has been widely and successfully utilized for more than 100 years.

Application - Slow rate systems are capable of producing the best results of all the land treatment systems. Gravity systems cost less and are better suited to heavier soils than sprinkler systems. It also provides the following benefits: (1) an economic return from the reuse of water and nutrients to produce marketable crops or forage; (2) water conservation when utilized for irrigating landscaped areas; (3) a means of recovering renovated water for reuse or for discharge; and (4) a means of controlling groundwater. Surface flooding is more difficult to apply uniformly than by sprinkler application, but is preferred for flat topography.

Limitations - Process is limited by soil type and depth, topography, underlying geology, climate, surface and groundwater hydrology and quality, crop selection and land availability. Crop water tolerances, nutrient requirements, and the nitrogen removal capacity of the soil-vegetation complex limit hydraulic loading rate. Graded land is essential; excessive slope increases runoff and erosion. Climate affects growing season and will dictate the period of application and the storage requirements. Application ceases during periods of frozen soil conditions. Regions where prolonged wet spells limit application include Gulf states and the Pacific Northwest coastal region. Border strip flooding has the following limitations: (1) It requires operator skill and experience to ensure uniform distribution and minimal runoff, and (2) Crop must be able to withstand periods of inundation. Pretreatment by primary settling will reduce clogging, odors and health hazards. Many states have regulations regarding preapplication disinfection, and minimum buffer areas.

Typical Equipment/No. of Mfrs. (23) - Pipe/9; pumps/34; valves/39; gates/9; plus farm equipment.

Performance (9) - Effluent quality is generally excellent and consistent regardless of quality of wastewater applied. Percent removals for typical pollution parameters when wastewater is applied through more than 5 ft unsaturated soil are: BOD_5 and TSS, 90 to 99 percent plus; Total N, 50 to 95 percent (depending on N uptake of vegetation); Total P, 80 to 99 percent (diminishes when P uptake exhausted); Fecal Coliforms, 99.99 percent plus (when applied counts $>10^4$/ 100ml).

Design Criteria - Field area 56 to 560 acres/Mgal/d; application rate 2 to 20 ft/yr, 0.5 to 4 in/wk; BOD_5 loading rate 0.2 to 5 lb/acre/d; soil depth 2 to 3 ft or more; soil permeability 0.06 in/h or more; minimum preapplication treatment - primary; lower temperature limit $25^{o}F$; tailwater return system capacity 10 to 50 percent applied surficial flow; underdrains, 4 to 8 in dia, 3 to 10 ft deep, 30 to 500 ft apart; soil texture - clay loams to sandy loams.

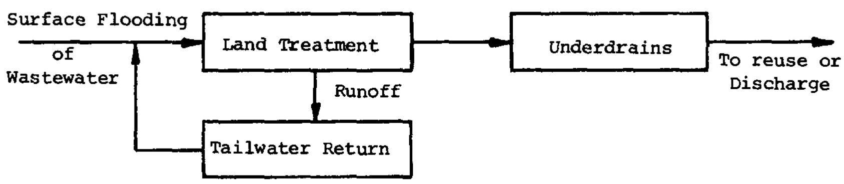
Process Reliability - Extremely reliable.

Environmental Impact - Requires long term commitment of large land area, i.e., largest land requirement of all land treatment systems. Concerns with vectors and crop contamination have been identified; but are generally controllable with proper design and operation.

References: 6, 9, 23

LAND TREATMENT, SLOW RATE, GRAVITY, UNDERDRAINED | FACT SHEET 1.2.8

FLOW DIAGRAM -

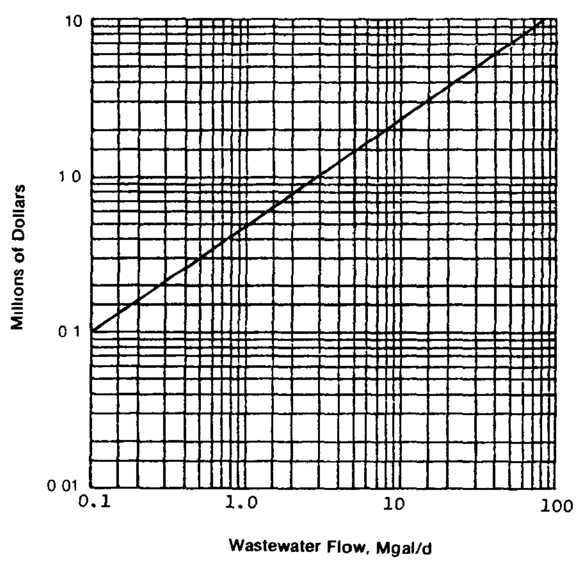


ENERGY NOTES - Gravity distribution methods consume no energy, as long as sufficient head available; tailwater return energy requirements are included in 1.2.7

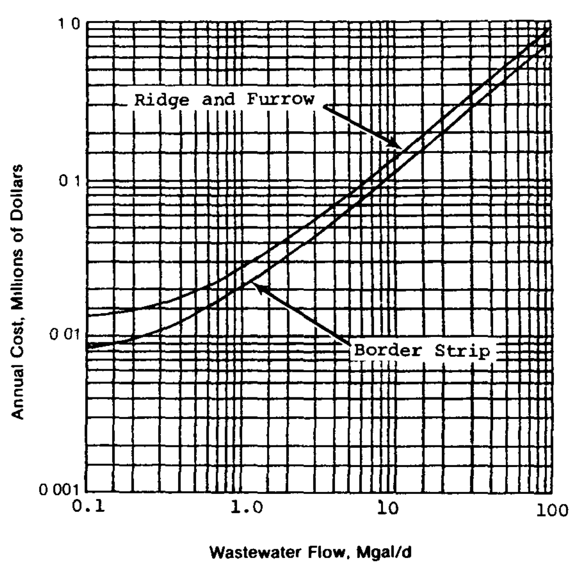
COSTS* - Assumptions: ENR Index = 1850

1. Costs are based on February 1973 figures; (EPA Index = 194.2) (Yearly average application rate = 0.33 in./d)
2. Labor rates including fringe benefits = $5/hr.
3. Storage for 75 days included (see Fact Sheet 1.2.5).
4. Clearing costs are for brush with few trees using bulldozer-type equipment.
5. Levelling costs are for moving 500 yd^3/acre.
6. Distribution is by surface flooding using border strips or ridge and furrow methods. Border strips are 40 ft wide by 1150 ft long; have concrete lined trapezoidal distribution ditches with 2 slide gates per strip. Ridge and furrow-gated aluminum pipe distribution based on 1200 ft long furrows, rectangular shaped fields.
7. Drain pipes (100-ft spacing) are buried 6 to 8 ft with interception ditch along length of field and weir for control of discharge.
8. O&M cost (border strip) includes rebordering every 2 yr and major relining of ditches after 10 yrs. O&M cost (ridge and furrow) includes replacement of gated pipe after 10 yrs. Also included are dike maintenance; scraping and patching storage liner every 10 yrs; and inspection and cleaning, underdrains, ditches, etc.
9. Materials cost includes high pressure jet cleaning of drain pipes every 5 yrs, annual cleaning of interceptor ditch, and major repair of ditches after 10 yrs.
10. A tailwater return rate of 20 percent is included (refer to 1.2.7).
11. Cost of pretreatment, monitoring wells, land and wastewater transmission costs to and from site are not included.

CONSTRUCTION COSTS



OPERATION & MAINTENANCE COST



REFERENCE - Derived from figures in reference 6.

*To convert construction cost to capital cost see Table A-2.

OVERLAND FLOW, GRAVITY — FACT SHEET 1.2.9

Description - Wastewater is applied over the upper reaches of sloped terraces and is treated as it flows across the vegetated surface to runoff collection ditches. The wastewater is renovated by physical, chemical and biological means as it flows in a thin film down the relatively impermeable slope. A secondary objective of the system is for crop production. Perennial grasses (Reed Canary, Bermuda, Red Top, tall fescue and Italian Rye) with long growing seasons, high moisture tolerance and extensive root formation are best suited to overland flow. Harvested grass is suitable for cattle feed. Biological oxidation, sedimentation and grass filtration are the primary removal mechanisms for organics and suspended solids. Nitrogen removal is attributed primarily to nitrification/denitrification and plant uptake. Loading rates and cycles are designed to maintain active microorganism growth on the soil surface. The operating principles are similar to a conventional trickling filter with intermittent dosing. The rate and length of application is controlled to minimize severe anaerobic conditions that result from overstressing the system. The resting period should be long enough to prevent surface ponding, yet short enough to keep the microorganisms in an active state. Surface methods of distribution include the use of gated pipe or bubbling orifice. Gated surface pipe, which is attached to aluminum hydrants, is aluminum pipe with multiple outlets. Control of flow is accomplished with slide gates or screw adjustable orifices at each outlet. Bubbling orifices are small diameter outlets from laterals used to introduce flow. Gravel may be necessary to dissipate energy and ensure uniform distribution of water from these surface methods. Slopes must be steep enough to prevent ponding of the runoff, yet mild enough to prevent erosion and provide sufficient detention time for the wastewater on the slopes. Slopes must have a uniform cross slope and be free from gullies to prevent channeling and allow uniform distribution over the surface. The network of slopes and terraces that make up an overland system may be adapted to natural rolling terrain. The use of this type of terrain will minimize land preparation costs. Storage must be provided for non-operating periods. Runoff is collected in open ditches. When unstable soil conditions are encountered or flow velocities are erosive, gravity pipe collection systems may be required. Common preapplication practices include the following: screening or comminution for isolated sites with no public access; screening or comminution plus aeration to control odors during storage or application for urban locations with no public access. Wastewaters high in metal content should be pretreated to avoid soil and plant contamination.

Common Modifications - A common method of distribution is with sprinklers. Recirculation of collected effluent is sometimes provided and/or required. Secondary treatment prior to overland flow permits reduced (as much as 2/3 reduction) land requirements. Effluent disinfection is required where stringent fecal coliform criteria exist.

Technology Status - Relatively new. Extensively used in the food processing industry. Very few municipal plants in operation. and most are in warm, dry areas.

Application - Because overland flow is basically a surface phenomenon, soil clogging is not a problem. High BOD_5 and suspended solids removals have been achieved with the application of raw comminuted municipal wastewater. Thus, preapplication treatment is not a prerequisite where other limitations are not operative. Depth to groundwater is less critical than with other land systems. It also provides the following benefits: an economic return from the reuse of water and nutrients to produce marketable crops or forage; and a means of recovering renovated water for reuse or discharge. Is preferred for gently sloping terrain with impermeable soils.

Limitations - Process is limited by soil type, crop water tolerances, climate, and slope of the land. Steep slopes reduce travel time over the treatment area and thus, treatment efficiency. Flat land may require extensive earthwork to create slopes. Ideally, slope should be 2 to 8 percent. High flotation tires are required for equipment. Cost and impact of the earthwork required to obtain terraced slopes can be major constraints. Application is restricted during rainy periods and stopped during very cold weather. Many states have regulations regarding preapplication disinfection, minimum buffer zones and control of public access.

Typical Equipment/No. of Mfrs. (23) - Pipes/9; pumps/34; valves/39; gates/9; plus farm equipment.

Performance - Percent removals for comminuted or screened municipal wastewater over about 150 ft of 2 to 6 percent slope: BOD_5 and suspended Solids, 80 to 95 percent; Total N, 75 to 90 percent; Total P, 30 to 60 percent, Fecal coliform 90 to 99.9 percent.

Chemicals Required - Normally none. Addition of alum, $FeCl_3$ or $CaCO_3$ prior to application increases phosphorus removals.

Design Criteria - Field area required, 35 to 100 acres/Mgal/d; terraced slopes 2 to 8 percent; application rate, 11 to 32 ft/yr, 2.5 to 16 in/wk; BOD_5 loading rate 5 to 50 lb/acre/d; soil depth, sufficient to form slopes that are uniform and to maintain a vegetative cover; soil permeability 0.2 in/h or less; hydraulic loading cycle 6 to 8 hr application period, 16 to 18 hr resting period; operating period 5 to 6 d/wk; soil texture clay and clay loams. Below are representative application rates for 2 to 8 percent sloped terraces:

in/wk	Pretreatment	Terrace Length, ft
2.5 to 8	untreated or primary	150
6 to 16	lagoon or secondary	120

Generally, 40 to 80 percent of applied wastewater reaches collection structures, lower percent in summer and higher in winter (southwest data).

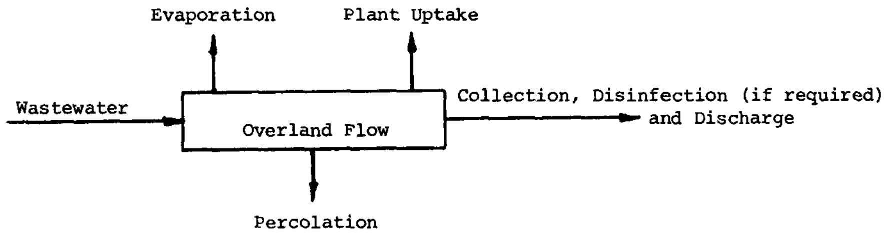
Environmental Impact - Requires long term commitment of large land area. Potential odor and vector problems exist, but careful design and operation generally can control them.

References - 6, 9, 23

OVERLAND FLOW, GRAVITY

FACT SHEET 1.2.9

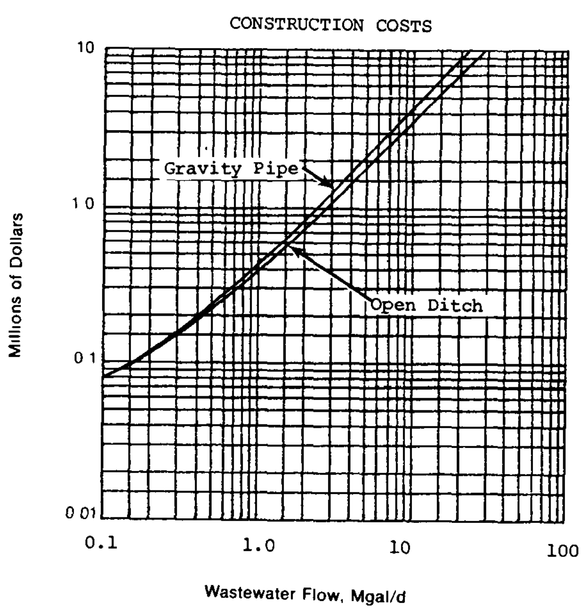
FLOW DIAGRAM -

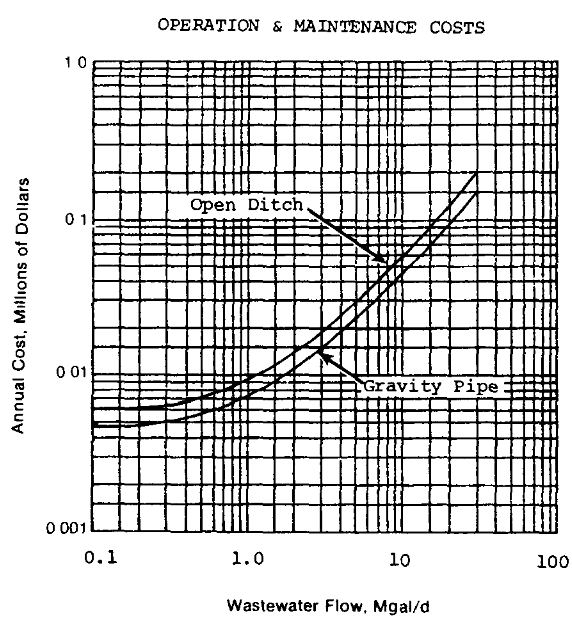


ENERGY NOTES - Overland flow surface distribution consumes no energy if sufficient head available. If sprinklers employed, see Fact Sheet 1.2.5 .

COSTS* - Assumptions: ENR Index = 1850

1. Costs are based on February 1973 figures (EPA Index = 194.2); labor rates, including fringe benefits = $5/h.
2. Storage for 75 days included (See Fact Sheet 1.2.5).
3. Site cleared of brush and trees using bulldozer-type equipment; terrace construction: 175 to 250 ft wide with 2.5 percent slope (1400 yd^3/acre of cut). Costs include surveying, earthmoving, finish grading, ripping two ways, disking, landplaning, equipment mobilization.
4. Distribution system: application rate, 0.064 in/h; yearly average rate of 3 in /wk (8 h/d; 6 d/wk); flow to sprinklers, 13 gal/min at 50 psi; laterals 70 ft from top of terrace, buried 18 in; flow to laterals controlled by hydraulically operated automatic valves; mainlines buried 36 in; all pipe 4 in diameter and smaller is PVC: all larger pipe is asbestos cement.
5. Open Ditch Collection: network of unlined interception ditches sized for a 2 in/h storm; culverts under service roads; concrete drop structures at 1,000 ft intervals.
6. Gravity Pipe Collection: network of gravity pipe interceptors with inlet/manholes every 250 ft along submains; storm runoff is allowed to pond at inlets; each inlet/manhole serves 1,000 ft of collection ditch; manholes every 500 ft along interceptor mains.
7. O&M cost includes replacement of sprinklers and air compressors for valve controls after 10 yr and either biannual cleaning of open ditches with major repair after 10 yr or the periodic cleaning of inlets and normal maintenance of gravity pipe. Also includes dike maintenance and scraping and patching of storage basin liner every 10 yr.
8. Costs for pretreatment, land, transmission to site, disinfection and service roads and fencing not included.





REFERENCE - Derived from figures of Reference 6.

*To convert construction cost to capital cost see Table A-2.

ACTIVATED SLUDGE, CONVENTIONAL, DIFFUSED AERATION — FACT SHEET 2.1.1

Description - Activated sludge is a continuous flow, biological treatment process characterized by a suspension of aerobic microorganisms, maintained in a relatively homogeneous state by the mixing and turbulence induced by aeration. The microorganisms are used to oxidize soluble and colloidal organics to CO_2 and H_2O in the presence of molecular oxygen. The process is generally, but not always, preceded by primary sedimentation. The mixture of microorganisms and wastewater formed in the aeration basins, called mixed liquor, is transferred to gravity clarifiers for liquid-solids separation. The major portion of the microorganisms settling out in the clarifiers is recycled to the aeration basins to be mixed with incoming wastewater, while the excess, which constitutes the waste sludge, is sent to the sludge handling facilities. The rate and concentration of activated sludge returned to the aeration basins determines the mixed liquor suspended solids (MLSS) level developed and maintained in the basins. During the oxidation process, a certain amount of the organic material is synthesized into new cells, some of which then undergoes auto-oxidation (self-oxidation, or endogenous respiration) in the aeration basins, the remainder forming net growth or excess sludge. Oxygen is required in the process to support the oxidation and synthesis reactions. Volatile compounds are driven off to a certain extent in the aeration process. Metals will also be partially removed, with accumulation in the sludge. Activated sludge systems are classified as high rate, conventional, or extended aeration (low rate) based on the organic loading. In the conventional activated sludge plant, the wastewater is commonly aerated for a period of four to eight hours (based on average daily flow) in a plug flow hydraulic mode. Either surface or submerged aeration systems can be employed to transfer oxygen from air to wastewater. Compressors are used to supply air to the submerged systems, normally through a network of diffusers, although newer submerged devices which don't come under the general category of diffusers (e.g., static aerators and jet aerators) are being developed and applied. Diffused air systems may be classified as fine bubble or coarse bubble. Diffusers commonly used in activated sludge service include the following: porous ceramic plates laid in the basin bottom (fine bubble), porous ceramic domes or ceramic or plastic tubes connected to a pipe header and lateral system (fine bubble), tubes covered with synthetic fabric or wound filaments (fine or coarse bubble), and specially designed spargers with multiple openings (coarse bubble).

Common Modifications - Step aeration; contact stabilization; and complete mix flow regimes. Alum or ferric chloride is sometimes added to the aeration tank for phosphorus removal.

Technology Status- Activated sludge is the most versatile and widely used biological process in wastewater treatment.

Typical Equipment/No. of Mfrs. (23, 97) - Equipment normally associated with diffused air, activated sludge systems include the following: air diffusers/19; compressors/44.

Applications - Domestic wastewater and biodegradable industrial wastewater. The main advantage of the conventional activated sludge system is the lower initial cost of the system, particularly where a high quality effluent is required. Industrial wastewater (including some "priority pollutants") which is amenable to biological treatment and degradation may be jointly treated with domestic wastewater in a conventional activated sludge system.

Limitations - Limited BOD_5 loading capacity; poor organic load distribution; required aeration time of four to eight hours; plant upset with extreme variations in hydraulic, organic, and toxic loadings; operational complexity; operating costs; energy consuming mechanical compressors; and diffuser maintenance.

Performance (26, 39) -

BOD_5 Removal (conventional activated sludge)	85-95 percent
NH_4-N removal (non-nitrified systems)	10-20 percent

Residuals Generated - The following table illustrates the anticipated increase in excess sludge, volatile suspended solids (VSS) production from the conventional activated sludge process as settled wastewater food-to-microorganism (F/M) loadings increase:

F/M (lb BOD_5/d/lb MLVSS)	Excess VSS (secondary effluent plus waste sludge)
0.3	0.5 lb/lb BOD_5 removed
0.5	0.7 " "

Design Criteria (26, 31, 30) - A partial listing of design criteria for the conventional activated sludge process is summarized as follows:

Volumetric loading, lb BOD_5/d/1000 ft^3	25-50
Aeration detention time, h (based on avg. daily flow)	4-8
MLSS, mg/l	1500-3000
F/M, lb BOD_5/d/lb MLVSS	0.25-0.5
Air required, std. ft^3/lb BOD_5 removed	800-1500
Sludge retention time, days	5-10

Unit Process Reliability (31) - Good.

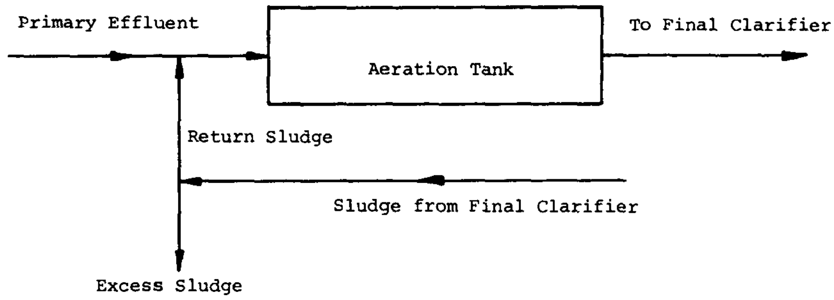
Environmental Impact - Sludge disposal; odor potential; and energy consumption.

References - 23, 26, 28, 30, 31, 39, 97

ACTIVATED SLUDGE, CONVENTIONAL, DIFFUSED AERATION

FACT SHEET 2.1.1

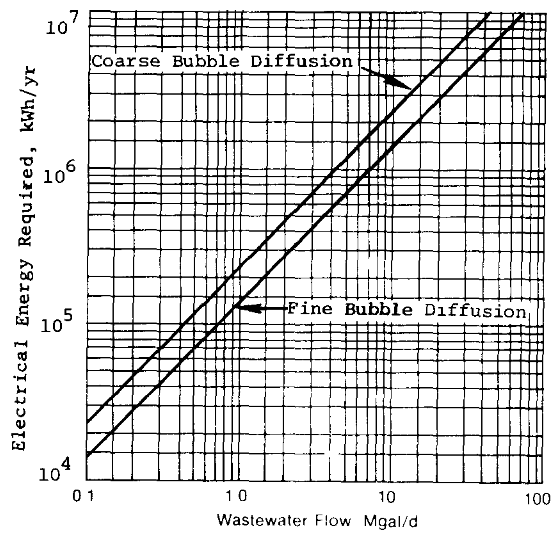
FLOW DIAGRAM -



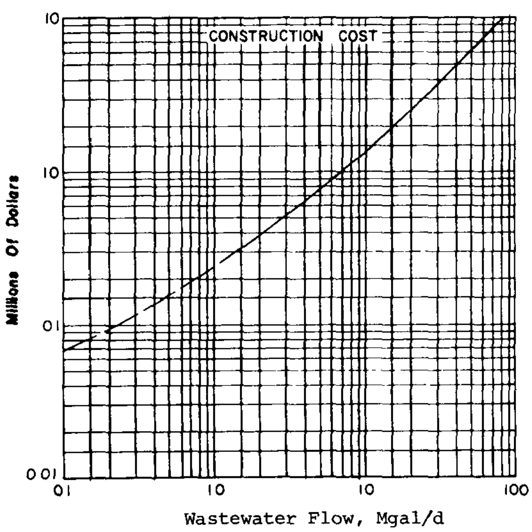
ENERGY NOTES - Assumptions:
The hydraulic head loss through the aeration tank is negligible. Sludge recycle and sludge wasting pumping energy are a part of clarifier operation.

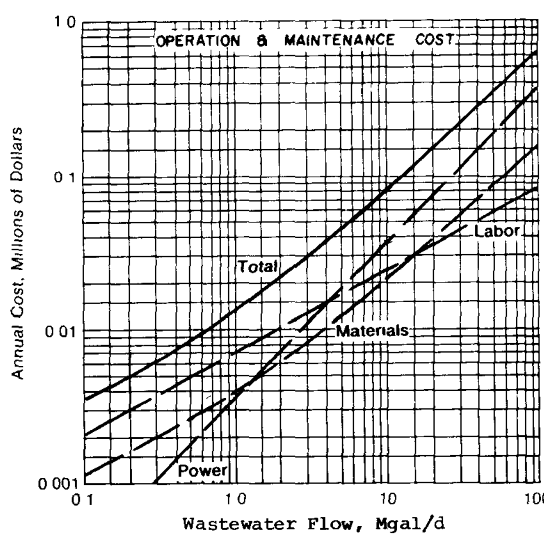
Water Quality:	Influent (mg/l)	Clarifier Effluent (mg/l)
BOD_5	130	20
Suspended Solids	100	20

Oxygen Transfer Rate (wire to water) in wastewater for:
Fine Bubble Diffusion = 2.5 lb O_2/hph
Coarse Bubble Diffusion = 1.5 lb O_2/hph
Average oxygen requirement = 1300 lb/d/Mgal/d



COSTS* - Assumptions:
Service life = 40 years. ENR Index = 2475
Construction cost includes aeration basins, air supply and dissolution equipment and piping, and blower building. Clarifier and recycle pumps are not included. 1.1 lb O_2 supplied/lb BOD_5 removed. MLVSS = 2100 mg/l. F/M = 0.25 lb BOD_5/d/lb MLVSS. Detention time = 6 hours (based on average daily flow). Volumetric loading = 32 lb BOD_5/d/1,000 ft^3. Power costs are for an average energy requirement of 2.0 lb O_2/hph @$.02/kWh.





REFERENCES 3, 4

*To convert construction cost to capital cost see Table A-2.

ACTIVATED SLUDGE, CONVENTIONAL, MECHANICAL AERATION — FACT SHEET 2.1.2

Description - The activated sludge system in general, and the conventional activated sludge plant in particular, are described in Fact Sheet 2.1.1. Mechanical aeration methods include the submerged turbine with compressed air spargers (agitator/sparger system) and the surface-type mechanical entrainment aerators. The surface-type aerators entrain atmospheric air by producing a region of intense turbulence at the surface around their periphery. They are designed to pump large quantities of liquid, thus dispersing the entrained air and agitating and mixing the basin contents. The agitator/sparger system consists of a radial-flow turbine located below the mid-depth of the basin, with compressed air supplied to the turbine through a sparger. Volatile compounds are driven off to a certain extent in the aeration process. Metals will also be partially removed, with accumulation in the sludge.

Common Modifications - In addition to the modifications listed on Fact Sheet 2.1.1 for conventional activated sludge plants, the following mechanical aeration modifications should also be considered. The submerged turbine aeration system affords a convenient and relatively economical method for upgrading overloaded activated sludge plants. To attain optimum flexibility of oxygen input, the surface aerator can be combined with the submerged turbine aerator. Several manufacturers supply such equipment, with both aerators mounted on the same vertical shaft. Such an arrangement might be advantageous if space limitations require the use of deep aeration basins. In addition, mechanical aerators may be either the floating or fixed installation type.

Technology Status - Highly developed and widely used, particularly in the industrial wastewater treatment field. Since 1950, the submerged turbine (widely used in the chemical industry) has come into use for activated sludge aeration.

Typical Equipment/No. of Mfrs. (23) - Equipment normally associated with mechanical aeration conventional activated sludge systems include the following: aerators/30; package treatment plants/21.

Applications - See Fact Sheet 2.1.1. Has been used primarily in industrial waste activated sludge treatment plants and is considered an attractive aeration system for very deep basins (with bottom mixers or spargers plus surface aerators), for activated sludges having high oxygen uptake rates, and for high concentrations of MLSS as in aerobic digesters.

Limitations - Limited BOD loading capacity; poor organic load distribution; required aeration time of four to eight hours; plant upset with extreme variations in hydraulic and organic loadings; operational complexity and the resulting operating costs; energy consuming mechanical aerators; aerator maintenance; and potential for ice formation around surface aerators.

Performance -

BOD Removal (conventional activated sludge system)	85 to 95 percent
NH_4-N Removal (Non-nitrified systems)	10 to 20 percent

Residuals Generated - See Fact Sheet 2.1.1.

Design Criteria - A partial listing of design criteria for the mechanically-aerated conventional activated sludge process is summarized as follows:

Volumetric loading, lb BOD_5/d/1000 ft^3	25-50
Aeration detention time, h (based on average daily flow)	4-8
MLSS, mg/l	1500-3000
F/M, lb BOD_5/d/lb MLVSS	0.25-0.5
Air required, std. ft^3/lb BOD_5 removed	800-1500 (agitator-sparger system only)
Sludge retention time, days	5-10

Note: The mixing equipment for aeration or oxygen transfer must be sized to keep the solids in uniform suspension at all times. Depending on basin shape and depth, 4000 mg/l of MLSS require about 0.75 to 1.0 hp/1000 ft^3 (0.02 to 0.03 kW/m^3) of basin volume to prevent settling if mechanical aerators are employed. However, the power required to transfer the necessary oxygen will usually equal or exceed this value.

Process Reliability - See Fact Sheet 2.1.1. Reliability of mechanical aeration equipment is dependent on the quality of manufacture and a planned maintenance program.

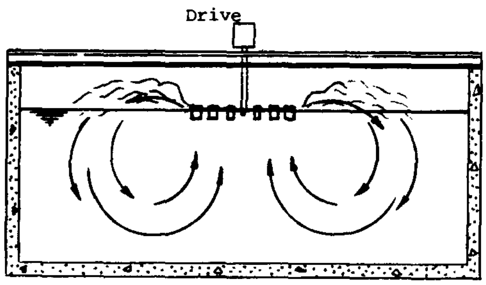
Environmental Impact - Sludge disposal, aerosol and odor potential, and energy consumption.

References - 23, 26, 28, 30, 31, 39

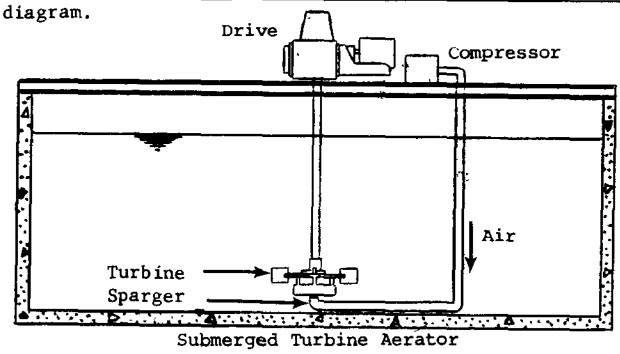
ACTIVATED SLUDGE, CONVENTIONAL, MECHANICAL AERATION

FACT SHEET 2.1.2

FLOW DIAGRAM- See Fact Sheet 2.1.1 for typical flow diagram.



Mechanical Surface Aerator

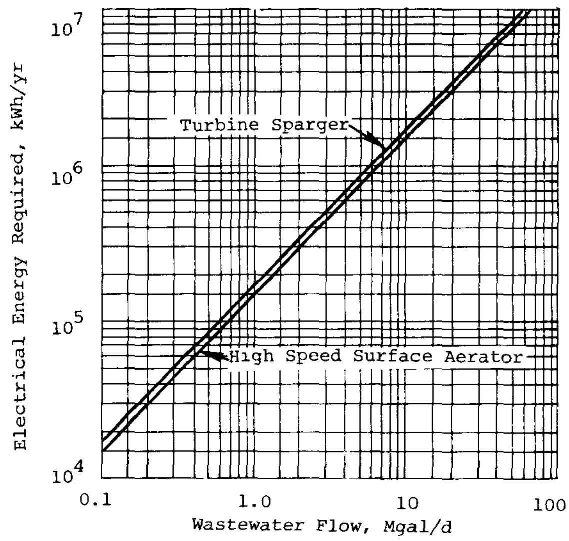


Submerged Turbine Aerator

ENERGY NOTES - Assumptions:
The hydraulic head loss through the aeration tank is negligible. Sludge recycle and sludge wasting pumping energy are a part of clarifier operation.

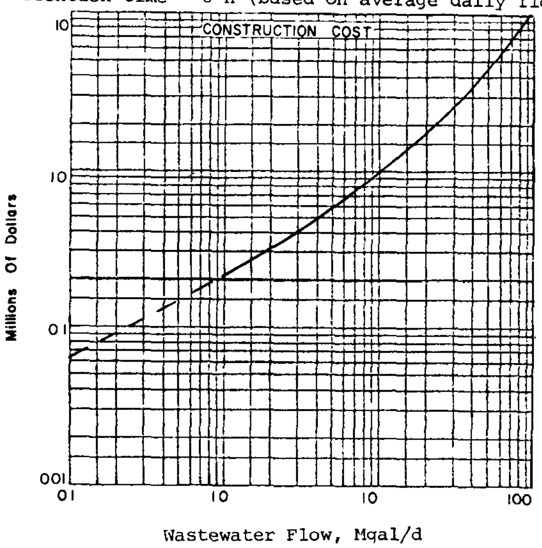
Water Quality:	Influent (mg/l)	Clarifier Effluent (mg/l)
BOD_5	130	20
Suspended Solids	100	20

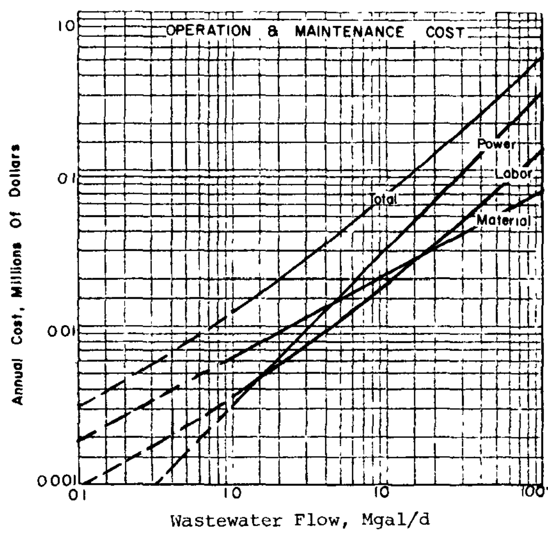
Assumed Oxygen Transfer Rate = 1.8 lb O_2/hph for high-speed surface aerator and 1.6 lb O_2/hph for turbine sparger (wire to water) in wastewater. Conventional activated sludge oxygen requirement = 1.1 lb O_2/lb BOD_5 removed.



COSTS*-
Design Basis: ENR Index = 2475

1. Construction cost includes aeration basins and surface aerators. Clarifier and recycle pumps are not included.
2. Volumetric loading = 32 lb BOD_5/d/1,000 ft^3.
3. 1.1 lb O_2 supplied/lb BOD_5 removed; Oxygen Transfer Rate = 1.8 lb/hph.(high speed surface aerators)
4. MLVSS = 2100 mg/l
5. F/M = 0.25 lb BOD_5/d/lb MLVSS
6. Detention time = 6 h (based on average daily flow).





REFERENCES - 3, 4

*To convert construction cost to capital cost see Table A-2.

ACTIVATED SLUDGE, HIGH RATE, DIFFUSED AERATION — FACT SHEET 2.1.3

Description - A description of the activated sludge process in general is presented in Fact Sheet 2.1.1. Activated sludge systems have traditionally been classified as high rate, conventional, or extended aeration (low rate) based on organic loading. The term modified aeration has been adopted to apply to those high rate air activated sludge systems with design F/M loadings in the range of 0.75 to 1.5 lb BOD_5/d/lb MLVSS. Modified aeration systems are characterized by low MLSS concentrations, short aeration detention times, high volumetric loadings, low air usage rates, and intermediate levels of BOD_5 and suspended solids removal efficiencies. Prior to enactment of nationwide secondary treatment regulations, modified aeration was utilized as an independent treatment system for plants where BOD_5 removals of 50 to 70 percent would suffice. With present-day treatment requirements, modified aeration no longer qualifies as a "stand-alone" activated sludge option.

Modified aeration basins are normally designed to operate in either complete mix or plug flow hydraulic configurations. Either surface or submerged aeration systems can be employed to transfer oxygen from air to wastewater, although submerged equipment is specified more frequently for this process. Compressors are used to supply air to submerged aeration systems. A description of diffuser alternatives and other submerged aeration devices is presented in Fact Sheet 2.1.1. Volatile compounds are driven off to a certain extent in the aeration process. Metals will also be partially removed, with accumulation in the sludge.

Common Modifications - Recently, due primarily to rapidly escalating power costs, interest has been expressed in the development of high rate, diffused aeration systems which would produce a high quality secondary effluent. As with modified aeration, aeration detention times would remain low and volumetric loadings high. In contrast to modified aeration systems, high MLSS concentrations would have to be utilized to permit F/M loadings to be maintained at reasonable levels. The key to development of efficient high rate air systems is the availability of submerged aeration equipment that could satisfy the high oxygen demand rates that accompany high MLSS levels and short aeration times. New innovations in fine bubble diffuser and jet aeration technology offer potential for uniting high efficiency oxygen transfer with high rate air activated sludge flow regimes to achieve acceptable secondary treatment as independent "stand alone" processes. Research evaluations and field studies currently underway should provide performance and cost data on this subject in the next several years.

Technology Status - Was more widely used in the 1950's and 1960's than it is today because of the less stringent effluent standards in effect during these periods.

Typical Equipment/No. of Mfrs. - Equipment normally associated with diffused air, activated sludge systems in general, include the following: air diffusers/19; compressors/44.

Applications - See Fact Sheet 2.1.1. Since the early 1970's, employed generally as a pretreatment or roughing process in a two-stage activated sludge system, where the second stage is used for biological nitrification. Alum or one of the iron salts is sometimes added to modified aeration basins preceding second-stage nitrification units for phosphorus removal.

Limitations - High rate activated sludge alone does not produce an effluent with BOD_5 and suspended solids concentrations suitable for discharge into most surface waters in the United States. (Cannot assure that 30 mg/l BOD_5 and SS in the final effluent will be achieved).

Performance -
BOD_5 Removal for modified aeration - 50 to 70 percent; for high solids, high rate air system - 85 to 95 percent (tentative).
NH_4-N Removal - 5 to 10 percent.

Residuals Generated - One modified air aeration system fed with degritted raw wastewater produced on the average over a two-year period 1.11 lb excess VSS (secondary effluent plus waste sludge)/lb BOD_5 removed at an average F/M ratio loading of 1.17 lb BOD_5 /d/lb MLVSS.

Design Criteria (39) - A partial listing of design criteria for the two high rate air activated sludge process options are summarized as follows:

	Modified Aeration	High Solids, High Rate Aeration (tentative)
Volumetric loading, lb BOD_5/d/1000 ft^3	50 - 100	50 - 125
MLSS, mg/l	800 - 2000	3000 - 5000
Aeration detention time, hours (based on influent flow)	2 - 3	2 - 4
F/M, lb BOD_5/d/lb MLVSS	0.75 - 1.5	0.4 - 0.8
Std ft^3 air/lb BOD_5 removed	400 - 800	800 - 1200
Lb O_2/lb BOD_5 removed	0.4 - 0.7	0.9 - 1.2
Sludge retention time, days	0.75 - 2	2 - 5
Recycle ratio (R)	0.25 - 1.0	0.25 - 0.5
Volatile fraction of MLSS	0.7 - 0.85	0.7 - 0.8

Process Reliability - Requires close operator attention.

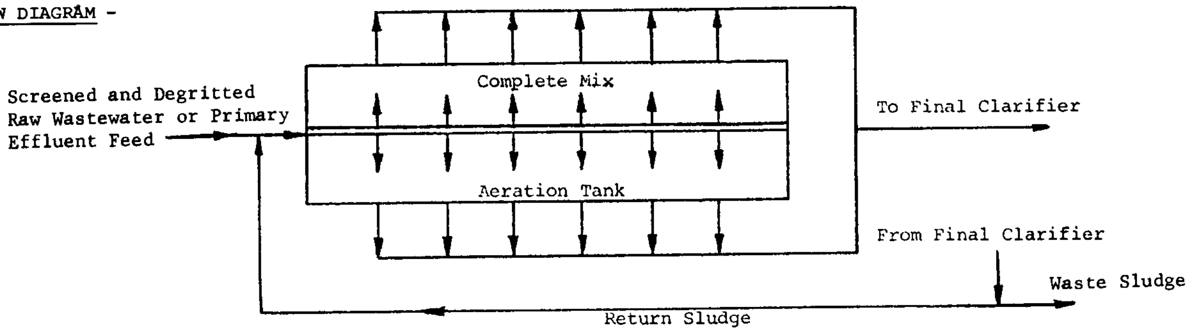
Environmental Impact- See Fact Sheet 2.1.1.

References - 23, 26, 31, 39, 263

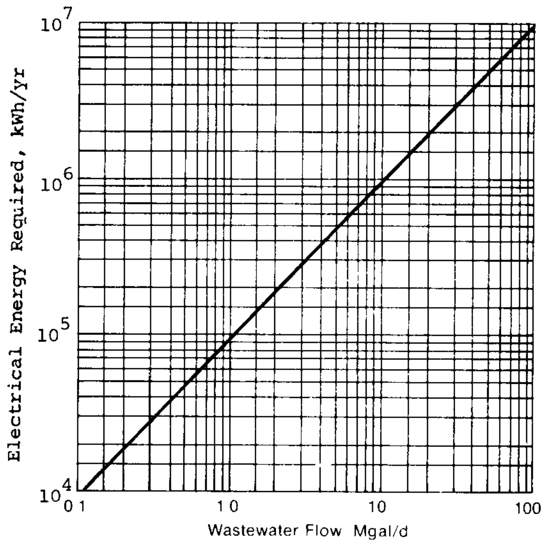
ACTIVATED SLUDGE, HIGH RATE, DIFFUSED AERATION

FACT SHEET 2.1.3

FLOW DIAGRAM -

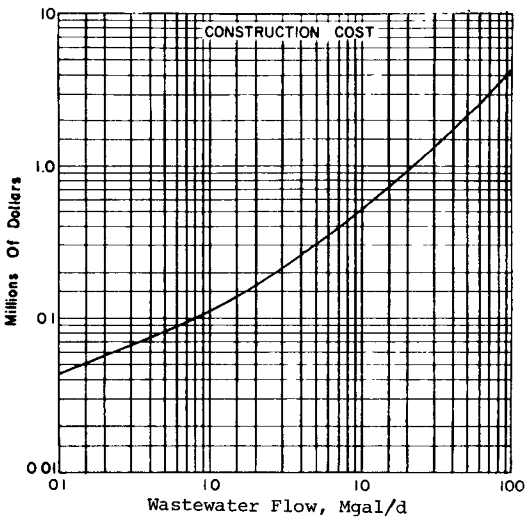


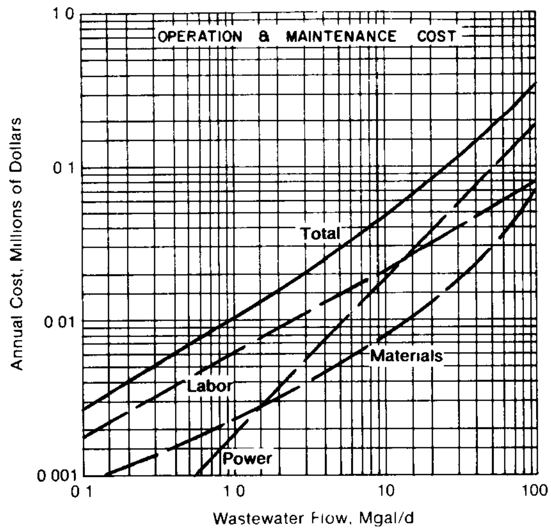
ENERGY NOTES - Assumptions: The hydraulic head loss through the aeration tank is negligible. Sludge recycle and sludge wasting pumping energy are a part of clarifier operation. Oxygen Transfer Rate with coarse bubble diffusers = 1.5 lb O_2/hph (wire to water) in wastewater. Other parameters in accordance with cost assumptions.



COSTS* - Assumptions: ENR Index = 2475. Construction cost includes aeration basins, air supply equipment and piping, and a blower building. Clarifier and recycle pumps are not included. Basins sized with 50 percent recycle flow. Detention time = 3 h (based on average daily flow). F/M = 1.0 lb BOD_5/d/lb MLVSS. 0.7 lb O_2 applied per lb BOD_5 removed. MLVSS = 1050 mg/l. Service life = 40 years. Costs are for modified aeration.

	Influent mg/l	Effluent mg/l
BOD_5	130	40





REFERENCES - 3, 4

*To convert construction cost to capital cost see Table A-2.

ACTIVATED SLUDGE, PURE OXYGEN, COVERED | FACT SHEET 2.1.4

Description - The use of pure oxygen for activated sludge treatment has become competitive with the use of air due to the development of efficient oxygen dissolution systems. The covered oxygen system is a high rate activated sludge system. The main benefits cited for the process include reduced power requirements for dissolving oxygen in the wastewater, reduced aeration tank volume requirements, and improved biokinetics of the activated sludge system. In the covered system, oxygenation is performed in a staged, covered reactor in which oxygen gas is recirculated within the system until it reaches a reduced level of purity and a decreased undissolved mass at which it can no longer be used and is vented to the atmosphere. High-purity oxygen gas (90 to 100 percent volume) enters the first stage of the system and flows concurrently with the wastewater being treated through the oxygenation basin. Pressure under the tank covers is essentially atmospheric, being held at 2 to 4 inches water column, sufficient to maintain oxygen gas feed control and prevent backmixing from stage to stage. Effluent mixed liquor is separated in conventional gravity clarifiers, and the thickened sludge is recycled to the first stage for contact with influent wastewater.

Mass transfer and mixing within each stage are accomplished either with surface aerators or with a submerged-turbine rotating-sparge system. In the first case, mass transfer occurs in the gas space; in the latter, oxygen is sparged into the mixed liquor where mass transfer occurs from the oxygen bubbles to the bulk liquid. In both cases, the mass-transfer process is enhanced by the high oxygen-partial pressure maintained under the tank covers in each stage.

Volatile compounds are driven off to a certain extent in the oxygenation process and removed in the vent gas. Metals may also be expected to be partially removed, with accumulation in the sludge. High purity oxygen may be produced on-site by cryogenic or PSA (Pressure Swing Adsorption) generators, or purchased as liquid oxygen produced off-site and stored at the treatment plant. Cost effectiveness of oxygen source depends upon plant size and process train.

Common Modifications - Although flexibility is claimed to permit operation in any of the normally used flow regimes, i.e., plug flow, complete mix, step aeration, and contact stabilization, the method of oxygen contact employed favors the plug flow mode. Process may be designed to achieve: optimum carbonaceous oxidation only, combined carbonaceous and nitrogenous oxidation, or optimum nitrogenous oxidation as a separate stage after secondary treatment.

Technology Status - Pilot and full scale plant studies since 1969; presently over 100 municipal and industrial plants.

Typical Equipment/No. of Mfrs. (23) - Oxygen activated sludge systems/5; Oxygen generators/1; Liquid oxygen storage tank (for standby and peak load capacity)/1; and aerators/30.

Applications - Domestic and biologically degradable industrial wastewaters; upgrading existing air activated sludge plants; new facilities - to reduce construction cost where effective odor control is required, where high effluent dissolved oxygen is required, where reduced quantity and higher concentration of waste sludge is required, and where reduced aeration detention time is required.

Limitations - Complexity of operation.

Performance (46) - Certain pilot test performance data are summarized here:

	Location A	Location B	Location C	Location D
Carbonaceous Oxidation:				
COD, percent removal	77	76	73	80
BOD_5, percent removal	89	95	91	95
Suspended solids, percent removal	89	64	75	76

Nitrogenous Oxidation; NH_4-N percent removals:	
Single stage with carbonaceous oxidation	20% - 90%
Separate stage nitrification after carbonaceous oxidation	80% - 98%

Residuals Generated (46) - Pilot test systems have generated between 0.42 and 1.0 lb VSS per lb BOD_5 removed.

Design Criteria (Carbonaceous BOD_5 Oxidation) -

Volumetric loading, lb BOD_5/d/1000 ft^3	100 to 200
F/M lb BOD_5/d/lb MLVSS	0.5 to 1.0
Oxygen requirement, lb O_2/lb COD removed	0.6 to 0.8
MLSS, mg/l	3,000 to 6,000
Aeration detention time, hours	1 to 3
Mixed liquor dissolved oxygen, mg/l	4 to 8
Oxygen required, lb O_2/lb BOD_5 removed	0.9-1.3

Process Reliability - Complex operation, high level of operator/maintenance attention required.

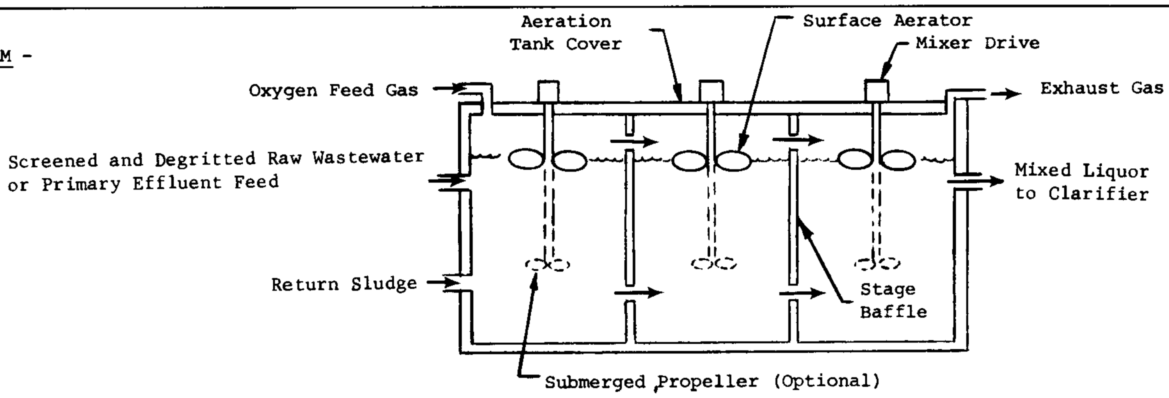
Environmental Impact - Sludge disposal; energy consumption.

References - 22, 26, 28, 46

ACTIVATED SLUDGE, PURE OXYGEN, COVERED

FACT SHEET 2.1.4

FLOW DIAGRAM -

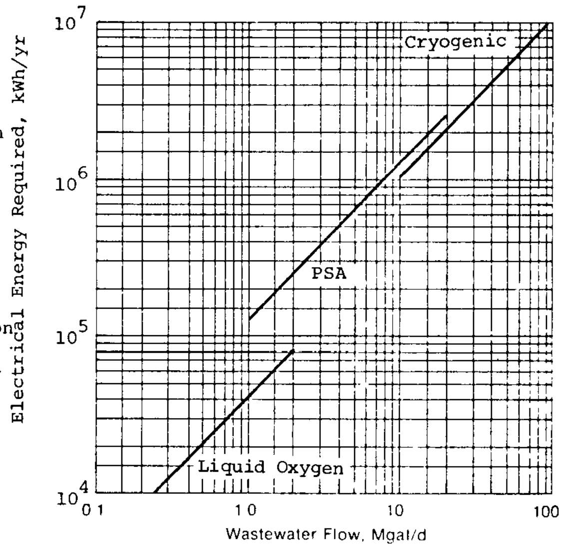


ENERGY NOTES (4) - Assumptions: Carbonaceous Oxidation.
Operating Parameters: Oxygen activated sludge oxygen requirement = 1.2 lb O_2/lb BOD_5 removed.

Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	130	20

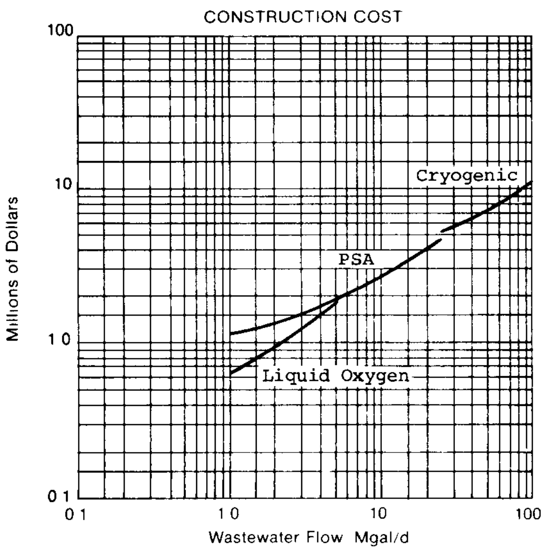
Oxygen Transfer Rate (OTR) includes oxygen production and oxygen dissolution.

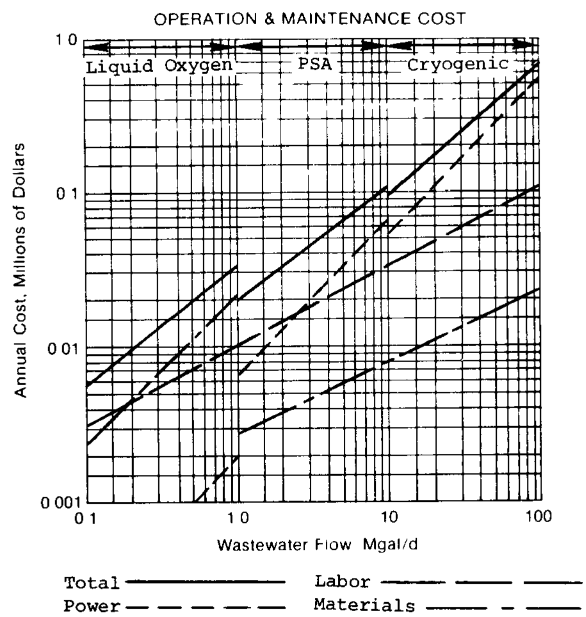
1. With cryogenic oxygen gas generation and surface aerators, OTR = 2.5 lb O_2/hph (wire to water) in wastewater.
2. With pressure swing adsorption (PSA) oxygen gas generation and surface aerators, OTR= 2.0 lb O_2/hph (wire to water) in wastewater.
3. Liquid O_2 supply and surface aerators, OTR = 6.5 lb O_2/hph (wire to water) in wastewater.



COSTS* - Design Basis: January 1979 dollars; ENR Index = 2872. Assumptions: Carbonaceous Oxidation.

1. Construction cost includes oxygenation basins, dissolution equipment, oxygen generators and liquid oxygen feed/storage facilities, instrumentation (where applicable), and licensing fees.
2. Oxygen was assumed to be delivered as liquid oxygen for plants from 0.1 to 1 Mgal/d size. For plants from 1.0 to 100 Mgal/d, oxygen was assumed to be generated on-site.
3. 1.2 lb O_2 supplied per lb BOD_5 removed.
4. MLVSS = 3100 mg/l. F/M = 0.5 lb BOD_5/d/lb MLVSS.
5. Volumetric loading = 97 lb BOD_5/d/1000 ft.
6. Detention time = 2 h (based on average daily flow).
7. Electricity @ \$.05/kWh, labor @ \$11/h, liquid O_2 @ \$100/t.





REFERENCES - 3, 4, 259

*To convert construction cost to capital cost, see Table A-2.

ACTIVATED SLUDGE, PURE OXYGEN, UNCOVERED — FACT SHEET 2.1.5

Description - The use of pure oxygen for activated sludge treatment has become competitive with the use of air due to the development of efficient oxygen dissolution systems. The open tank oxygen system is a high rate activated sludge system. The main benefits cited for the process include reduced power requirements for dissolving oxygen in the wastewater, reduced aeration tank volume requirements, and improved biokinetics of the activated sludge system. In the uncovered system, oxygenation is performed in an open reactor in which extremely fine porous diffusers are utilized to develop small oxygen gas bubbles that are completely dissolved before breaking surface in normal-depth tanks. The basic principles which apply in the transfer of oxygen in conventional diffused air systems also apply to the open tank pure oxygen system.

The pure oxygen open tank system produces ultra-fine bubbles with a correspondingly high gas surface area. These ultra-fine bubbles are of micron size, whereas "fine bubbles" normally produced in diffused air systems are in millimeter sizes. The complete oxygenation system is composed of an oxygen dissolution system comprised of rotating diffusers; a source of high-purity oxygen gas (normally, an on-site oxygen generator); and an oxygen control system which balances oxygen supply with oxygen demand through use of basin-located dissolved oxygen probes and control valves. High purity oxygen may be produced on-site by cryogenic or PSA (Pressure Swing Adsorption) generators, or purchased as liquid oxygen produced off-site and stored at the treatment plant. Selection of cost effective oxygen source depends upon plant size and treatment train.

The influent to the system enters the oxygenation tank and is mixed with return activated sludge. The mixed liquor is continuously and thoroughly mixed using low energy mechanical agitation deep in the mixed liquor. Mixing is produced by radial turbine impellers located on both surfaces (top and bottom) of the rotating diffusion discs. Pure oxygen gas in the form of micron-size bubbles is simultaneously introduced into the tank to accomplish mass oxygen transfer. The rotating diffuser is a gear-driven disc-shaped diffusion device equipped with a porous medium to assist in the diffusion process. As the diffuser rotates at constant speed in the mixed liquor, hydraulic shear wipes bubbles from the medium before they have an opportunity to coalesce and enlarge.

Common Modifications - Operation in any of the normally-used flow regimes, i.e., plug flow, complete mix, step aeration, and contact stabilization, can be used as conditions dictate since the method of oxygen contact employed does not favor one particular operating mode. System may be designed to optimize carbonaceous (BOD_5) oxidation, combined carbonaceous (BOD_5) and nitrogenous (NOD) oxidation as a single stage, or nitrogenous oxidation as a separate stage after secondary treatment.

Technology Status - Recently developed; supplied under proprietary status.

Applications - Domestic and biologically degradable industrial wastewaters; plant flows greater than 1 Mgal/d; upgrading existing air activated sludge plants; new facilities - to reduce construction cost where high effluent dissolved oxygen is required, where reduced quantity and higher concentration of waste sludge is required, and where reduced aeration detention time is required.

Limitations - Complexity of operation.

Performance - Removal efficiencies of various pollutants are similar to those of activated sludge and vary with mode of operation, aeration detention time, and character of influent wastewater. Examples of operational and pilot test data have demonstrated the following removals:

Carbonaceous Oxidation:	
BOD_5	75-95%
COD	60-85%
SS	60-90%
Nitrogenous Oxidation:	
Single stage nitrification, NH_4-N	20-90%
Separate stage nitrification after carbonaceous oxidation, NH_4-N	80-98%

Residuals Generated - Between 0.42 ane 1.00 lb VSS per lb BOD_5 removed.

Design Criteria -

Volumetric Loading	100 to 200 lb BOD_5/d/1000 ft^3
F/M	0.5 to 1.0 lb BOD_5/d/lb MLVSS
Oxygen requirement,	
lb O_2/lb BOD_5 removed	0.9-1.3
lb O_2/lb COD removed	0.6 to 0.8
Aeration Detention Time	1 to 3 h (based on avg. daily flow)
Mixed Liquor D.O.	2 to 6 mg/l
MLSS	3,000 to 6,000 mg/l

Process Reliability - Not yet fully established.

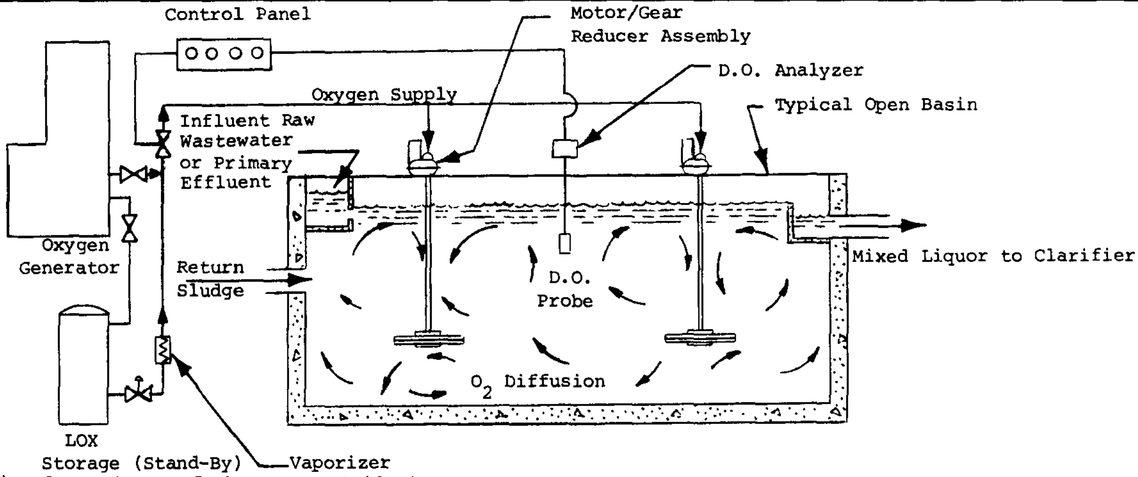
Environmental Impact - Sludge disposal; odor potential; and energy consumption.

References - 26, 185, 186

ACTIVATED SLUDGE, PURE OXYGEN, UNCOVERED

FACT SHEET 2.1.5

FLOW DIAGRAM -



ENERGY NOTES (4) - Assumptions: Carbonaceous Oxidation.
Operating Parameters: Oxygen activated sludge oxygen requirement = 1.2 lb O_2/lb BOD_5 removed.

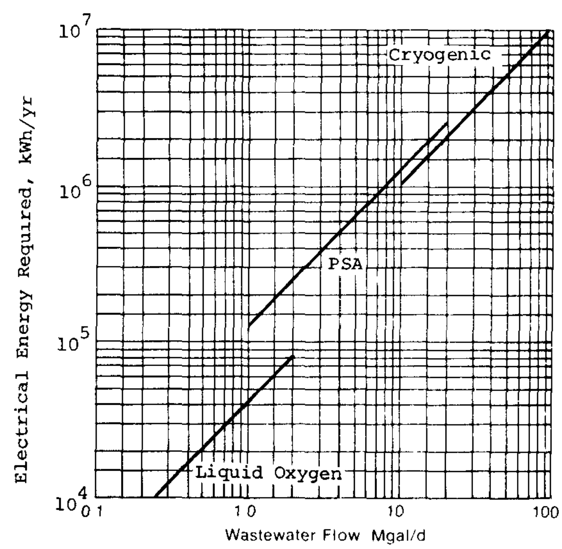
Water Quality:	Influent (mg/l)	Effluent (mg/l)
BOD_5	130	20

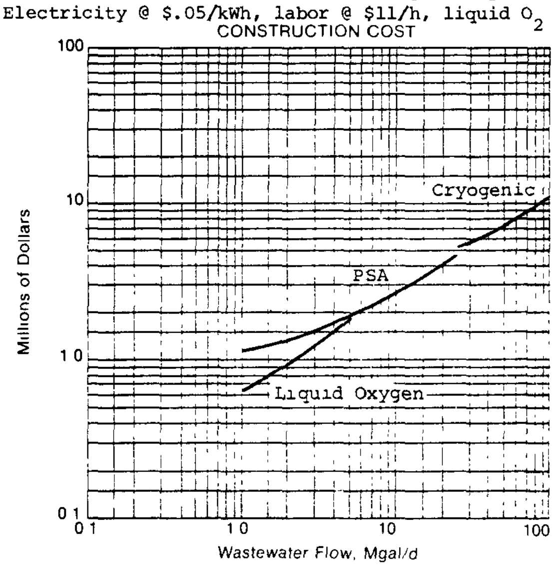
Oxygen Transfer Rate (OTR) includes oxygen production and oxygen dissolution.

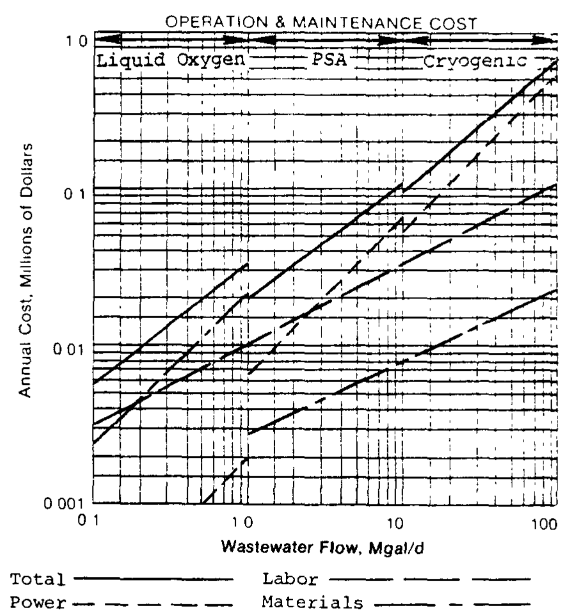
1. With cryogenic oxygen gas generation and surface aerators, OTR = 2.5 lb O_2/hph (wire to water) in wastewater.
2. With pressure swing adsorption (PSA) oxygen gas generation and surface aerators, OTR = 2.0 lb O_2/hph (wire to water) in wastewater.
3. Liquid O_2 supply and surface aerators, OTR = 6.5 lb O_2/hph (wire to water) in wastewater.

COSTS* - Design Basis: January 1979 dollars; ENR Index = 2872. Assumptions: Carbonaceous Oxidation.

1. Construction cost includes oxygenation basins, dissolution equipment, oxygen generators and liquid oxygen feed/storage facilities, instrumentation (where applicable), and licensing fees.
2. Oxygen was assumed to be delivered as liquid oxygen for plants from 0.1 to 1 Mgal/d size. For plants from 1.0 to 100 Mgal/d, oxygen was assumed to be generated on-site.
3. 1.2 lb O_2 supplied per lb BOD_5 removed.
4. MLVSS = 3100 mg/l. F/M = 0.5 lb BOD_5/d/lb MLVSS.
5. Volumetric loading = 97 lb BOD_5/d/1000 ft^3.
6. Detention time = 2 h (based on average daily flow).
7. Electricity @ \$.05/kWh, labor @ \$11/h, liquid O_2 @ \$100/t.







REFERENCES - 3, 4, 259

*To convert construction cost to capital cost, see Table A-2.

ACTIVATED SLUDGE WITH NITRIFICATION — FACT SHEET 2.1.6

Description - This process is also referred to as single-stage nitrification, because ammonia and carbonaceous materials are oxidized in the same aeration unit. As in any aerobic biological process, carbonaceous materials are oxidized by heterotrophic aerobes. In addition, a special group of autotrophic aerobic organisms called nitrifiers oxidize ammonia in two stages: Nitrosomonas bacteria convert ammonia to nitrite and Nitrobacter convert nitrite to nitrate. The optimal conditions for nitrification, in general, are: temperature of about $30^{o}C$; pH of about 7.2 to 8.5; F/M of about 0.05 to 0.15; relatively long aeration detention time as nitrifiers have a lower growth rate than other aerobes; and sludge retention time of about 20 to 30 days, depending upon temperature.

The degree of nitrification depends mainly on three factors, SRT, mixed liquor DO concentration and wastewater temperature, of which SRT is of primary importance because of the slow growth rate of nitrifiers. If the sludge is wasted at too high a rate, the nitrifiers will be eliminated from the system. Generally, nitrification begins at an SRT of about five days, but does not become appreciable until the SRT reaches about 15 days, depending upon temperature. The aeration system is designed to provide the additional oxygen needed to oxidize the ammonia nitrogen.

The conventional and high rate modifications of the activated sludge process do not provide the necessary hydraulic and sludge detention time. Besides, the F/M ratio is higher. As a result, single stage nitrification cannot be achieved in these configurations, although they effect a small reduction, about 20 percent in ammonia.

Common Modifications - Any low rate modification of the activated sludge process such as the extended aeration and the oxidation ditch can be used. In addition, the use of powdered activated carbon has the potential to enhance ammonia removal, although its application is in a state of infancy.

Technology Status - Over all, the process is fully demonstrated. There are nearly 650 shallow oxidation ditch installations in the U.S. and Canada. In addition, pre-engineered extended aeration plants are also widely used.

Typical Equipment/No. of Mfrs. (23) - Aerators/30; extended aeration package treatment plants/21; air diffusers/19; compressors/44; oxidation ditch equipment (brush aerators, etc.)/6; hydraulic controls/29.

Application - Applicable during warm weather if levels of 1 to 3 mg/l of ammonia nitrogen in the effluent is permitted.

Limitations - Biological nitrification is very sensitive to temperature, resulting in poor reduction in colder months. In addition, heavy metals such as Cd, Cr, Cu, Ni, Pb and Zn, phenolic compounds, cyanide and halogenated compounds can inhibit nitrification reactions.

Performance - A well-established extended aeration process will decrease ammonia-nitrogen to around 1 mg/l if the aerator temperature is about $55^{o}F$.

Residuals Generated - This process produces no primary sludge. The secondary sludge is lesser in quantity and better stabilized than the high rate and conventional activated sludge process, which minimizes the magnitude of the disposal problem considerably.

Design Criteria -

	Extended Aeration	Oxidation Ditch
Volumetric loading, lb BOD_5/d/1000 ft^3	5 to 10	10 to 15
MLSS, mg/l	3,000 to 6,000	3,000 to 5,000
F/M, lb BOD_5/d/lb MLVSS	0.05 to 0.15	0.03 to 0.10
Aeration detention time (based on average daily flow)h,	18 to 36	24
Air supplied, std. ft^3/lb BOD_5 applied	3,000 to 4,000	-
lb O_2/lb BOD_5 applied	2.0 to 2.5	2.0 to 2.5
Sludge Retention Time, d	20 to 30	20 to 30
Recycle Ratio	0.7 to 1.5	0.25 to 0.75
Volatile fraction of MLSS, mg/l	0.6 to 0.7	0.6 to 0.7

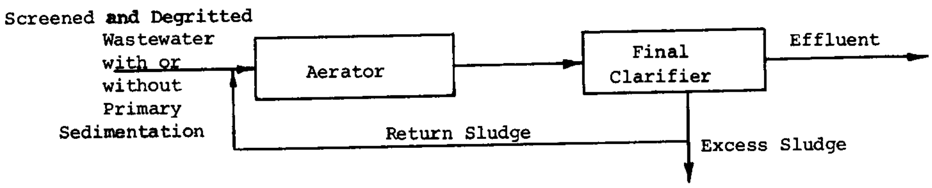
Process Reliability - Good.

Environmental Impact - From the solid waste point of view, the impact is very minimal compared to high rate and conventional activated sludge processes. However, odor and air pollution problems are very similar to other activated sludge processes.

References - 28, 29

ACTIVATED SLUDGE WITH NITRIFICATION	FACT SHEET 2.1.6

FLOW DIAGRAM -



ENERGY NOTES - Assumptions: The hydraulic head loss through the aeration tank is negligible. Sludge recycle and sludge wasting pumping energy are part of clarifier operation.

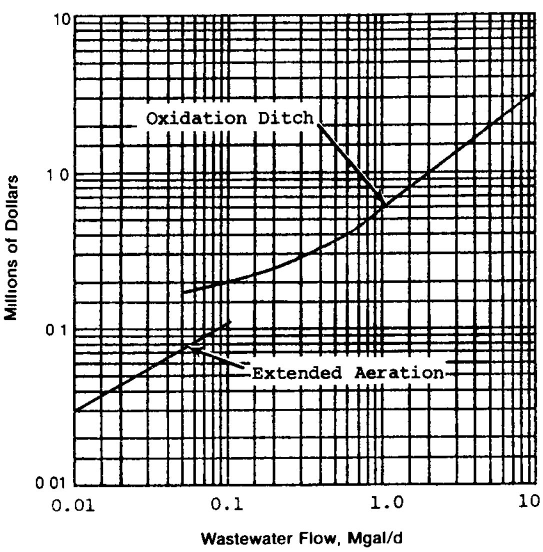
Water Quality	Influent, mg/l	Effluent, mg/l Warm Months	Effluent, mg/l Cold Months
Ammonia as N	15	1.0	Up to 12.0
BOD_5	130	20.0	20.0

Oxygen Requirement = 1.5 lb O_2/lb BOD_5 removed + 4.6 lb O_2/lb NH_4-N removed.

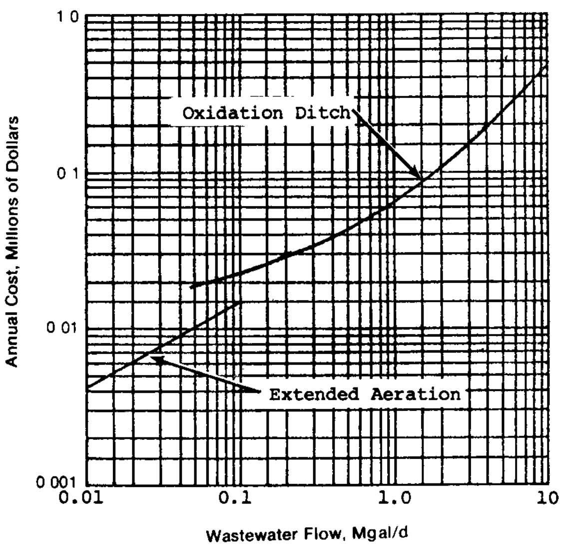
Oxygen Transfer Rate (wire to water) in wastewater:
- Extended Aeration
  - Coarse Bubble Diffusion = 1.08 lb O_2/hph
  - Fine Bubble Diffusion = 1.44 lb O_2/hph
  - Mechanical aeration = 1.08 lb O_2/hph
- Oxidation Ditch = 1.8 lb O_2/hph

COSTS* (1976 dollars) - Assumptions: Construction cost includes building, laboratory, outdoor sludge drying beds, but excludes land, engineering, legal and financing during construction. ENR Index = 2401.

CONSTRUCTION COSTS



OPERATION AND MAINTENANCE COSTS



REFERENCES - 3, 4, 16

*To convert construction cost to capital cost see Table A-2.

BIO-FILTER, ACTIVATED (WITH AERATOR) — FACT SHEET 2.1.7

Description - Activated bio filters (ABF) are a recent innovation in the biological treatment field. This process has been developed and promoted by one manufacturer, and it consists of the series combination of an aerobic tower (bio-cell) with wood packing material, followed by an activated sludge aeration tank and secondary clarifier. Settled sludge from the clarifier is recycled to the top of the tower. In addition, the mixture of wastewater and recycle sludge passing through the tower is also recycled around the tower, in a similar manner to a high rate trickling filter. No intermediate clarifier is utilized. Forward flow passes directly from the tower discharge to the aeration tank. The use of the two forms of biological treatment combines the effects of both fixed and suspended growth processes in one system. The microorganisms formed in the fixed growth phase are passed along to the suspended growth unit, whereas the suspended growth microorganisms are recycled to the top of the fixed media unit.

The bio-media in the bio-cell consists of individual racks made of wooden laths fixed to supporting rails. The wooden laths are placed in the horizontal direction, permitting wastewater to pass downward, and air horizontally and vertically. The horizontal surfaces reduce premature sloughing of biota. Droplet formation and breakup induced by wastewater dripping from lath to lath enhances oxygen transfer. The aeration basin is a short detention unit that can be designed for either plug flow or complete mix operation. The effluent from the aeration basin passes to a secondary clarifier where the activated sludge is collected and recycled to the top of the bio-cell tower and to waste.

Common Modifications - ABF units can be used for the removal of either carbonaceous material or for carbonaceous removal plus nitrification by appropriately modifying the detention time of the aeration basin. When nitrification is desired, the bio-cell acts as a first-stage roughing unit and the aeration basin as a second-stage nitrification unit. ABF bio-cells can be either rectangular or round. Various types of aeration equipment can be used in the aeration system, including both surface and diffused aerators. The detention time of the aeration tank can be modified, depending on influent quality and desired effluent quality. ABF units can be supplied with mixed media effluent filters for enhanced treatment.

Technology Status - This technology has been developed recently, with full scale units first built approximately five years ago. Presently, only one manufacturer is producing these units, and claims over 65 installations operating or under construction.

Typical Equipment/No. of Mfrs. - Activated bio filter systems/1.

Applications - Domestic wastewater and biodegradable industrial wastewater. Can be used when both BOD_5 removal and nitrification are required. Is applicable where land availability is low. Can be used where raw wastewater organic loadings fluctuate greatly, due to its ability to handle shock conditions. Existing trickling filter facilities and overloaded existing secondary plants can be upgraded to ABF at reduced cost.

Limitations - Will only treat biodegradable substances. Limited data are available on metals removal and sludge characteristics.

Performance - ABF systems can treat standard municipal, combined municipal/industrial, or industrial wastewaters to BOD_5 and suspended solids levels of 20 mg/l or less. One test study on a package system produced the following results:

	Average Values	
	Influent, mg/l	Effluent, mg/l
BOD_5	153	14
COD	330	58
TSS	222	20
NH_4-N (when used for nitrification)	20	1

Chemicals Required - None

Residuals Generated - Sludge. One study showed that 0.25 to 1.0 pounds of waste VSS are produced per pound of BOD_5 removed. The mean yield over the course of the pilot study was 0.60 pounds VSS per pound of BOD_5 removed.

Design Criteria -

Bio-cell organic load	100 to 200 lb BOD_5/d/1000 ft^3
Return sludge rate	25 to 100 percent
Bio-cell recycle rate	0 to 100 percent
Bio-cell hydraulic load	1 to 5.5 gal/min/ft^2
Aeration basin detention time	0.5 to 7.5 h (0.5-3.0, BOD_5 removal only; 5.8-7.5, two-stage nitrification)
System F/M	0.25 to 1.5 lb BOD_5/d/lb MLVSS for BOD_5 removal (defined as influent BOD_5 to bio-cell/d/MLVSS in aeration basin); about 0.18 lb BOD_5/d/lb MLVSS for two-stage nitrification

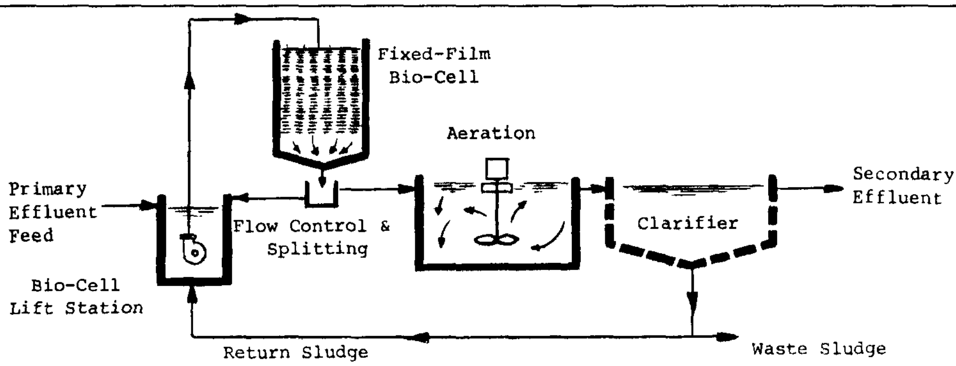
Unit Process Reliability - The mechanical and operational simplicity allows for a high unit reliability. Short term data indicate that the process reliability is also high.

Environmental Impact - Sludge will be generated, as described above. Volatile materials will be stripped due to the aeration action of the bio-cell. ABF systems require less land than traditional attached growth biological treatment systems that do not employ a suspended growth element.

References - 178, 179, 180, 181, 182, 183, 184, 227, 259

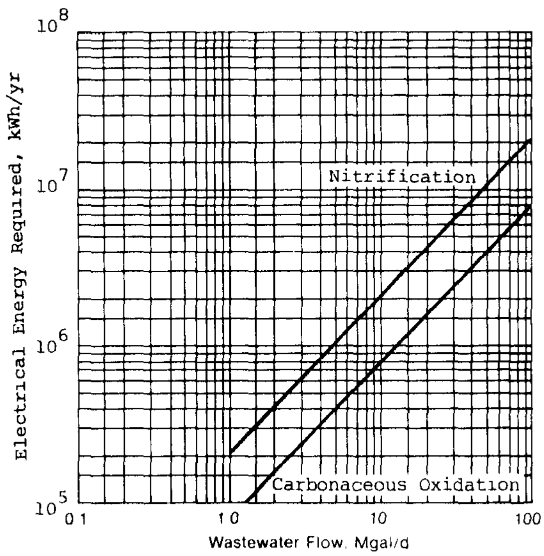
BIO-FILTER, ACTIVATED (WITH AERATOR) FACT SHEET 2.1.7

FLOW DIAGRAM -

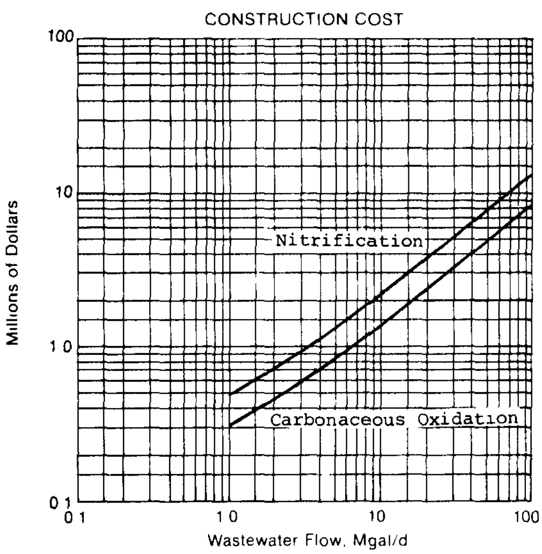


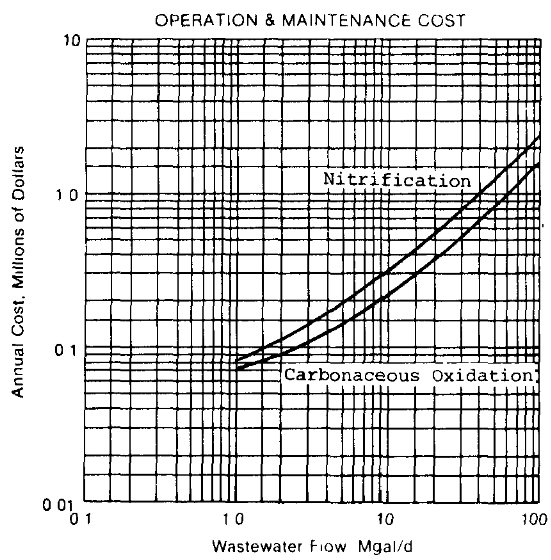
ENERGY NOTES - Assumptions: Bio-cell flow = 1.0 Q + 0.5 Q/RAS + 0.4 Q bio-cell recycle = 1.9 Q; TDH = 22' @ 14' media depth; pump efficiency = 70% (wire to water); bio-cell BOD_5 removal = 50% @ 200 lb/d/1000 ft^3; ABF aeration basin oxygen requirement = 1.4 lb O_2/lb BOD_5 removed in aeration basin; assumed OTR = 1.8 lb O_2/hph (wire to water) in wastewater for high speed surface aerator; for nitrification, oxygen requirement = 1.8 lb O_2/lb BOD_5 removed plus 4.6 lb O_2/lb NH_4-N removed. Energy requirement is for energy in aeration basin only.

Water Quality	Influent mg/l	Effluent mg/l
BOD_5	130	20
SS	100	20
(Nitrification)		
NH_4-N	20	1



COSTS* - January 1979 cost, ENR Index = 2872. Assumptions: Construction cost includes the following: bio-filter, bio-cell lift station, and mechanical aeration equipment. Total operation and maintenance costs have been derived from the following: energy @ $0.05kWh from reference 227, materials, and labor @ $11.00/h from reference 259. Aeration basin detention time = 2.5 h for carbonaceous oxidation and 6.5 h for nitrification (based on average daily flow).





REFERENCE - 259

*To convert construction cost to capital cost see Table A-2.

CONTACT STABILIZATION, DIFFUSED AERATION FACT SHEET 2.1.8

Description - Contact stabilization is a modification of the activated sludge process (described more completely in Fact Sheet 2.1.1). In this modification, the adsorptive capacity of the floc is utilized in the contact tank to adsorb suspended, colloidal, and some dissolved organics. The hydraulic detention time in the contact tank is only 30 to 60 minutes (based on average daily flow). After the biological sludge is separated from the wastewater in the secondary clarifier, the concentrated sludge is separately aerated in the stabilization tank with a detention time of 2 to 6 hours (based on sludge recycle flow). The adsorbed organics undergo oxidation in the stabilization tank and are synthesized into microbial cells. If the detention time is long enough in the stabilization tank, endogenous respiration will occur, along with a concomitant decrease in excess biological sludge production. Following stabilization, the reaerated sludge is mixed with incoming wastewater in the contact tank and the cycle starts anew. Volatile compounds are driven off to a certain extent by aeration in the contact and stabilization tanks. Metals will also be partially removed, with accumulation in the sludge.

This process requires smaller total aeration volume than the conventional activated sludge process. It also can handle greater organic shock and toxic loadings because of the biological buffering capacity of the stabilization tank and the fact that at any given time the majority of the activated sludge is isolated from the main stream of the plant flow. Generally, the total aeration basin volume (contact plus stabilization basins) is only 50 - 75 percent of that required in the conventional activated sludge system. A description of diffused aeration techniques is presented in Fact Sheet 2.1.1.

Common Modifications - Used in a package treatment plant with clarification and chlorination facilities in one vessel. Other modifications include raw wastewater feed to aeration tank; flow equalization; integral aerobic digester.

Technology Status - Contact stabilization has evolved as an outgrowth of activated sludge technology since 1950 and seen common usage in package plants and some usage for on-site constructed plants.

Typical Equipment/No. of Mfrs. - Air diffusers/19; compressors/44; package treatment plants/21.

Applications - Wastewaters that have an appreciable amount of BOD_5 in the form of suspended and colloidal solids; upgrading of an existing, hydraulically overloaded conventional activated sludge plant; new installations, to take advantage of low aeration volume requirements; where the plant might be subject to shock organic or toxic loadings; where larger, more uniform flow conditions are anticipated (or if the flows to the plant have been equalized).

Limitations - It is unlikely that effluent standards can be met using contact stabilization in plants smaller than 50,000 gal/d without some prior flow equalization. Other limitations include operational complexity, high operating costs, high energy consumption and high diffuser maintenance. As the fraction of soluble BOD_5 in the influent wastewater increases, the required total aeration volume of the contact stabilization process approaches that of the conventional process.

Performance -

BOD_5 Removal	80 to 95 percent
NH_4-N Removal	10 to 20 percent

Residuals Generated - See Fact Sheet 2.1.1.

Design Criteria (39) - A partial listing of design criteria for the contact stabilization process is summarized as follows:

F/M, lb BOD_5/d/lb MLVSS	0.2 to 0.6
Volumetric loading, lb BOD_5/d/1,000 ft^3	30 to 50 (based on contact and stabilization volume)
MLSS, mg/l	1,000 to 2,500, contact tank; 4,000 to 10,000, stabilization tank
Aeration time, h	0.5 to 1.0, contact tank (based on average daily flow) 2 to 6, stabilization basin (based on sludge recycle flow)
Sludge retention time, days	5 to 10
Recycle ratio (R)	0.25 to 1.0
Std. ft^3 air/lb BOD_5 removed	800 to 2,100
lb O_2/lb BOD_5 removed	0.7 to 1.0
Volatile fraction of MLSS	0.6 to 0.8

Process Reliability - Requires close operator attention.

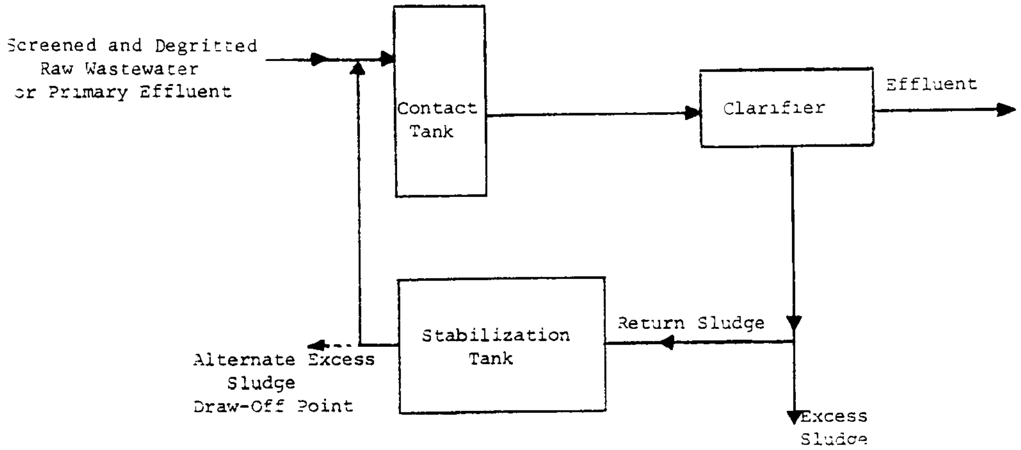
Environmental Impact - See Fact Sheet 2.1.1

References - 23, 26, 31, 39

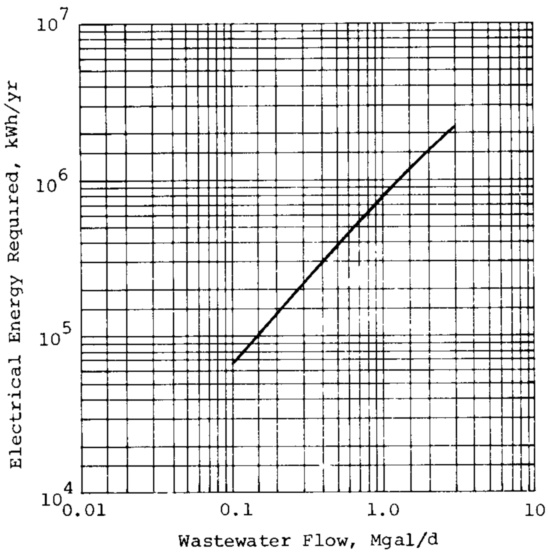
CONTACT STABILIZATION, DIFFUSED AERATION

FACT SHEET 2.1.8

FLOW DIAGRAM -



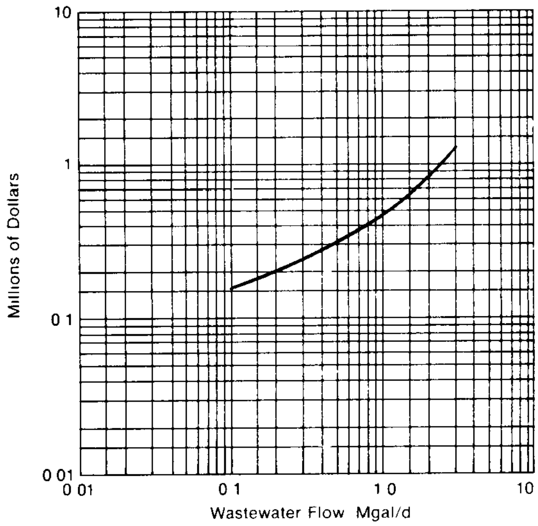
ENERGY NOTES - Assumptions: Air requirements are based on 2100 ft^3/lb BOD_5 removed (2 lb BOD_5/1000 gal/d). Positive displacement blowers with 100% standby are provided. Electricity = \$.03/kWh. Includes energy requirements for entire package plant.



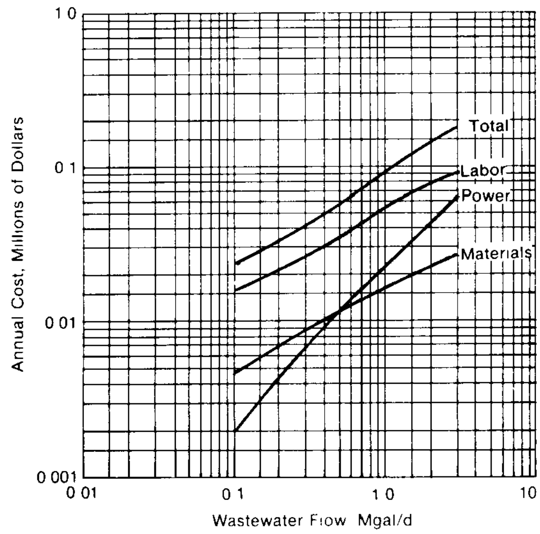
COSTS* - Assumptions: Costs are in 1976 dollars; ENR Index = 2401.

1. Construction cost is for package plants and includes tankage and equipment in place for aeration chambers, chlorination equipment, clarification and sludge stabilization. Costs include concrete and yardwork, 15% contingency, electrical and instrumentation, and contractor's overhead and profit at 25% of equipment costs but exclude land, engineering, legal or financing during construction.
2. O&M costs are based on a labor rate of \$9/h, including fringe benefits, with 7 d/wk staffing and electricity @ \$.03/kWh. Maintenance materials include chlorine.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCE - 16

DENITRIFICATION, SEPARATE STAGE, WITH CLARIFIER — FACT SHEET 2.1.9

Description and Common Modifications - Denitrification involves the reduction of nitrates and nitrites to nitrogen gas through the action of facultative heterotrophic bacteria. In suspended growth, separate stage denitrification processes, nitrified wastewater containing primarily nitrates is passed through a mixed anaerobic vessel containing denitrifying bacteria. Since the nitrified feedwater contains very little carbonaceous material, a supplemental source of carbon is required to maintain the denitrifying biomass. This supplemental energy is provided by feeding methanol to the biological reactor along with the nitrified wastewater. Mixing in the anaerobic denitrification reaction vessel may be accomplished using low speed paddles analogous to standard flocculation equipment. Following the reactor, the denitrified effluent is aerated for a short period (5 to 10 min) to strip out gaseous nitrogen formed in the previous step which might otherwise inhibit sludge settling. Clarification follows the stripping step with the collected sludge being either returned to the head end of the denitrification system, or wasted.

Common modifications include the use of alternate energy sources such as sugars, acetic acid, ethanol or other compounds. Nitrogen deficient materials such as brewery wastewater may also be used. An intermediate aeration step for stabilization (about 50 min) between the denitrification reactor and the stripping step may be used to guard against carryover of carbonaceous materials. The denitrification reactor may be covered but not air tight to assure anaerobic conditions by minimizing surface reaeration. See Fact Sheets 2.2.2 and 2.2.3 for information on attached growth denitrification systems.

Technology Status - Well developed at full scale but not in widespread use.

Typical Equipment/No. of Mfrs. (23) - Clarifier equipment/38; controls/29; air diffusers/19; aeration tanks/1; controls/29; instrumentation/9; chemical feed equipment/25; flocculators/32.

Applications - Used almost exclusively to denitrify municipal wastewaters that have undergone carbon oxidation and nitrification. May also be used to reduce nitrate in industrial wastewaters.

Limitations - Specifically acts on nitrate and nitrite. Will not affect other forms of nitrogen.

Performance - Capable of reducing 80 to 98 percent of the nitrate and nitrite entering the system to gaseous nitrogen. Overall nitrogen removals of 70 to 95 percent are achievable. Typical wastewater characteristics for NO_3-N: influent 19 mg/l, effluent 1 mg/l.

Chemicals Required - An energy source is needed and usually supplied in the form of methanol. Methanol feed concentration may be estimated using the following values per mg/l of the material at the inlet to the process.

mg/l CH_3OH	per	mg/l of
2.47		NO_3-N
1.53		NO_2-N
0.87		D.O.

Residuals Generated - If supplemental energy feed rates are controlled, very little excess sludge is generated. Sludge production 0.6 to .8 lb/lb NH_3-N reduced.

Design Criteria -

Flow Scheme	Plug Flow (preferable, but not mandatory)
Optimum pH	6.5 to 7.5
MLVSS	1000 to 3000 mg/l
Mixer power requirement	0.25 to 0.5 HP/1000 ft^3
Clarifier depth	12 to 15 ft
Clarifier surface loading rate	400 to 600 gal/d/ft^2
Solids loading	20 to 30 lb/d/ft^2
Return sludge rate	50 to 100 percent
Sludge generation	0.2 lb/lb CH_3OH or 0.7 lb/lb NH_3-N reduced
Detention time	0.2 to 2 h
Cell residence time	1 to 5 d

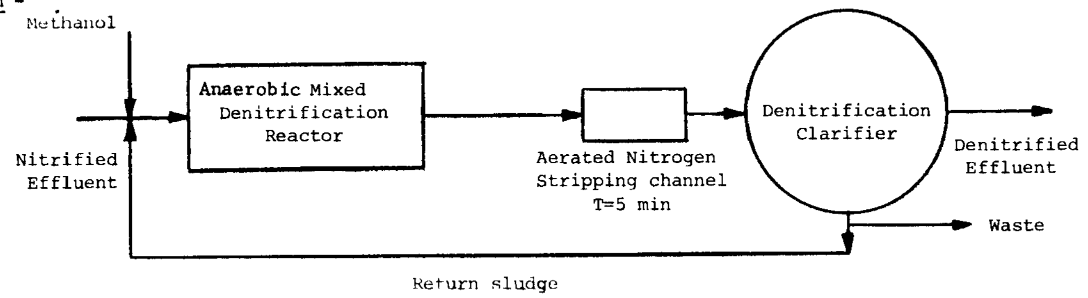
Unit Process Reliability - Under controlled pH, temperature, loading, and chemical feed, high levels of reliability are achievable.

Environmental Impact - Reduces the nitrogen loading on receiving stream.

References - 3, 7, 23, 28, 45, 95

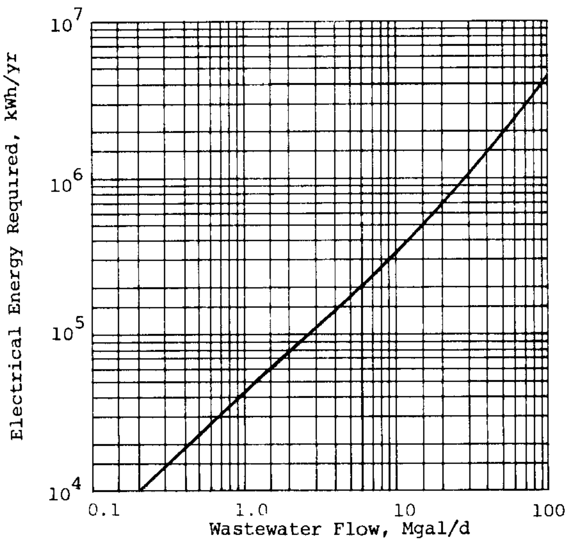
DENITRIFICATION, SEPARATE STAGE, WITH CLARIFIER — FACT SHEET 2.1.9

FLOW DIAGRAM -



ENERGY NOTES - Assumptions:

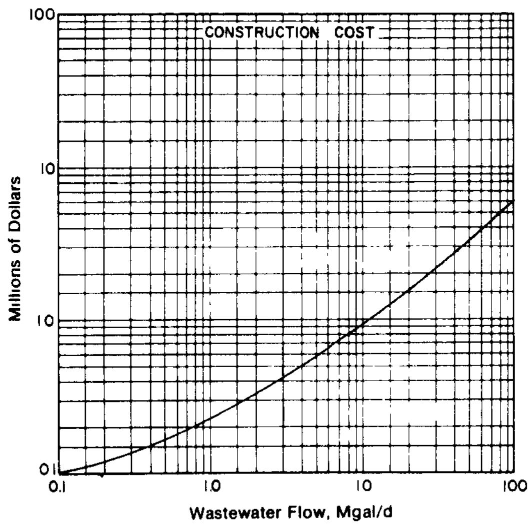
1. CH_3OH/N = 3:1
2. Same design basis as in costs.

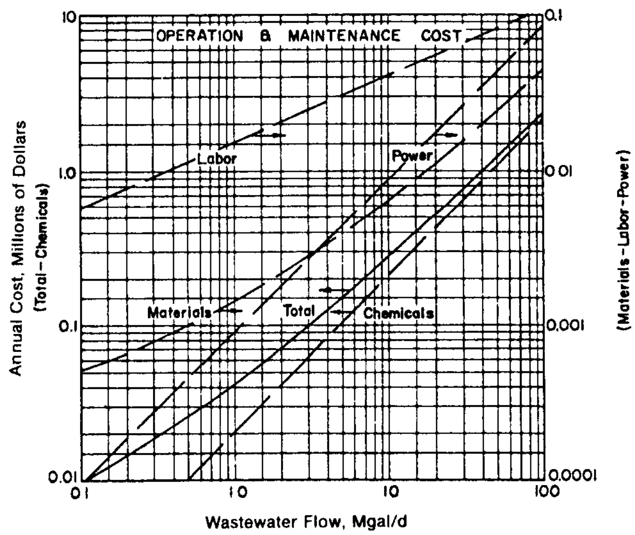


COSTS*- Assumptions: ENR Index = 2475.

1. Construction costs include denitrification tanks (uncovered), mixers, methanol feed, clarifiers, sludge recycle and waste pumps, but do not include reaeration facility.
2. Two hours detention time in denitrification tank.
3. MLVSS = 2,000 mg/l.
4. Denitrification recycle pumps sized for 100 percent recycle, operated at 50% recycle.
5. Final clarifier overflow rate = 600 gal/d/ft^2.
6. 3 lb methanol/lb of nitrate nitrogen removed.
7. Methanol storage - 30 d supply with a minimum tank size of 500 gal.
8. Wastewater characteristics

	Influent (mg/l)	Effluent (mg/l)
NO_3-N	19	1
NH_4-N	1	1





REFERENCES - 3, 28

*To convert construction cost to capital cost see Table A-2.

EXTENDED AERATION, MECHANICAL AND DIFFUSED AERATION — FACT SHEET 2.1.10

Description - Extended aeration is the "low rate" modification of the activated sludge process. The F/M loading is in the range of 0.05 to 0.15 lb BOD_5/d/lb MLVSS, and the detention time is about 24 hours. Primary clarification is rarely used. The extended aeration system operates in the endogenous respiration phase of the bacterial growth cycle, because of the low BOD_5 loading. The organisms are starved and forced to undergo partial autooxidation. Volatile compounds are driven off to a certain extent in the aeration process. Metals will also be partially removed, with accumulation in the sludge.

In the complete mix version of the extended aeration process, all portions of the aeration basin are essentially homogeneous, resulting in a uniform oxygen demand throughout the aeration tank. This condition can be accomplished fairly simply in a symmetrical (square or circular) basin with a single mechanical aerator or by diffused aeration. The raw wastewater and return sludge enter at a point (e.g., under a mechanical aerator) where they are quickly dispersed throughout the basin. In rectangular basins with mechanical aerators or diffused air, the incoming waste and return sludge are distributed along one side of the basin and the mixed liquor is withdrawn from the opposite side.

Common Modifications - Step aeration, contact stabilization, and plug flow regimes. Alum or ferric chloride is sometimes added to the aeration tank for phosphorus removal.

Technology Status - Extended aeration plants have evolved since the latter part of the 1940's. Pre-engineered, package plants have been widely utilized for this process.

Typical Equipment/No. of Mfrs. - Aerators/30; package treatment plants/21; air diffusers/19; compressors/44.

Applications - Commonly flows of less than 50,000 gal/d; emergency or temporary treatment needs; and biodegradable wastewater.

Limitations - High power costs, operation costs, and capital costs (for large permanent installations where the pre-engineered plants would not be appropriate).

Performance

BOD_5 Removal	85-95%
NH_4 - N Removed (Nitrification)	50-90%

Residuals Generated - Because of the low F/M loadings and long hydraulic detention times employed, excess sludge production for the extended aeration process (and the closely related oxidation ditch process) is the lowest of any of the activated sludge process alternatives, generally in the range of 0.15 to 0.3 lb excess total suspended solids/lb BOD_5 removed.

Design Criteria (39) - A partial listing of design criteria for the extended aeration modification of the activated sludge process is summarized as follows:

Volumetric loading, lb BOD_5/d/1,000 ft^3	5 to 10
MLSS, mg/l	3,000 to 6,000
F/M, lb BOD_5/d/lb MLVSS	0.05 to 0.15
Aeration detention time, hours (based on average daily flow)	18 to 36
Standard ft^3 air/lb BOD_5 applied	3,000 to 4,000
lb O_2/lb BOD_5 applied	2.0 to 2.5 (based on 1.5 lb O_2/lb BOD_5 removed + 4.6 lb O_2/ lb NH_4-N removed)
Sludge retention time, days	20 to 40
Recycle ratio (R)	0.75 to 1.5
Volatile fraction of MLSS	0.6 to 0.7

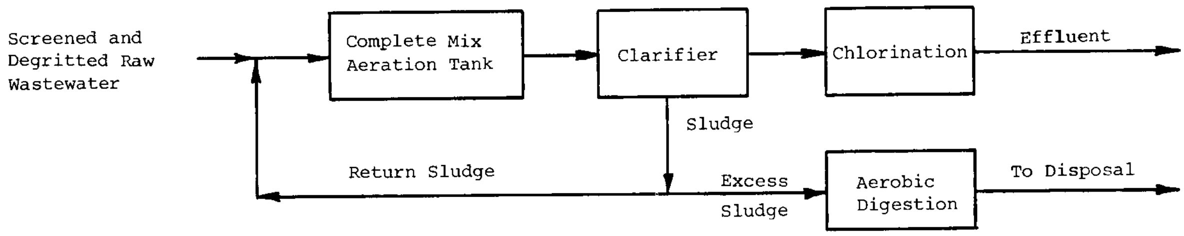
Process Reliability - Good

Environmental Impact - See Fact Sheet 2.1.1

References - 23, 26, 31, 39

EXTENDED AERATION, MECHANICAL AND DIFFUSED AERATION | FACT SHEET 2.1.10

FLOW DIAGRAM -

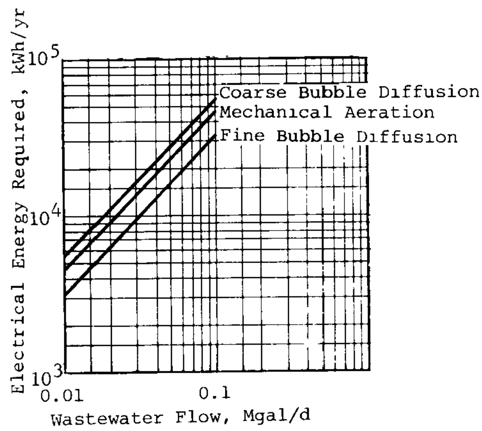


ENERGY NOTES - Assumptions: The hydraulic head loss through the aeration tank is negligible. Sludge recycle and sludge wasting pumping energy are included.

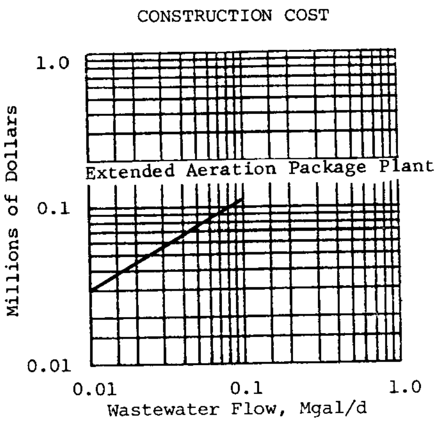
Water Quality:	Influent(mg/l)	Effluent(mg/l)
BOD_5	210	20
Suspended Solids	230	20
NH_4-N	20	1

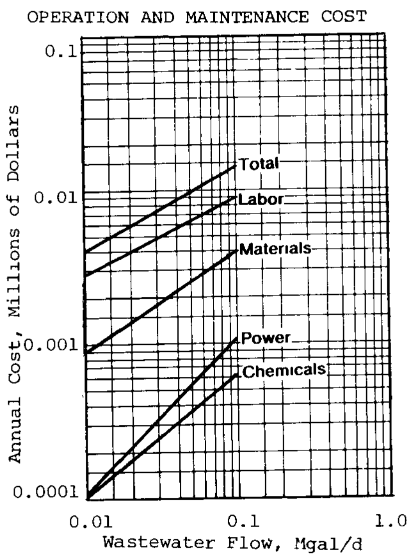
Oxygen Transfer Rate (wire to water) in wastewater for:
- Mechanical Aeration = 1.8 lb O_2/hph
- Diffused Aeration
  - Coarse Bubble Diffusion - 1.5 lb O_2/hph
  - Fine Bubble Diffusion = 2.5 lb O_2/hph

Oxygen Requirement:
1.5 lb O_2/lb BOD_5 removed plus 4.6 lb O_2/lb of NH_4-N removed



COSTS* - Assumptions: Construction cost includes comminutor, aeration basin, clarifier, chlorine contact chamber, aerobic digester, chlorine feed facility, building, fencing for extended aeration package plants between 0.01 and 0.1 Mgal/d. Detention time: 24 hours (based on average daily flow). ENR Index = 2475 Annual power costs based on coarse bubble diffuser.





REFERENCES - 3, 4

*To convert construction cost to capital cost see Table A-2.

Description - Aerated lagoons are medium-depth basins designed for the biological treatment of wastewater on a continuous basis. In contrast to stabilization ponds, which obtain oxygen from photosynthesis and surface re-aeration, they employ aeration devices which supply supplemental oxygen to the system. The aeration devices may be mechanical (i.e., surface aerator), or diffused air systems. Surface aerators are divided into two types: cage aerators and the more common turbine and vertical shaft aerators. The many diffused air systems utilized in lagoons consist of plastic pipes supported near the bottom of the cells with regularly spaced sparger holes drilled in the tops of the pipes. Because aerated lagoons are normally designed to achieve partial mixing only, aerobic-anaerobic stratification will occur, and a large fraction of the incoming solids and a large fraction of the biological solids produced from waste conversion settle to the bottom of the lagoon cells. As the solids begin to build up, a portion will undergo anaerobic decomposition. Volatile toxics can potentially be removed by the aeration process, and incidental removal of other toxics can be expected to be similar to an activated sludge system. Several smaller aerated lagoon cells in series are more effective than one large cell. Tapering aeration intensity downward in the direction of flow promotes settling out of solids in the last cell. A non-aerated polishing cell following the last aerated cell is an optional, but recommended, design technique to enhance suspended solids removal prior to discharge.

Common Modifications - The lagoons may be lined with concrete or an impervious flexible lining, depending on soil conditions and environmental regulations. Use of various types of aeration. When high-intensity aeration produces completely mixed (all aerobic) conditions, a final settling tank is required. Solids are recycled to maintain about 800 mg/l MLVSS in this mode.

Technology Status - While not as widely used when compared with the large number of stabilization ponds in common use throughout the U. S., it has been fully demonstrated, and used for years.

Applications - Used for domestic and industrial wastewater of low and medium strength. Commonly used where land is inexpensive and costs and operational control are to be minimized. It is relatively simple to upgrade existing oxidation ponds, lagoons, and natural bodies of water to this type of treatment. Aeration increases the oxidation capacity of the pond and is useful in overloaded ponds that generate odors. Useful when supplemental oxygen requirements are high or when the requirements are either seasonal or intermittent.

Limitations - In very cold climates aerated lagoons may experience reduced biological activity and treatment efficiency, and the formation of ice.

Typical Equipment/No. Mfrs. (23) - Lining systems/6; Aerators/30; Hydraulic Controls/29

Performance

	Influent	% Removed
BOD	200 - 500 mg/l	60 - 90
COD	-	70 - 90
TSS	200 - 500 mg/l	70 - 90

Residuals - Settled solids on pond bottom may require clean-out every 10 to 20 years, or possibly more often if a polishing pond is used behind the aerated pond.

Design Criteria (12, 67)

Operation: One or more aerated cells, followed by a settling (unaerated) cell
Detention time: 3 to 10 days
Depth, ft: 6 to 20
pH: 6.5 to 8.0

Water Temperature range: 0 to 40°C
Optimum Water Temperature: 20°C
Oxygen requirement: 0.7 to 1.4 times the amount of BOD_5 removed
Organic Loading: 10 to 300 lb BOD_5/acre/d

Energy requirements:
- For aeration: 6 to 10 hp/million gallons capacity
- To maintain all solids in suspension: 60 to 100 hp/million gallons capacity
- To maintain some solids in suspension: 30 to 40 hp/million gallons capacity

Process Reliability - The service life of a lagoon is estimated at 30 years or more. The reliability of equipment and the process is high. Little operator expertise is required.

Environmental Impacts - There is opportunity for volatile organic material and pathogens in aerated lagoons to enter the air as with any aerated wastewater treatment process. This opportunity depends on air/water contact afforded by the aeration system. There is potential for seepage of wastewater into ground water unless a lagoon is lined. Compared to other secondary treatment processes, aerated lagoons generate less solid residue.

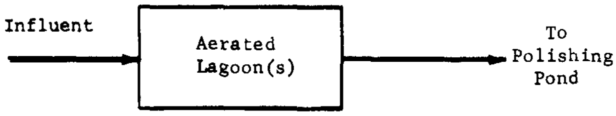
Toxics - Volatile toxics will be removed, and incidental removal of other toxics can be expected to be similar to an activated sludge system.

References - 7, 12, 13, 18, 23, 67

LAGOONS, AERATED

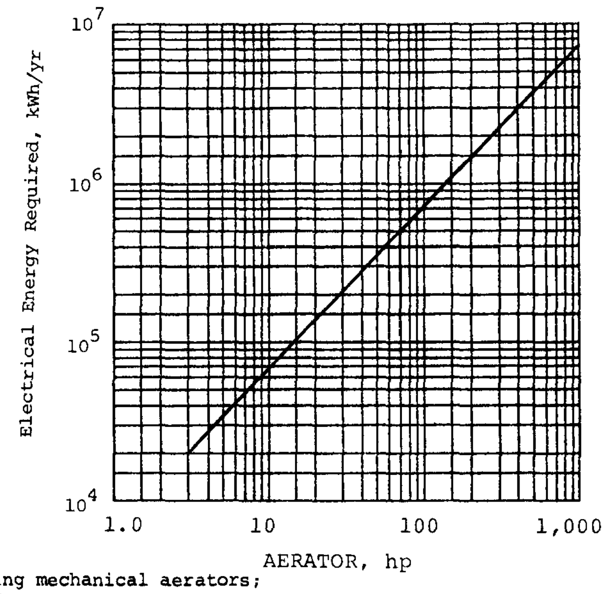
FACT SHEET 2.1.11

FLOW DIAGRAM -



ENERGY NOTES (4) -
Low speed mechanical surface aerators; motor efficiency = 90%; aerator efficiency = 1.8 lb O_2/hph (wire to water); head loss negligible. Type of energy required: electrical

For additional information on energy requirements and transfer efficiency of selected aeration devices, refer to Table D-1.

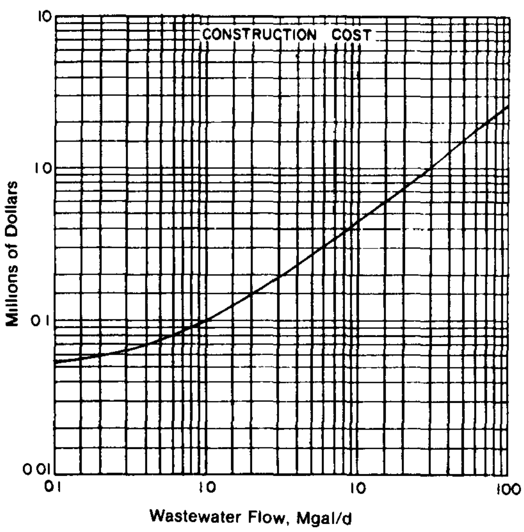


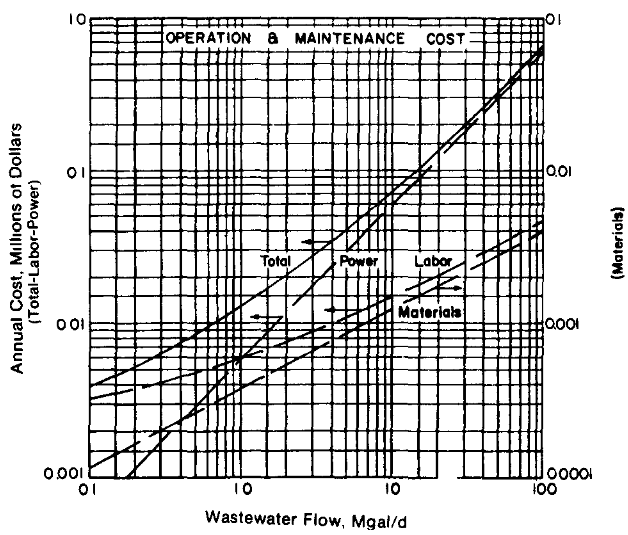
COSTS* (3) -Assumptions:
1. Service life, 30 years; ENR Index = 2475
2. Theoretical detention time = 7 d; 15-ft water depth; floating mechanical aerators;
3. Horsepower required = 36 hp/Mgal of capacity; power @ $.02/kWh;
4. Construction cost includes excavation, embankment, and seeding of lagoon/slopes (3 cells); service road and fencing; riprap embankment protection; hydraulic control works; aeration equipment and electrical equipment.

Wastewater Characteristics:	In	Out
BOD_5, mg/l	210	25
COD, mg/l	400	50
TSS, mg/l	230	40
Total-P, mg/l	11	8
NH_3-N, mg/l	20	18

To adjust construction cost for detention time other than above, enter curve at effective flow (Q_E)

$$Q_E = Q_{DESIGN} \times \frac{\text{New Design Detention Time}}{\text{7 days}}$$





REFERENCES - 3, 4

*To convert construction cost to capital cost see Table A-2.

LAGOONS, ANAEROBIC — FACT SHEET 2.1.12

Description - Anaerobic lagoons are relatively deep (up to 20 ft) ponds with steep sidewalls in which anaerobic conditions are maintained by keeping loading so high that complete deoxygenation is prevalent. Although some oxygenation is possible in a shallow surface zone, once greases form an impervious surface layer, complete anaerobic conditions develop. Treatment or stabilization results from thermophilic anaerobic digestion of organic wastes. The treatment process is analogous to that occurring in single stage untreated anaerobic digestion of sludge in which acid forming bacteria break down organics. The resultant acids are then converted to carbon dioxide, methane, cells and other end products.

In the typical anaerobic lagoon, raw wastewater enters near the bottom of the pond (often at the center) and mixes with the active microbial mass in the sludge blanket, which is usually about 6 ft deep. The discharge is located near one of the sides of the pond, submerged below the liquid surface. Excess undigested grease floats to the top, forming a heat retaining and relatively air tight cover. Wastewater flow equalization and heating are generally not practiced. Excess sludge is washed out with the effluent. Recirculation of waste sludge is not required.

Anaerobic lagoons are capable of providing treatment of high strength wastewaters and are resistant to shock loads.

Common Modifications- Anaerobic lagoons are customarily contained within earthen dikes. Depending on soil characteristics, lining with various impervious materials such as rubber, plastic or clay may be necessary. Pond geometry may vary, but surface area to volume ratios are minimized to enhance heat retention.

Technology Status - Although anaerobic processes are common for sludge digestion, anaerobic lagoons for wastewater treatment have found only limited application. The process is well demonstrated for stabilization of highly concentrated organic wastes.

Typical Equipment/No.of Mfrs. (23) -

Lining Systems/6; Hydraulic controls/29

Applications - Typically used in series with aerobic or facultative lagoons. Anaerobic lagoons are effective as roughing units prior to aerobic treatment of high strength wastes.

Limitations - May generate odors. Requires relatively large land area. For efficient operation, water temperatures above 75^{o}F should be maintained.

Performance - BOD_5 removals of 50 to 70 percent are achievable depending on loading and temperature conditions. TSS concentrations may increase, especially if the influent BOD_5 is primarily dissolved. Generally does not produce an effluent suitable for direct discharge to receiving waters.

Residuals Generated - In anaerobic lagoons excess sludge is usually washed out in the effluent. Since anaerobic lagoons are often used for preliminary treatment recirculation or removal of sludge not generally required.

Chemicals Required - Nutrients as needed to make up deficiencies in raw wastewater. No other chemicals required.

Design Criteria -

Operation: Parallel or series
Detention Time: 20 to 50 d
Depth, ft: 8 to 20
pH: 6.8 to 7.2
Water Temperature Range: 35 to 120^{o}F
Optimum Water Temperature: 86^{o}F
Organic loading: 200 to 2200 lb BOD_5/acre/d

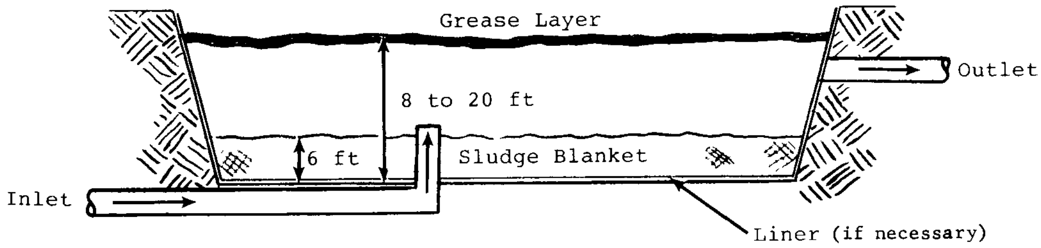
Unit Process Reliability - Generally resistant to upsets. Highly reliable if pH in the relatively narrow optimum range is maintained.

Environmental Impact - May create odors. Have relatively high land requirements. There is potential for seepage of wastewater into groundwater unless lagoon is lined.

Joint Treatment Potential - Valuable as a preliminary treatment process for combined industrial and municipal wastes containing high concentrations of organic materials. Can be used preceding most standard biological treatment processes.

References - 7, 16, 18, 20, 23, 67, 107, 110

FLOW DIAGRAM -



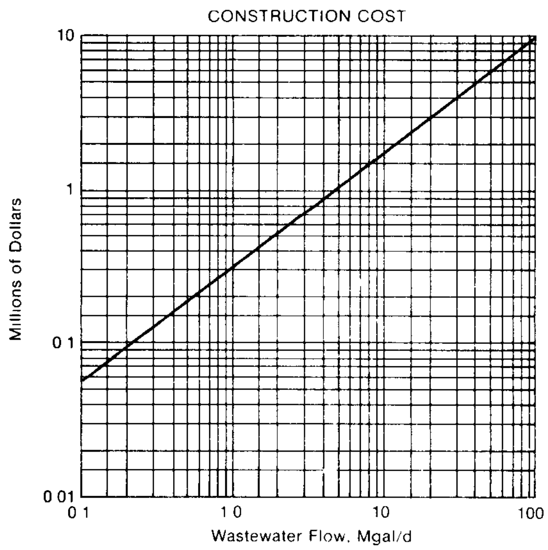
ENERGY NOTES - Anaerobic lagoons are operated by gravity flow and therefore have no energy requirements other than any pumping that may be necessary to lift the influent wastewater into the lagoons.

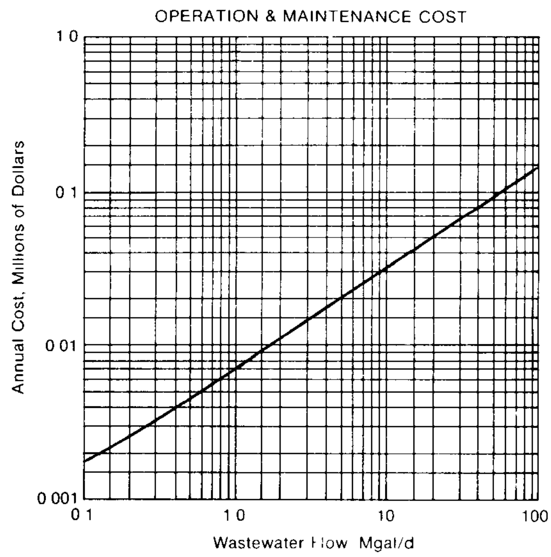
COSTS* - Assumptions: January 1979 dollars; ENR Index = 2872.
Service Life: 50 years
Average detention time = 35 days; depth = 10 ft; BOD_5 loading = 466 lb/acre/d. Construction cost includes excavating, grading and other earthwork and service roads. Costs do not include land and pumping. Liner cost not included in estimate. Operation and maintenance costs consist of labor and material.

Wastewater Characteristics	Influent, mg/l	Effluent, mg/l
BOD_5	600	240

To adjust costs for other BOD_5 loadings and/or detention times, enter curve at effective flow (Q_E):

$$Q_E = Q_{DESIGN} \times \frac{(466\ \text{lb/acre/d})\ (\text{New detention time})}{(\text{New Design Loading})\ (35\ \text{days})}$$





REFERENCE - Curves derived from reference 3.

*To convert construction cost to capital cost see Table A-2.

LAGOONS, FACULTATIVE

.FACT SHEET 2.1.13

Description - Facultative lagoons are intermediate depth (3 to 8 feet) ponds in which the wastewater is stratified into three zones. These zones consist of an anaerobic bottom layer, an aerobic surface layer, and an intermediate zone. Stratification is a result of solids settling and temperature-water density variations. Oxygen in the surface stabilization zone is provided by reaeration and photosynthesis. This is in contrast to aerated lagoons in which mechanical aeration is used to create aerobic surface conditions. In general, the aerobic surface layer serves to reduce odors while providing treatment of soluble organic by-products of the anaerobic processes operating at the bottom.

Sludge at the bottom of facultative lagoons will undergo anaerobic digestion producing carbon dioxide, methane and cells. The photosynthetic activity at the lagoon surface produces oxygen diurnally, increasing the dissolved oxygen during daylight hours, while surface oxygen is depleted at night.

Facultative lagoons are often and for optimum performance should be operated in series. When three or more cells are linked, the effluent from either the second or third cell may be recirculated to the first. Recirculation rates of 0.5 to 2.0 times the plant flow have been used to improve overall performance.

Common Modifications - Facultative lagoons are customarily contained within earthen dikes. Depending on soil characteristics, lining with various impervious materials such as rubber, plastic or clay may be necessary. Use of supplemental top layer aeration can improve overall treatment capacity, particularly in northern climates where icing over of facultative lagoons is common in the winter.

Technology Status -Fully demonstrated and in moderate use especially for treatment of relatively weak municipal wastewater in areas where real estate costs are not a restricting factor.

Applications - Used for treating raw, screened, or primary settled domestic wastewaters and weak biodegradable industrial wastewaters. Most applicable when land costs are low and operation and maintenance costs are to be minimized.

Limitations - In very cold climates, facultative lagoons may experience reduced biological activity and treatment efficiency. Ice formation can also hamper operations. In overloading situations, odors can be a problem.

Typical Equipment/No. of Mfrs. (23) - Lining systems/6; Hydraulic controls/29.

Performance - BOD_5 reductions of 75 to 95 percent have been reported. Effluent suspended solids concentrations of 20 to 150 mg/l can be expected, depending on the degree of algae separation achieved in the last cell. Efficiencies are strongly related to pond depth, detention time and temperature.

Chemicals Required - If wastewater is nutrient deficient, a source of supplemental nitrogen or phosphorus may be needed. No other chemicals are required.

Residuals - Settled solids may require clean out and removal once every 10 to 20 years.

Design Criteria -
Operation: At least three cells in series. Parallel trains of cells may be used for larger systems.
Detention time: 20 to 180 days.
Depth, ft: 3 to 8, although a portion of the anaerobic zone of the first cell may be up to 12 ft deep to accommodate large initial solids deposition.
pH: 6.5 to 9.0
Water temperature range: 35 to 90°F for municipal applications
Optimum water temperature: 68°F
Organic loading: 10 to 100 lb BOD_5/acre/d

Process Reliability - The service life of the lagoon is estimated to be 50 years. Little operator expertise is required. Overall, the system is highly reliable.

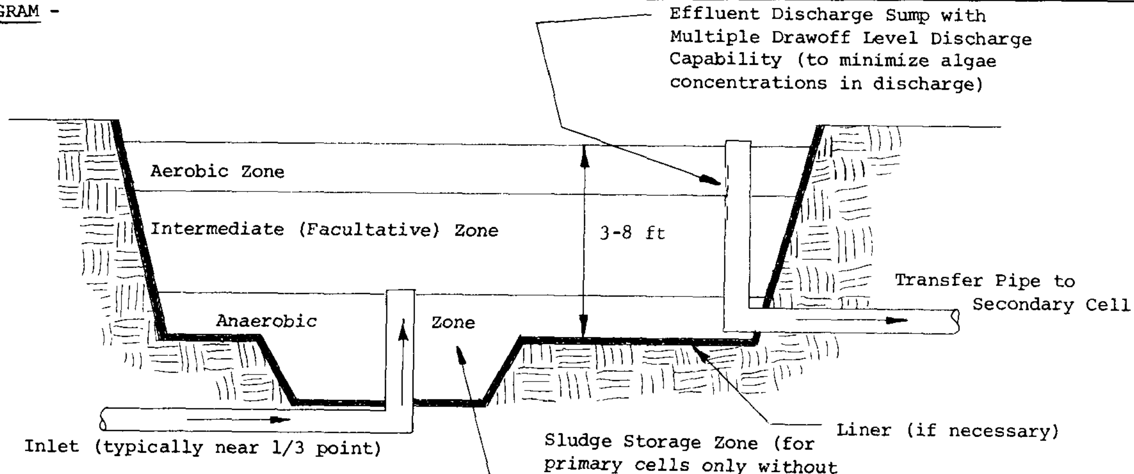
Environmental Impact - There is potential for seepage of wastewater into ground water unless lagoon is lined. Compared to other secondary processes, relatively small quantities of sludge are produced.

References - 3, 7, 18, 23, 67, 109, 110

LAGOONS, FACULTATIVE

FACT SHEET 2.1.13

FLOW DIAGRAM -



ENERGY NOTES - Facultative lagoons are operated by gravity and therefore have no energy requirements other than any pumping that may be necessary to lift the influent wastewater into the lagoons.

COSTS* -Assumptions:

1. Warm climate - lagoon loading = 40 lb BOD_5/acre/d.
2. Cool climate (northern U.S.) - lagoon loading = 20 lb BOD_5/acre/d.
3. Water depth = 4 ft.
4. Construction cost includes excavating, grading, and other earthwork required for normal subgrade preparation and service roads. Costs do not include land and pumping.
5. Process performance:

	Wastewater Characteristics In	Out
BOD_5, mg/l	210	30
COD, mg/l	400	100
TSS, mg/l	230	60
Total-P, mg/l	11	8
NH_3-N, mg/l	20	15 (cool climate)
		1 (warm climate)

6. No liner included in cost estimate.
7. ENR Index = 2475

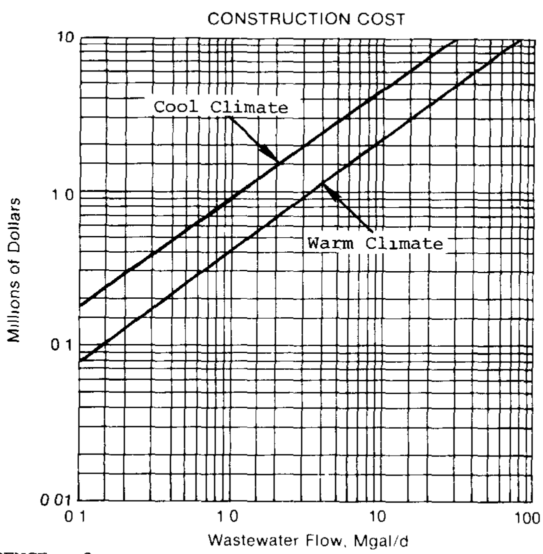
Adjustment Factor: To adjust costs for loadings other than those above, enter curve at effective flow (Q_E).

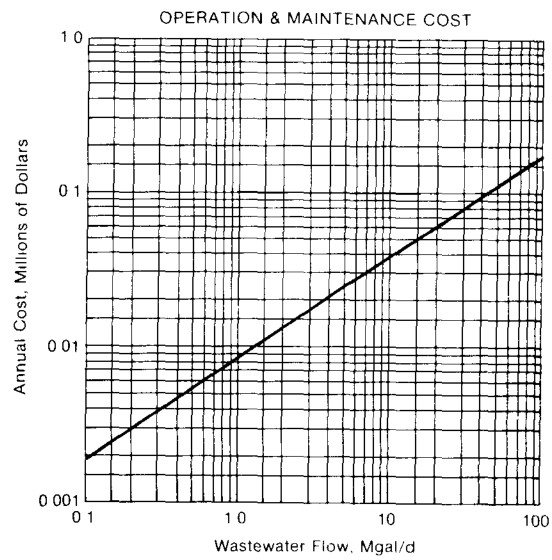
Warm Climates

$$Q_E = Q_{DESIGN} \times \frac{40 \text{ lb } BOD_5\text{/acre/day}}{\text{New Design Loading}}$$

Cool Climates

$$Q_E = Q_{DESIGN} \times \frac{20 \text{ lb } BOD_5\text{/acre/day}}{\text{New Design Loading}}$$





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

NITRIFICATION, SEPARATE STAGE, WITH CLARIFIER — FACT SHEET 2.1.14

Description - The process by which ammonia is converted to nitrate in wastewater is referred to as nitrification. In the process, Nitrosomonas and Nitrobacter act sequentially to oxidize ammonia (and nitrite) to nitrate. The biological reactions involved in these conversions may take place during activated sludge treatment or as a separate stage following removal of carbonaceous materials. Separate stage nitrification may be accomplished via suspended growth or attached growth unit processes. In either case, the nitrification step is preceded by a pretreatment sequence to reduce the carbonaceous demand. Possible pretreatment schemes include: activated sludge, trickling filter, roughing filter, primary treatment with chemical addition and physical chemical treatment. In general, if the pretreatment effluent has a BOD_5/TKN ratio of less than 3.0, sufficient carbonaceous removal has occurred such that the following nitrification process may be classified as a separate stage. Low BOD is required to assure a high concentration of nitrifiers in the nitrification biomass.

The most common separate stage nitrification process is the plug flow suspended growth configuration with clarification. In this process, pretreatment effluent is pH adjusted (as required) and aerated, in a plug flow mode. Because the carbonaceous demand is low, nitrifiers predominate. A clarifier follows aeration, and nitrification sludge is returned to the aeration tank. A possible modification is the use of pure oxygen in place of conventional aeration during the plug flow operation.

Common Modifications - Less prevalent are attached growth separate stage nitrification processes. These processes may be operated analogously to trickling filter, packed bed or rotating biological disc systems. Since the biomass is attached to the reactor surface and solids synthesis is low, a clarifier may not be required. Final filtration is sometimes practiced to reduce effluent suspended solids, although this is often not required. Refer to Fact Sheet 2.2.6 for costs of nitrification utilizing the attached growth process.

Technology Status - Nitrification is a well known phenomenon in biological treatment processes. Separate stage nitrification has been well demonstrated throughout the United States and England in numerous pilot studies and several full-scale designs. Separate stage suspended growth systems outnumber separate stage attached growth systems in these applications by about four to one.

Typical Equipment/No. Mfrs (23) - Air diffusers/19; aeration tanks/1; clarifier equipment/38; controls/29; filter equipment/35; instrumentation/9.

Applications - Applicable for conversion of ammonia to nitrate, particularly as a preliminary step prior to denitrification. Commonly used as an add-on process after secondary treatment.

Limitations - Sensitive to toxicant upset. Design should compensate for reduced efficiency at low temperature. Only oxidizes ammonia to nitrate. Cannot remove nitrogen effectively; does not significantly treat organic nitrogen.

Performance - Conversions of ammonia (and nitrite) to nitrate of up to 98 percent are achievable. Properly designed systems have effluent ammonia in the 1 to 3 mg/l range. BOD_5 reductions are generally 70 to 80 percent (influent BOD_5 assumed as approximately 50 mg/l).

Chemicals Required - Acid or alkali for pH control as needed.

Residuals Generated - A separate nitrification sludge is generated as a result of separate stage suspended growth systems. Attached growth systems may generate a filter backwash wastewater.

Design Criteria -

Suspended Growth Systems	
Flow Scheme	Plug Flow (preferable, but not mandatory)
Optimum pH	8.2-8.6
MLVSS	1200-2400 mg/l
Min. Aeration Tank D.O.	2.0 mg/l
Clarifier Surface Loading Rate	400-600 gal/d/ft^2
Solids Loading	20 to 30 lb/d/ft^2
Return Sludge Rate	50 to 100 percent
Detention Time	0.5 to 3 hr
Mean Cell Residence Time	10 to 20 d

Attached Growth Systems (Trickling Filters)	
Media Area	3,000-10,000 ft^2/lb NH_4-N oxidized/d
Recirculation Rate	up to 100 percent (variable)

Unit Process Reliability - Under controlled pH, temperature, loading and toxicant conditions, high levels of reliability are achievable.

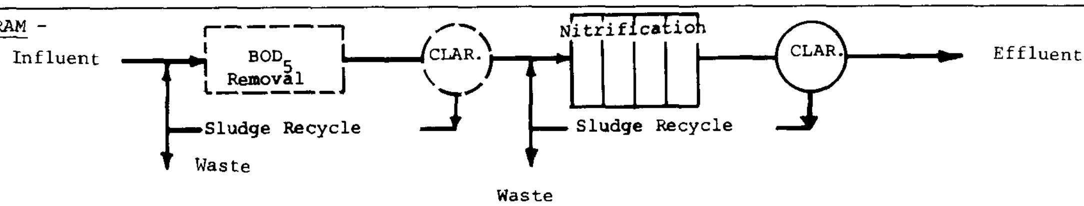
Environmental Impact - Nitrification sludge by itself is relatively difficult to dewater. However, it is usually combined with other sludges, resulting in a very small impact on overall dewaterability. Other environmental impacts are similar to those of standard biological treatment.

References 7, 23, 28, 45, 95, 262

NITRIFICATION, SEPARATE STAGE, WITH CLARIFIER

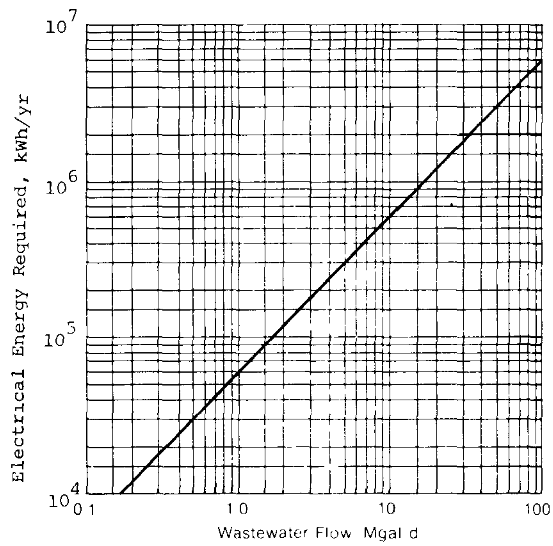
FACT SHEET 2.1.14

FLOW DIAGRAM -



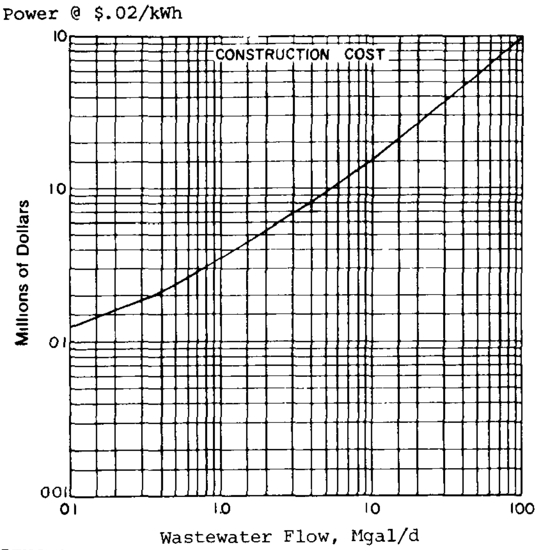
ENERGY NOTES -
Suspended Growth
Assumptions:
Mechanical Aeration
O_2 Transfer Rate = 1.8 lb O_2/hph
O_2 required = 4.6 lb O_2/lb NH_4-N, 1.0 lb O_2/lb BOD_5

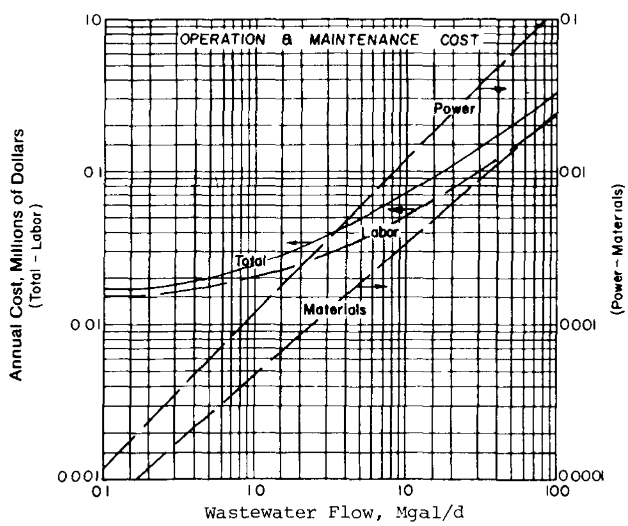
	In (mg/l)	Out (mg/l)
NH_4-N	19	1
BOD_5	40	10



COSTS* - ENR Index = 2475
Design Basis (suspended growth):

1. Construction costs include nitrification tanks, aeration devices, clarifiers, and sludge recycle and waste pumps, but not pH adjustment facilities.
1. System to follow high-rate activated sludge system.
3. Detention time = 3 hours.
4. O_2 requirements: 1.5 lb O_2/lb BOD_5 removed, plus 4.6 lb O_2/lb NH_4-N oxidized.
5. Sludge return pumps sized for 100 percent recycle. Operated at 50 percent recycle.
6. Final clarifier overflow rate = 600 gal/d/ft^2 (30 lb/ft^2/d)
7. Power @ $.02/kWh





REFERENCES - 3, 4, 45

*To convert construction cost to capital cost see Table A-2.

OXIDATION DITCH — FACT SHEET 2.1.15

Description - An oxidation ditch is an activated sludge biological treatment process; commonly operated in the extended aeration mode, although conventional activated sludge treatment is also possible. Typical oxidation ditch treatment systems consist of a single or closed loop channel 4 to 6 ft deep, with 45° sloping sidewalls.

Some form of preliminary treatment such as screening, comminution or grit removal normally precedes the process. After pretreatment (primary clarification is usually not practiced) the wastewater is aerated in the ditch using mechanical aerators which are mounted across the channel. Horizontal brush, cage or disc-type aerators, specially designed for oxidation ditch applications are normally used. The aerators provide mixing and circulation in the ditch, as well as sufficient oxygen transfer. Mixing in the channels is uniform, but zones of low dissolved oxygen concentration can develop. Aerators operate in the 60 to 110 RPM range and provide sufficient velocity to maintain solids in suspension. A high degree of nitrification may occur in the process without special modification because of the long detention times and high solid retention times (10 to 50 d) utilized. Secondary settling of the aeration ditch effluent is provided in a separate clarifier.

Common Modifications - Ditches may be constructed of various materials, including concrete, gunite, asphalt, or impervious membranes. Concrete is the most common. Ditch loops may be oval or circular in shape. "Ell" and "horseshoe" configurations have been constructed to maximize land usage. Conventional activated sludge treatment, in contrast to extended aeration, may be practiced. Oxidation ditch systems with depths of 10 ft or more with vertical sidewalls and vertical shaft aerators may also be used.

Technology Status - There are nearly 650 shallow oxidation ditch installations in the United States and Canada. Numerous shallow and deep oxidation ditch systems are in operation in Europe. The overall process is fully demonstrated for carbon removal, as a secondary treatment process.

Typical Equipment/No. of Mfrs. (16, 23) - Oxidation ditch equipment (brush aerators, etc.)/6; hydraulic controls/ 29.

Applications - Oxidation ditch technology is applicable in any situation where activated sludge treatment (conventional or extended aeration) is appropriate. The process cost of treatment is generally less than other biological processes in the range of wastewater flows between 0.1 and 10 Mgal/d.

Limitations - Oxidation ditches offer an added measure of reliability and performance over other biological processes but are subject to some of the same limitations that other activated sludge treatment processes face.

Performance - The average performance of 29 shallow oxidation ditch plants is summarized below:

	Effluent, mg/l			Removal, Percent		
	Winter	Summer	Annual Avg.	Winter	Summer	Annual Avg.
BOD	15.2	1.2	12.3	92	94	93
Suspended Solids	13.6	9.3	10.5	93	94	94

40 to 80 percent ammonia nitrogen removal has been achieved.

Chemicals Required - None

Residuals Generated - No primary sludge is generated. Sludge produced is less volatile due to higher oxidation efficiency and increased solids retention times.

Design Criteria - (Extended Aeration Mode)
BOD_5 Loading: 8.6 to 15 lb BOD_5/1000 ft^3 of aeration volume/d; Sludge Age: 10 to 33 d;
Channel Depth: 4 to 6 ft
Channel Geometry: 45 degree or vertical sidewalls
Aeration Channel Detention Time: 1 d

Unit Process Reliability - The average reliability of 12 shallow oxidation ditch plants is summarized below:

	Percent of Time Effluent Concentration mg/l Less Than					
	10 mg/l		20 mg/l		30 mg/l	
	TSS	BOD	TSS	BOD	TSS	BOD
Average of all plants	65	65	85	90	94	96

Environmental Impact - Solid waste, odor and air pollution impacts are similar to those encountered with standard activated sludge processes.

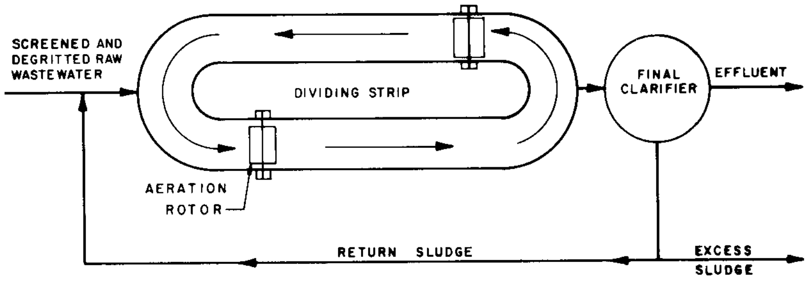
Toxics Management - The same potential for sludge contamination, upsets and pass through of toxic pollutants exists for oxidation ditch plants as standard activated sludge processes.

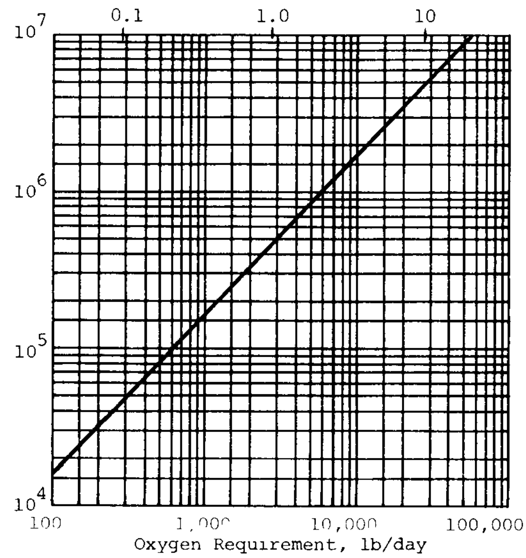
References - 7, 16, 20, 23, 110, 259

OXIDATION DITCH

FACT SHEET 2.1.15

FLOW DIAGRAM





ENERGY NOTES - Assumptions:
Energy requirement based on:

Water Quality	Influent (mg/l)	Effluent (mg/l)
BOD_5	136	20

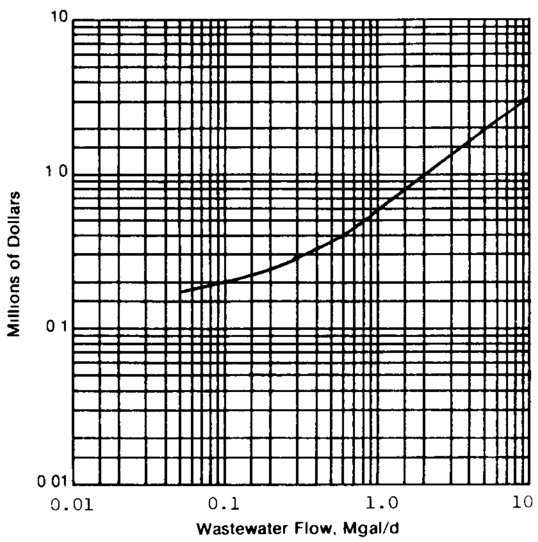
Design Assumptions -
Oxygen transfer efficiency = 1.8 lb O_2/hph (wire to water). No appreciable nitrification occurs.

Operating Parameters -
Oxygen requirement = 1.5 lb O_2/lb BOD_5 removed

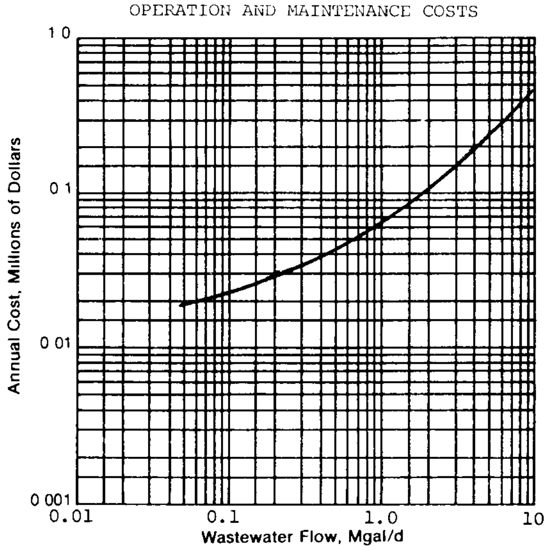
Type of Energy Required: Electrical

COSTS* - 3rd quarter 1976 dollars; ENR Index = 2445.
Assumptions: Construction cost includes oxidation ditch, clarifier, pumps, building, laboratory, out-door sludge drying beds, but excludes land, engineering, **legal and financing during construction.** O&M costs include labor, utilities, chemicals, maintenance materials.

CONSTRUCTION COSTS



OPERATION AND MAINTENANCE COSTS



REFERENCES - 4, 16

*To convert construction cost to capital cost see Table A-2.

Description - "PhoStrip" is a combined biological-chemical precipitation process based on the use of activated sludge microorganisms to transfer phosphorus from incoming wastewater to a small concentrated substream for precipitation. The activated sludge is subjected to anoxic conditions to induce phosphorus release into the substream and to provide phosphorus uptake capacity when the sludge is returned to the aeration tank. Settled wastewater is mixed with return activated sludge in the aeration tank. Under aeration, sludge microorganisms can be induced to take up dissolved phosphorus in excess of the amount required for growth. The mixed liquor then flows to the secondary clarifier where liquid effluent, now largely free of phosphorus, is separated from the sludge and discharged. A portion of the phosphorus-rich sludge is transferred from the bottom of the clarifier to a thickener-type holding tank: the phosphate stripper. The settling sludge quickly becomes anoxic and, thereupon, the organisms surrender phosphorus, which is mixed into the supernatant. The phosphorus-rich supernatant, a low volume, high concentration substream, is removed from the stripper and treated with lime for phosphorus precipitation. The thickened sludge, now depleted in phosphorus, is returned to the aeration tank for a new cycle.

Modifications - The PhoStrip process has demonstrated a compatibility with the conventional activated sludge process and appears to be compatible with modifications of it. The process can operate in various flow schemes, including full or split flow of return activated sludge through the phosphate stripper, use of an elutriate to aid in the release of phosphorus from the anoxic zone of the stripper, or returning lime-treated stripper supernatant to the primary clarifier for removal of chemical sludge.

Technology Status - This technique is a new development in municipal wastewater treatment and has been demonstrated in pilot plant and full-scale studies. Notable large scale evaluations have been conducted at Seneca Falls, New York and, more recently, Reno/Sparks, Nevada. Nearly a dozen commercial installations are reported to be in the design or construction phase now. (190)

Typical Equipment - The equipment package for this proprietary process includes phosphate stripper tanks, chemical feeders, mixers, and precipitator tanks.

Applications - This method, which involves a modification of the activated sludge process, can be used in removing phosphorus from municipal wastewaters to comply with most effluent standards. Direct chemical treatment is simple and reliable, but it has the two disadvantages of significant sludge production and high operating costs. The PhoStrip system reduces the volume of the substream to be treated, thereby reducing the chemical dosage required, the amount of chemical sludge produced, and associated costs. Lime is used to remove phosphorus from the stripper supernatant at lower pH levels (8.5 to 9.0) than normally required. The cycling of sludge through an anoxic phase may also assist in the control of bulking by the destruction of filamentous organisms to which bulking is generally attributed.

Limitations - More equipment and automation, along with a greater capital investment, are normally required than for conventional chemical addition systems. Since this method relies on activated sludge microorganisms for phosphorus removal, any biological upset that hinders uptake ability will also affect effluent concentrations. It has been found that sludge in the stripper tank is very sensitive to the presence of oxygen. Anoxic conditions must be maintained for phosphorus release to occur.

Performance - Pilot and full-scale studies of the process have shown it to be capable of reducing the total phosphorus concentration of typical municipal wastewaters to 1 mg/l or less. A plant-scale evaluation of the method treating 6 Mgal/d of municipal wastewater at the Reno/Sparks Joint Water Pollution Control Plant in Nevada demonstrated satisfactory performance for achieving greater than 90 percent phosphorus removal. Results showed that the process enhanced the overall operation and performance of the activated sludge process, since it produced a more stable, better settling sludge. (191)

Chemicals Required - Lime (CaO).

Residuals Generated - Chemical sludge containing hydroxyapatite is formed from lime treatment.

Design Criteria - The fraction of the total sludge flow which must be processed through the stripper tank is determined by the phosphorus concentration in the influent wastewater to the treatment plant and the level required in the treated effluent. Required detention time in the stripper tank ranges from five to fifteen hours. Typical phosphorus concentrations produced in the stripper are in the range of 40 to 70 mg/l. The volume of the phosphorus-rich supernatant stream to be lime treated is 10 to 20 percent of the total flow.

Process Reliability - As yet, the process has not been evaluated over a long period of time. Regular maintenance of mechanical equipment, including pumps and mixers, is necessary to ensure proper functioning of entire system.

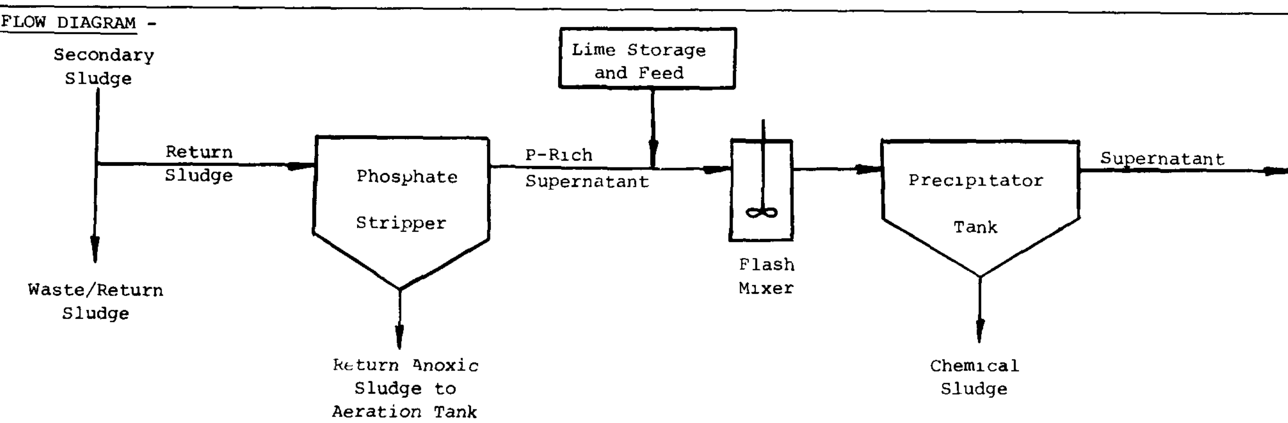
Environmental Impact - Controlling the discharge of phosphorus can arrest eutrophication of receiving waters. Less chemical sludge requiring disposal is produced than from other phosphorus removal methods.

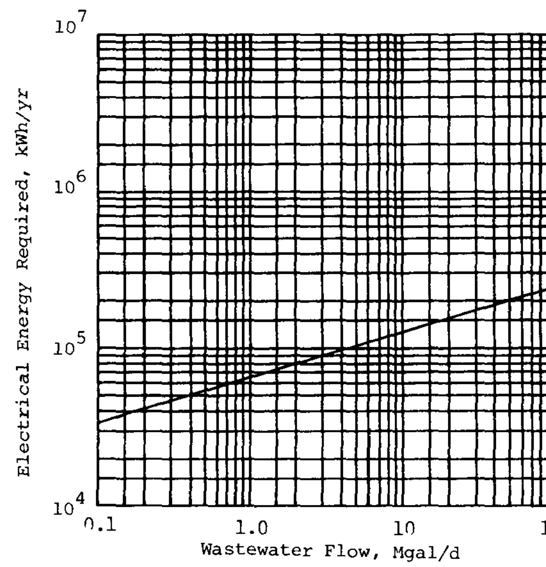
References - 188-193

PHOSTRIP

FACT SHEET 2.1.17

FLOW DIAGRAM -





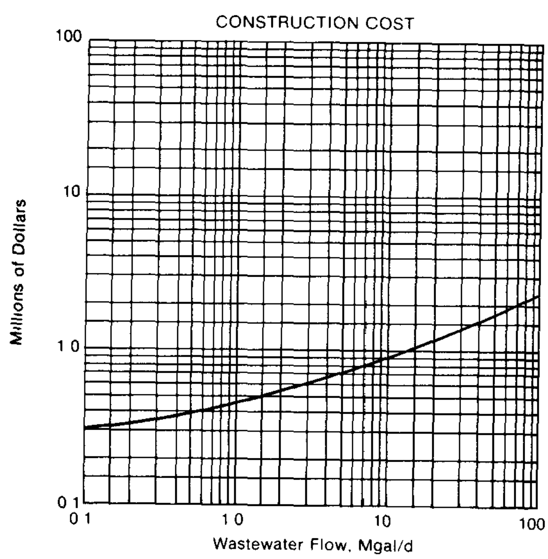
ENERGY NOTES - Assumptions: Power required for operation of pumps, lime mixing equipment and clarifiers.

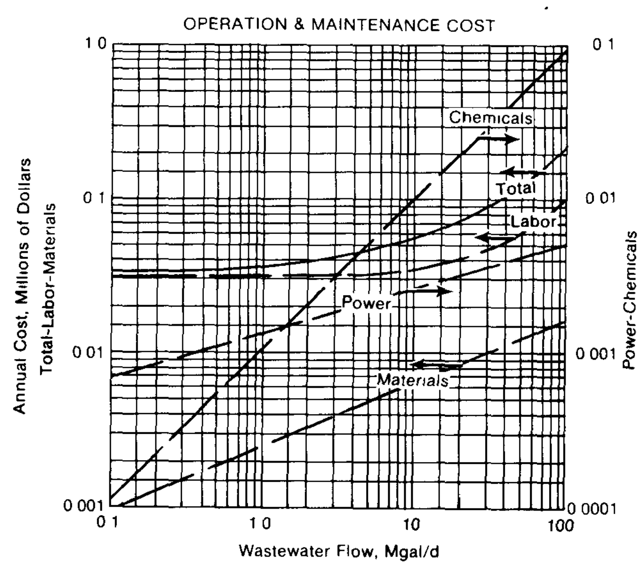
COSTS* - Assumptions:

ENR Index = 2475
Service Life: 40 years

1. Construction costs include: stripper (10 h detention time at 50% of return sludge); flash mixer; flocculator-clarifier; thickeners; lime feed and storage facilities.

2. Operation and maintenance costs include: labor for operation, preventive maintenance, and minor repairs at $7.50/h, including benefits; materials to include replacement parts and major repair work; lime cost based on $25/ton and 225 lb/Mgal; power cost at $0.02/kWh.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

BIOLOGICAL CONTACTORS, ROTATING (RBC) FACT SHEET 2.2.1

Description - The process is a fixed film biological reactor consisting of plastic media mounted on a horizontal shaft and placed in a tank. Common media forms are disc type made of styrofoam and a denser lattice type made of polyethylene. While wastewater flows through the tank, the media are slowly rotated, about 40% immersed, for contact with the wastewater for removal of organic matter by the biological film that develops on the media. Rotation results in exposure of the film to the atmosphere as a means of aeration. Excess biomass on the media is stripped off by rotational shear forces and the stripped solids are maintained in suspension by the mixing action of the rotating media. Multiple staging of RBC's increases treatment efficiency and could aid in achieving nitrification year round. A complete system could consist of two or more parallel trains with each train consisting of multiple stages in series.

Common Modifications - Multiple staging; use of dense media for latter stages in train; use of molded covers or housing of units; various methods of pretreatment and after treatment of wastewater; use in combination with trickling filter or activated sludge processes; use of air driven system in lieu of mechanically driven system; addition of air to the tanks; addition of chemicals for pH control; and sludge recycle to enhance nitrification.

Technology Status- The process has only been in use in the United States since 1969 and thus is not yet in widespread use in this country. However, because of its characteristic modular construction, low hydraulic head loss and shallow excavation, which make it adaptable to new or existing treatment facilities, its use is growing.

Application - Treatment of domestic and compatible industrial wastewater amenable to aerobic biological treatment in conjunction with suitable pre and post treatment. Can be used for nitrification, roughing, secondary treatment and polishing.

Limitations - Can be vulnerable to climatic changes and low temperatures if not housed or covered. Performance may diminish significantly at temperatures below 55°F. Enclosed units can result in considerable wintertime condensation if heat is not added to the enclosure. High organic loadings can result in first stage septicity and supplemental aeration may be required. Use of dense media for early stages can result in media clogging. Alkalinity deficit can result from nitrification; supplemental alkalinity source may be required.

Typical Equipment/No. Mfrs. (10) - Rotating Disc Systems/5

Performance - Four stage system with final clarifier and preceded by primary treatment (percent removal).

BOD_5, 80-90% SS, 80-90% Phosphorus, 10-30% NH_4-N, Up to 95%*

*Dependent upon temperature, alkalinity, organic loading, and unoxidized nitrogen loading.

Residuals Generated - Sludge in the secondary clarifier. 3000 to 4000 gal sludge/Mgal wastewater, 500 to 700 lb dry solids/Mgal wastewater.

Design Criteria -
Organic Loading - Without nitrification - 30 to 60 lb BOD_5/d/1000 ft^3 media, with nitrification - 15 to 20 lb BOD_5/d/1000 ft^3 media
Hydraulic Loading - Without nitrification - 0.75 to 1.5 gal/d/ft^2 of media surface area, with nitrification - 0.3 to 0.6 gal/d/ft^2 of media surface area
Number of stages per train - 1-4 depending upon treatment objectives
Number of parallel trains - Recommended at least two
Rotational Velocity - Peripheral velocity = 60 ft/min for mechanically driven, 30-60 ft/min for air driven
Typical media surface area - Disc type - 20-25 ft^2/ft^3, standard lattice type - 30-40 ft^2/ft^3; high density lattice - 50-60 ft^2/ft^3
Percent media submerged - 40%
Tank volume = 0.12 gal/ft^2 of disc area
Detention time based on 0.12 gal/ft^2 - Without nitrification - 40-120 minutes, with nitrification - 90-250 minutes
Secondary clarifier overflow rate - 500-800 gal/d/ft^2
HP - 3.0-5.0 consumed/25 ft shaft; 5-7.5 connected/25 ft shaft

Process and Mechanical Reliability - Moderately reliable in absence of high organic loading and temperatures below 55°F. Mechanical reliability is generally high provided first stage of system is designed to hold large biomass. Dense media in first stage can result in clogging and structural failure.

Toxics Management - Little data exists concerning removal of toxics by this process. As with any fixed film process, this process is presumably sensitive to variable inputs of toxics. Treatability studies are advisable to determine degree of toxics removal.

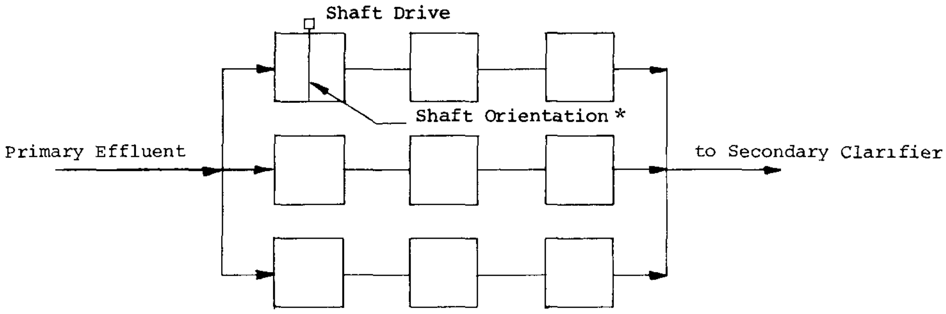
Environmental Impact - Negative impacts have not been documented. Presumably, odor can be a problem if septic conditions develop in the first stage.

References - 3, 4, 22, 28, 54, 60, 61, 62, 63, 233

BIOLOGICAL CONTACTORS, ROTATING, (RBC) FACT SHEET 2.2.1

FLOW DIAGRAM -

TYPICAL STAGED RBC CONFIGURATION



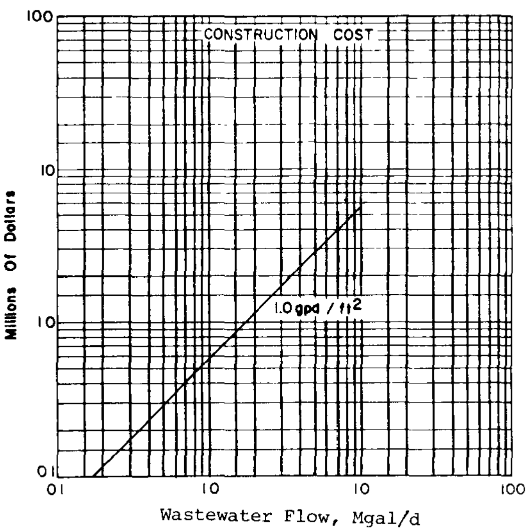
*Alternate shaft orientation is parallel to direction of flow with a common drive for all the stages in a single train.

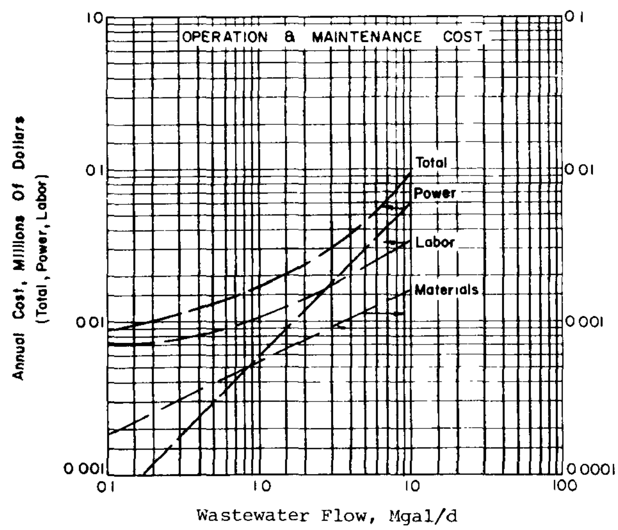
ENERGY NOTES - Approximate drive energy for operating the contactors can be determined from the following relationship:

kWh/yr= K x(Effective surface area of the biological contactor)
where K is 0.3 for standard media and 0.2 for dense media.

COSTS** - Assumptions: (ENR Index = 2475)

1. Construction cost includes RBC shafts (standard media, 100,000 ft^2/shaft), motor drives (5 hp/shaft), molded fiberglass covers, and reinforced concrete basins.
2. Cost does not include primary and secondary clarifiers.
3. Loading rate - 1.0 gal/d/ft^2.
4. Treatment is for carbonaceous oxidation.





REFERENCES - 3, 4

**To convert construction cost to capital cost see Table A-2.

DENITRIFICATION FILTER, COARSE MEDIA — FACT SHEET 2.2.2

Description and Common Modifications - During denitrification, nitrates and nitrites are reduced to nitrogen gas through the action of facultative heterotrophic bacteria. Coarse media denitrification filters are attached growth biological processes in which nitrified wastewater is passed through submerged beds containing natural (gravel or stone) or synthetic (plastic) media. The systems may be pressure or gravity. Minimum media diameter is about 15 mm. Anaerobic or near anaerobic conditions are maintained in the submerged bed, and since the nitrified wastewater is usually deficient in carbonaceous materials a supplemental carbon source (usually methanol) is required to maintain the attached denitrifying slime. Because of the high void percent and low specific surface area characteristic of high porosity coarse denitrification filters, biomass (attached slime) continuously sloughs off. As a result, the coarse media column effluent is usually moderately high in suspended solids (20-40 mg/l), requiring a final polishing step. (See Fact Sheet 2.2.3 on fine media denitrification filters.)

A wide variety of media types may be used as long as high void volume and low specific volume are maintained. Both dumped plastic media and corrugated sheet media have been used. Backwashing is infrequent and is usually done to control effluent suspended solids rather than pressure drop. Alternate energy sources such as sugars, volatile acids, ethanol, or other organic compounds, as well as nitrogen deficient materials such as brewery wastes may be used. Nitrogen gas filled coarse media denitrification filters are a possible modification. See Fact Sheet 2.1.9 for information on suspended growth denitrification systems.

Technology Status - Well developed at full scale, but not in widespread use.

Typical Equipment/No. of Mfrs. (23) - Filter Equipment/35; Controls/29; Instrumentation/9; Chemical Feed Equipment/25; Clarifier Equipment/38.

Applications - Used almost exclusively to denitrify municipal wastewater that has undergone carbon oxidation and nitrification. May also be used to reduce nitrate in industrial wastewater.

Limitations - Specifically acts on nitrate and nitrite, will not affect other forms of nitrogen.

Performance - Capable of converting nearly all nitrate in a nitrified secondary effluent to gaseous nitrogen. Overall nitrogen removals of 70-90 percent are achievable.

Chemicals Required - The amount of the most common energy source, methanol, required may be estimated using the following values per mg/l of the material in the inlet to the process.

mg/l CH_3OH	per	mg/l of
2.47		NO_3-N
1.53		NO_2-N
0.87		D.O.

Residuals Generated - With controlled supplemental carbon feed rates, little excess sludge is generated. Sludge production 0.6-0.8 lb/lb NH_3-N reduced.

Design Criteria (28, 204) - Optimum pH$_2$- 6.5 to 7.5. Voids - 70 to 96 percent. Specific surface - 65 to 274 ft^2/ft^3. Loading Rate lb NO_3-N rem/ft^2 packing surface/d is a function of temperature up to 0.5 x 10^{-4} at $5^{o}C$, 0.2 to 0.8 X 10^{-4} at $15^{o}C$ and 0.8 to 1.3 X 10^{-4} at $25^{o}C$. Surface loading rate of 2.5 and 4.1 gal/ft^2/d for a flow of 0.3 and 0.5 Mgal/d respectively have been found to apply at El Lago, Texas facility.

Unit Process Reliability - Under controlled pH, temperature, loading and chemical feed high levels of reliability are achievable. Less operator attention required than with fine media systems.

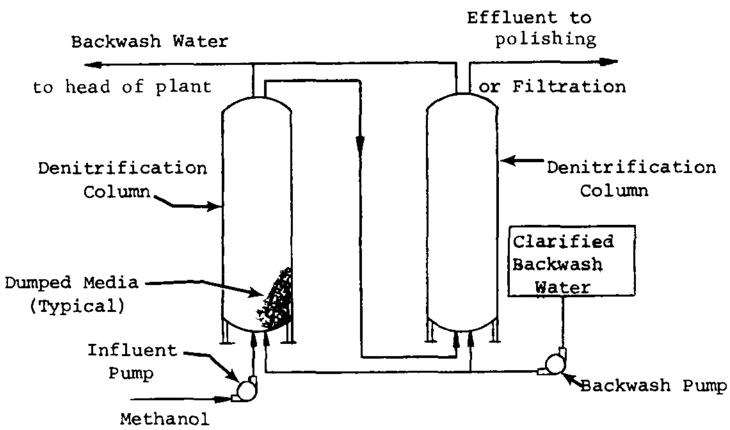
Environmental Impact - Reduction of nitrogen loading on streams; less land requirement than suspended growth system.

References - 7, 23, 28, 45, 95, 204

DENITRIFICATION FILTER, COARSE MEDIA

FACT SHEET 2.2.2

FLOW DIAGRAM -



ENERGY NOTES - Pumping energy can be computed from the following equation:

$$kWh/yr = \frac{1140\ (Mgal/d\quad X\ ft\ of\ total\ average\ head}{wire\ to\ water\ efficiency}$$

For a 0.5 Mgal/d plant treating 14 mg/l of NO_3-N two 10-ft diameter by 10-ft deep tanks would be required. Therefore, using 15 ft of total head and a wire to water efficiency of 0.60, 14,250 kWh will be required for wastewater pumping.

Backwashing at a rate of 20 gal/min/ft^2 once a month for four hours would require an additional energy consumption of 1425 kWh/yr.

Upflow and downflow operations consume roughly the same amount of energy.

COSTS* - Assumptions: Mid 1972 costs; ENR Index = 1761. For an 0.5 Mgal/d plant treating 14 mg/l NO_3-N, two 10-ft diameter by 10-ft deep tanks would be required. Construction costs for such a system would be approximately $200,000 (28).

Operation and maintenance costs would be as follows:

Item		O/M Costs per 1000 gal Treated
Chemicals (Methanol)		$0.03
Labor at $5/h		0.03
	Total	$0.06/1000 gal

*To convert construction cost to capital cost see Table A-2.

REFERENCES - 4, 28, 204

DENITRIFICATION FILTER, FINE MEDIA — FACT SHEET 2.2.3

Description - In the denitrification process, nitrates and nitrites in nitrified wastewater are converted to nitrogen gas by the action of facultative heterotrophic bacteria. The fine media denitrification filter is an attached growth biological process in which nitrified wastewater is passed through a pressurized submerged bed of sand or other fine filter media (up to about 15 mm in diameter) in which anoxic conditions are maintained. The nitrified wastewater contains very little carbonaceous material, and consequently requires a supplemental energy source (usually methanol) to maintain the attached denitrifying slime. Because of the relatively fine media used, physical filtration analogous to that occuring in a pressure filter takes place. As a result, a clear effluent is produced, eliminating the need for final clarification. Backwashing is required to maintain an acceptable pressure drop. Surface loading rates may be somewhat lower than those common for pressure filtration. Development of the denitrifying slime, and consequent denitrification efficiency are a function of the specific surface area of the filter, and in practice fine media denitrification filters convert nitrates to nitrogen gas at a much higher rate than suspended growth systems. The coarser the media, the less frequent the backwashing, although the effluent may be more turbid. (See Fact Sheet 2.2.2 on coarse media denitrification filters.)

Common Modifications - Common modifications include the use of various media such as garnet sand, silica sand or anthracite coal with varying size distributions. Multimedia systems have also been used. Alternate energy sources such as sugars, volatile acids, ethanol or other organic compounds as well as nitrogen deficient materials such as brewery wastewater may be used. An air scour may be incorporated into the backwashing cycle; however, temporary inhibition of denitrification may result. Various types of underdrains may be used. A bumping procedure (short periodic flow reversals) has been used to remove entraped nitrogen gas bubbles produced during denitrification. Denitrification may be combined with refractory organic removal. Upflow systems utilizing fine media (sand or activated carbon) have been operated as fluidized bed reactors.

Technology Status - Well demonstrated but not in widespread use.

Typical Equipment/No. of Mfrs. (23) - Filter Equipment/35; Controls/29; Instrumentation/9; Chemical Feed Equipment/25.

Applications - Used almost exclusively to denitrify municipal wastewaters that have undergone carbon oxidation and nitrification. May also be used to reduce nitrate in industrial wastewater.

Limitations - Specifically acts on nitrate and nitrite and will not affect other forms of nitrogen.

Performance - Capable of converting nearly all nitrate and nitrite in a nitrified secondary effluent to gaseous nitrogen. Overall nitrogen removals of 75-90 percent are achievable. Suspended solids removals of up to 93 percent have been achieved.

Chemicals Required - An energy source is commonly supplied in the form of methanol. Methanol feed concentrations may be estimated using the following values per mg/l of the material at the inlet to the process.

mg/l CH_3OH	per	mg/l of
2.47		NO_3-N
1.53		NO_2-N
0.87		D.O.

Residuals Generated - If supplemental energy feed rates are controlled, little excess sludge is generated.

Design Criteria (28) -

Flow Scheme	Downflow (although upflow systems with different design criteria have been utilized (28))
Optimum pH	6.5-7.5
Surface Loading Rates, gal/min/ft^2	0.5-7.0
Media Diameter (d_{50}) mm	2-15
Column Depth, ft	3-20 (function of specific surface ft^2/ft^3 and contact time) (28)
Backwash Rate, gal/min/ft^2	8-25
Backwash Cycle Frequency, d	0.5-4.0
Specific Surface ft^2/ft^3	85-300
Voids, %	40-50

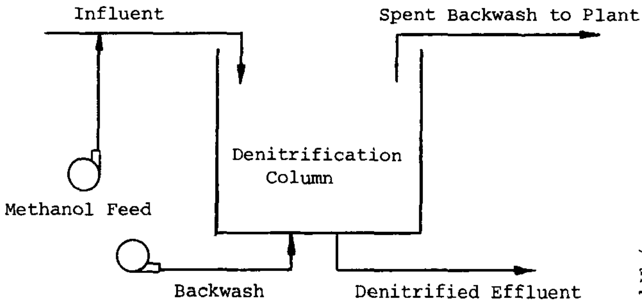
Unit Process Reliability - Under controlled pH, temperature, loading and chemical feed high levels of reliability are achievable.

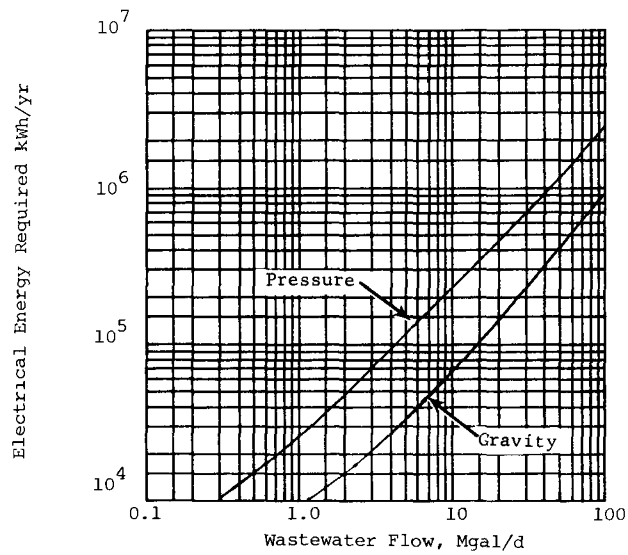
Environmental Impact - High nitrogen removal efficiency; smaller structures (land use) than suspended growth systems.

References - 7, 23, 28, 45, 95

DENITRIFICATION FILTER, FINE MEDIA — FACT SHEET 2.2.3

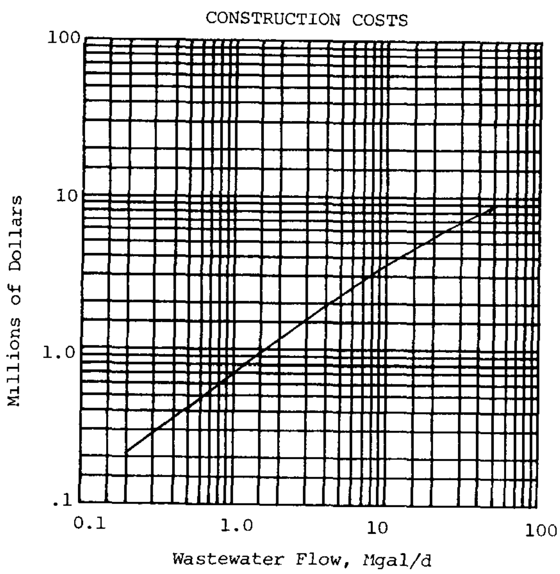
FLOW DIAGRAM -





ENERGY NOTES (4) - Assumptions:

1. Influent NO_3-N = 25 mg/l; effluent = 0.5 mg/l
2. Media size = 2 - 4mm
3. Temperature is 15°C
4. Methanol feed rate = 3:1 ($CH_3OH:NO_3$-N)
5. Loading rate = 1.7 gal/min/ft^2
6. Depth = 6 ft
7. Backwash for 15 min @ 25 gal/min/ft^2 and 25 ft TDH once per 2 d for pressure and daily for gravity system.



COSTS* (204) - Assumptions: 1975 prices ; ENR Index = 2212

OPERATION AND MAINTENANCE COSTS: For a 0.5 Mgal/d plant treating 14 mg/l NO_3-N operation and maintenance costs would be as follows:

Item	O/M Costs per 1,000 gal Treated
Chemicals (methanol @ $0.58/gal)	$0.03
Labor at $5/h	0.04
Total	$0.07

Note: Labor includes normal maintenance and daily backwash.

REFERENCES - 4, 28, 204

*To convert construction cost to capital cost see Table A-2.

INTERMITTENT SAND FILTRATION, LAGOON UPGRADING — FACT SHEET 2.2.4

Description - The intermittent sand filter is an outdoor, gravity, filtration system that capitalizes on the availability of land area. It is a biological and physical wastewater treatment mechanism consisting of an underdrained bed of granular material, usually sand. The filter surface is flooded intermittently with lagoon effluent at intervals which permit the surface to drain between applications. It is recommended that the flow be directed to one filter for 24 hours. That filter is then allowed to drain and dry for one to two days, and the flow goes to an adjacent filter. It is preferable to have three filter beds where good operation and treatment may be accomplished over a three-day cycle.

The filter contains drainage pipes that are laid with open joints at depths of 3 to 4 ft and surrounded with layers of coarse stone and gravel graded from coarse to fine to keep sand out. When the filter is located in natural sand deposits, the percolating waters may reach the groundwater table, and no effluent may come to view. In areas where percolation to the groundwater is not permitted, the filter must be provided with an impermeable base or lining. Influent wastewater is piped to the beds for discharge into a protective stone or concrete apron or into a concrete flume distributor. Surface accumulations of solids are periodically removed and disposed of as fill or by some other means. Filters must be resanded when they become too shallow as a result of the periodic surface cleaning. In cold weather the beds are plowed into ridges and furrows (1 to 1.5 ft deep) to keep them from freezing and opening up cracks through which the applied wastewater can escape with little treatment. To form protective sheets of ice spanning the furrows and keep the beds warm, furrowed beds are dosed deeply on cold nights.

Common Modifications - Continuous application; series application where effluent is applied to filter beds of progressively smaller size; e.g., #1 e.s. = 0.72 mm, #2 e.s. = 0.40 mm, #3 e.s. = 0.17 mm.

Technology Status - Practiced for many years where land is available; proven performance; current emphasis on development of scientific basis and optimum design criteria through pilot research and demonstration activities.

Typical Equipment - Piping; graded sand and gravel.

Applications - Polishing of domestic wastewater stabilization pond effluent; also for final treatment of biodegradable industrial wastewater stabilization pond effluent; where minimum maintenance is required.

Limitations - High land requirements; unsuitable for anaerobic lagoon effluents; suitable for aerated lagoons if aerated lagoons followed by facultative lagoon.

Performance (12) -

Filter effluent quality (treatment of domestic wastewater stabilization pond):
BOD_5, mg/l - less than 10.
SS, mg/l - less than 10.
Nitrogen - nearly complete nitrification except during winter when cold temperatures can retard nitrification.
Phosphorus - negligible removal

Residuals Generated (12) - For an average loading of 500,000 gal/acre/d (490,000 m^3/m^2.d) the filters would operate approximately 30 to 60 days before cleaning would be required. Therefore, it might be expected that two to three inches of surface material will need to be disposed of after 30 to 60 days of operation. Disposal is usually to landfill.

Design Criteria (39) -

Filter drain - open joint or perforated tiles, at least 4 inches, laid on impervious layer.
Sand depth - 30 to 36 inches (0.75 to 0.90 m)
Sand characteristics - graded, effective size between 0.15 to 0.75 mm.
Loading rate (24 h application), 400,000 to 600,000 gal/acre/d

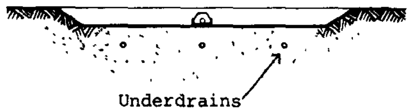
Process Reliability - Highly reliable; requires minimal operator attention.

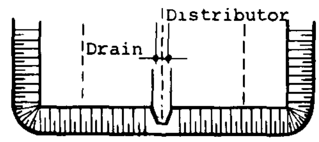
Environmental Impact - Land area requirements are great; odor potential exists; public acceptance may be difficult due to potential adverse effects to surrounding land uses.

References - 12, 14, 39, 133, 137, 149

INTERMITTENT SAND FILTRATION, LAGOON UPGRADING | FACT SHEET 2.2.4

FLOW DIAGRAM





ENERGY NOTES - Assuming influent pumping requirements of 30 ft TDH and pumping operation of 3 h/d, with gravity discharge, an energy requirement of 35,000 kWh will be required per Mgal/d.

COSTS (137) - Costs for this process are particularly site specific due to the land requirements. Generalized cost curves are therefore not available. Presented below is a capital cost estimate for a particular application where influent pumping and impervious lining are required. November 1974 dollars. ENR = 2094.

Single intermittent filters (duplicate facilities).

Design flow rate: 0.5 Mgal/acre/day
Locally available sand: 0.17 mm effective size @ 30 inch bed depth (760 mm)

Initial Construction Cost (in place):

	Quantity	Unit Cost	Total Cost
Granular media (sand)	6,250 yd^3	$ 4.40	$27,500
Gravel	2,220 yd^3	$ 4.40	$ 9,770
6 inch lateral drains (10 ft spacing)	7,380 ft	$ 1.00	$ 7,380
Ductile iron pipe	500 ft	$ 9.50	$ 4,750
Pumps (3 h application, 1 pump for each filter, plus 1 standby, 2 800 gal/min and timer, 30 ft TDH)	3	$3,200.00	$ 9,600
Excavation and embankment (Slopes 3:1 interior, 2:1 exterior; line with clay type impervious material; 10 ft wide at top of dike)	13,828 yd^3	$ 1.00	$13,830
Building	1	$2,000.00	$ 2,000
Distribution system	2	$1,000.00	$ 2,000
Pipe distribution	1000 ft	$ 2.00	$ 2,000
Land	6 acres	$1,000.00	$ 6,000

Total Capital Cost $84,830

Annual Operating and Maintenance Costs

Maintenance cost:	$1,000/yr
Manpower cost: (at $10,000/yr)	4,500
Power: 22 hp or 16 kW	3,500
16 kW (3 h/d) (365 d/yr) = 17,520 kWh/yr	
17,520 kWh/yr X $0.03/kWh	526
Total Operating and Maintenance Costs	$9,526/yr

REFERENCE - 137

Description (173) - The rock filter, as an alternative for the removal of algae from lagoon effluents, consists of a submerged bed of rocks (5 to 20 cm diameter) through which the lagoon effluent is passed vertically or horizontally, allowing the algae to become attached to the rock surface and thereby be removed. The basic simplicity of operation and maintenance are the key advantages of this process. The effluent quality achievable and the dependability of long-term operation, however, have not yet been proven.

This fact sheet is based upon a full-scale rock filter which was designed and constructed as part of a lagoon expansion and upgrading project at Veneta, Oregon in 1975. The system treats wastewater from a population of approximately 2200 with no industrial wastewater contribution. The lagoon effluent enters the bottom of the filter through an influent channel. The lagoon effluent then rises from the influent channel and moves horizontally toward the discharge weirs where it flows into a covered effluent channel. Finally, the flow from each side of the rock filter is combined, chlorinated, and discharged. The rock surface is approximately 0.30 m (1.0 ft) above the water elevation to prevent growth of algae on the rock filter.

Common Modifications - Not applicable; only one plant in operation.

Technology Status - Experimental stage of development.

Application - Polishing of domestic wastewater stabilization pond effluent; also for final treatment of biodegradable industrial wastewater stabilization pond effluent; where low maintenance is required.

Limitations - Effluent quality and operational dependability are not yet proven.

Performance - The following table is a summary of performance data for the demonstration filter at Veneta, Oregon:

	Weekly Averages													
Parameter	Wk. 1		Wk. 2		Wk. 3		Wk. 4		Wk. 5		Wk. 6		Wk. 7	
	I*	E*	I	E	I	E	I	E	I	E	I	E	I	E
DO (mg/l)	10.1	4.5	15.4	6.2	11.2	3.2	10.8	3.0	10.8	3.2	17.4	2.9	6.9	1.8
TSS (mg/l)	42	9	29	14	28	10	22	9	44	7	43	9	105	10
BOD_5 (mg/l)	20	9	27	14	20	10	21	15	39	19	42	18	43	11
COD (mg/l)	121	77	67	45	51	36	61	44	147	80	159	104		
NH_4^+-N (mg/l)	0.8	1.7	3.5	2.9	15.5	12.4	15.9	14.3	3.8	5.5	2.6	7.2	0.2	3.5
Org-N (mg/l)	4.1	3.4	5.8	5.4	5.7	1.4	3.9	3.3	8.8	4.5	8.4	5.2		
NO_3^--N (mg/l)	1.5	2.1	1.0	1.6	0.8	1.1	1.1	0.8	1.7	1.5	2.3	1.0	1.9	1.2
Soluble P (mg/l)	4.8	3.9	1.7	1.6	2.5	3.1	2.1	3.5	6.0	4.6	3.7	4.9		
Total P (mg/l)	5.2	4.1	2.1	1.6	3.2	3.4	2.7	3.1	6.8	5.0	5.6	5.4		
Chlorophyll a (ug/l)	-	-	340	160	260	72	160	32	690	13	210	34		
Chlorophyll b (ug/l)	-	-	39	23	59	15	17	3	348	12	240	38		
Chlorophyll c (ug/l)	-	-	23	15	29	6	19	5	148	22	380	80		

*I = rock filter influent; *E = rock filter effluent.

Residuals Generated - Sludge accumulation and periodic clean out requirements should be anticipated.

Design Criteria - The following is a list of design data from the Veneta, Oregon facility:

Influent pump capacity, l/s (gal/min)	25 (400)
Effective surface area of the rock filter, m^2 (ft^2)	5,400 (58,000)
Effective volume, m^3 (ft^3)	8,200 (290,000)
Rock size, cm (inches)	7.6 to 15.2 (3 to 6)
Porosity, in situ average, percent	42
Hydraulic loading, m^3 water/m^3 rock filter/d	0.07 to 0.28

Process Reliability - Short-term data favorable; minimum operator attention required.

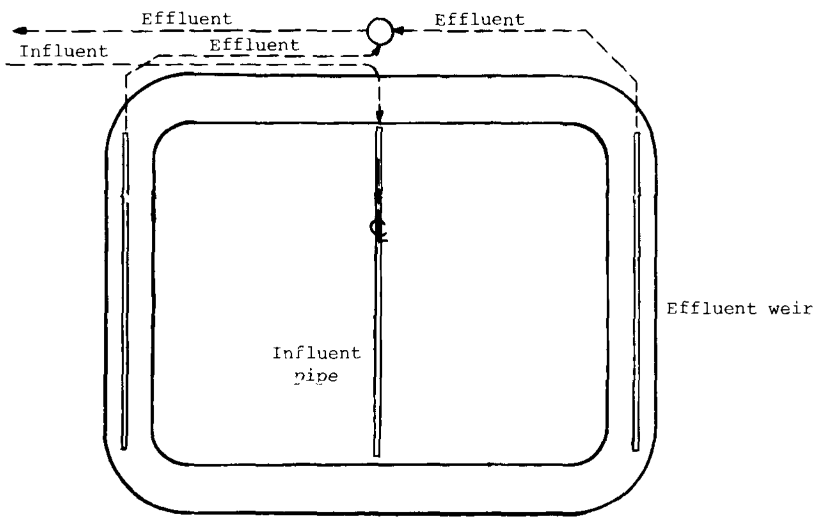
Environmental Impact - Potential odors; large land requirements

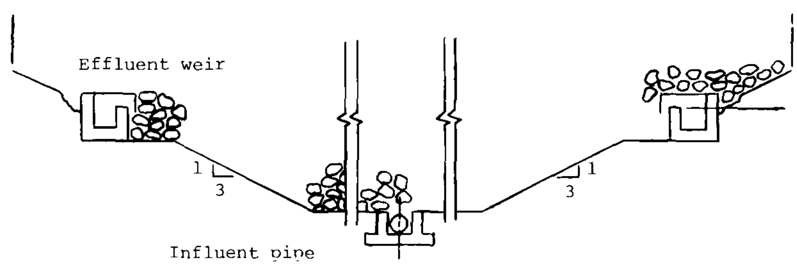
Reference - 173

POLISHING FILTER FOR LAGOON, ROCK MEDIA FACT SHEET 2.2.5

FLOW DIAGRAM

Rock Filter located at Veneta, Oregon.





PROFILE

ENERGY NOTES -
Depending on site conditions, the influent to the filter may require pumping; otherwise, there are no energy requirements. Pumping energy requirements may be approximated by using the following equation; kWhr/year= 1900 x Mgal/day x discharge head ft., assuming a wire to water efficiency of 60%. For the typical head requirements of 6 ft. for this process, an energy requirement of 11,400 kWhr/year/Mgal/day can be expected.

COSTS (177) -
There are no generalized cost data for the rock filter. The best data presently available is on the Veneta, Oregon facility, which is currently the only such filter in operation. This facility was constructed in 1976 at a cost of 11¢ per gal/d of design capacity. It is estimated that with a design flow of 300 gal/min, the filter cost was $47,500. In terms of generalized costs, it may also be estimated that the rock media present-day cost (1978) is $8/yd^3, ENR Index = 2776

REFERENCES - 173, 177

TRICKLING FILTER, PLASTIC MEDIA — FACT SHEET 2.2.6

Description - The process consists of a fixed bed of plastic media over which wastewater is applied for aerobic biological treatment. Zoogleal slimes form on the media which assimilate and oxidize substances in the wastewater. The bed is dosed by a distributor system, and the treated wastewater is collected by an underdrain system. Primary treatment is normally required to optimize trickling filter performance, whereas post-treatment is generally not required to meet secondary standards.

The rotary distributor has become the standard because of its reliability and ease of maintenance, however, fixed nozzles are often used in roughing filters. Plastic media is comparatively light with a specific weight 10 to 30 times less than rock media. Its high void space (approximately 95 percent) promotes better oxygen transfer during passage through the filter than rock media with its approximate 50 percent void space. Because of its light weight, plastic media containment structures are normally constructed as elevated towers 20 to 30 feet high. Excavated containment structures for rock media can sometimes serve as a foundation for elevated towers for converting an existing facility to plastic media.

Plastic media trickling filters can be employed to provide independent secondary treatment or roughing ahead of a second-stage biological process. When used for secondary treatment, the media bed is generally circular in plan and dosed by a rotary distributor. Roughing applications often utilize rectangular media beds with fixed nozzles for distribution.

The organic material present in the wastewater is degraded by a population of microorganisms attached to the filter media. As the microorganisms grow, the thickness of the slime layer increases. Periodically, the liquid will wash some slime off the media, and a new slime layer will start to grow. This phenomenon of losing the slime layer is called sloughing and is primarily a function of the organic and hydraulic loadings on the filter. Filter effluent recirculation is vital with plastic media trickling filters to ensure proper wetting of the media and to promote effective sloughing control compatible with the high organic loadings employed.

Common Modifications - Recirculation flow schemes, rate of recirculation, multistaging, electrically powered distributors, forced ventilation, filter covers, and use of various methods of pretreatment and post treatment of wastewater. Can also be used as a roughing filter at flow rates above 1400 gal/d/ft^2. Can be used as a separate stage nitrification process. Discussion of this application is presented in Fact Sheet 2.1.14.

Technology Status - Has been used as a modification of rock media filters for 10 to 20 years.

Applications - Treatment of domestic and compatible industrial wastewaters amenable to aerobic biological treatment. Industrial and joint wastewater treatment facilities may use the process as a roughing filter prior to activated sludge or other unit processes. Existing rock filter facilities can be upgraded via elevation of the containment structure and conversion to plastic media. Can be used for nitrification following prior (first-stage) biological treatment.

Limitations - Vulnerable to below freezing weather, recirculation may be restricted during cold weather due to cooling effects, marginal treatment capability in single stage operation. It is less effective in treatment of wastewater containing high concentrations of soluble organics. Has limited flexibility and control in comparison with competing processes, and has potential for vector and odor problems although they are not as prevalent as with low rate rock media trickling filters. Long recovery times with upsets.

Typical Equipment/No. of Mfrs. (23) - Underdrains/3; Distributors/10; Filter covers/2; Plastic media/5.

Performance - Employing the loadings listed below for secondary treatment and using a single-stage configuration with filter effluent recirculation and primary and secondary clarification (percent removal).
BOD_5 - 80 to 90 percent   Phosphorus - 10 to 30 percent NH_4-N - 20 to 30 percent   SS - 80 to 90 percent

Chemicals Required - None

Residuals Generated - Sludge is withdrawn from the secondary clarifier at a rate of 3000 to 4000 gal/Mgal of wastewater, containing 500 to 700 lb dry solids.

Design Criteria -

Hydraulic loading (with recirculation)
a. Secondary treatment - 15 to 90 Mgal/acre/d
   350 to 2050 gal/d/ft^2
b. Roughing - 60 to 200 Mgal/acre/d
   1400 to 4600 gal/d/ft^2
Recirculation ratio - 0.5:1 to 5:1
Dosing interval - Not more than 15 sec (continuous)
Sloughing - continuous

Organic loading
a. Secondary treatment - 450 to 1750 lb BOD_5/d/acre ft
   10 to 40 lb BOD_5/d/1000 ft^3
b. Roughing - 4500 to 22,000 lb BOD_5/d/acre ft
   100 to 500 lb BOD_5/d/1000 ft^3
Bed Depth - 20 to 30 ft
Power requirements - 10 to 50 hp/Mgal
Underdrain minimum slope = 1%

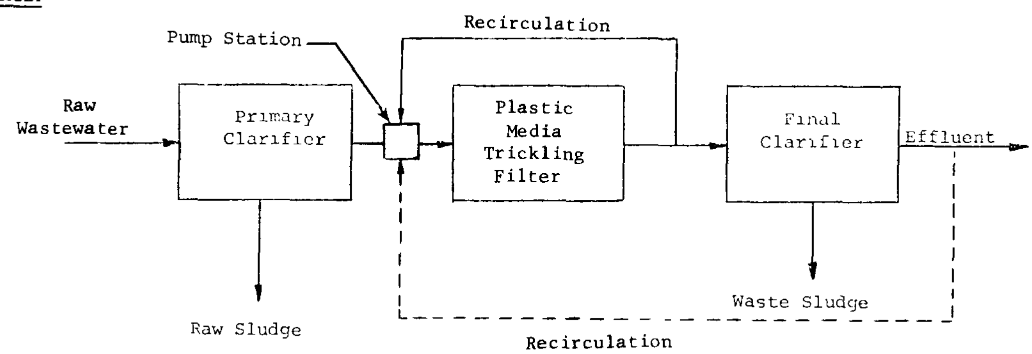
Process and Mechanical Reliability - The process can be expected to have a high degree of reliability if operating conditions minimize variability and the installation is in a climate where wastewater temperatures do not fall below 13°C for prolonged periods. Mechanical reliability is high. The process is simple to operate.

Environmental Impact - Air: Odor problems if improperly operated.

References - 7, 10, 22, 26, 27, 28, 29, 30, 31, 259

TRICKLING FILTER, PLASTIC MEDIA — FACT SHEET 2.2.6

FLOW DIAGRAM -

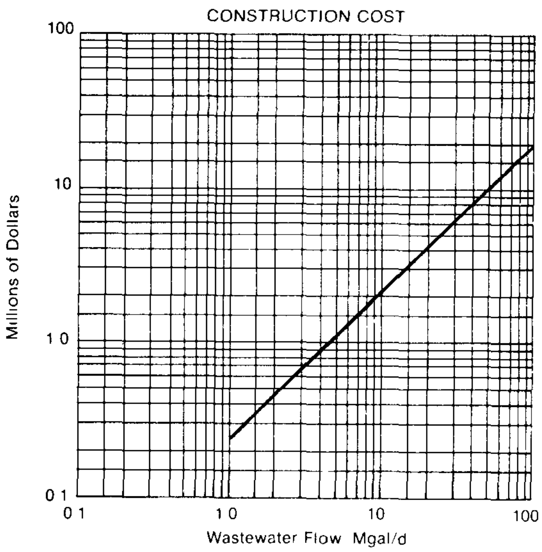


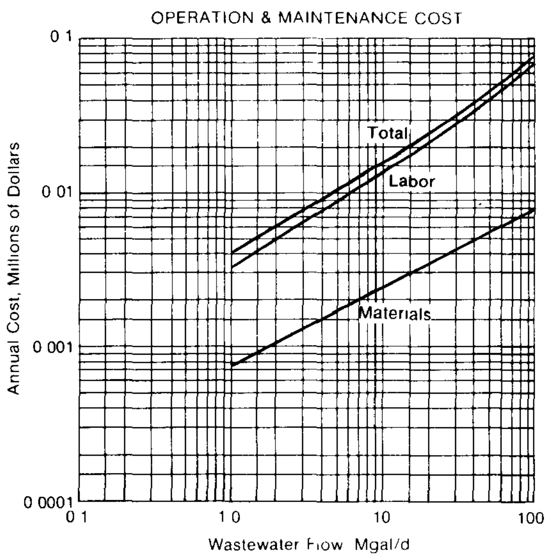
ENERGY NOTES - Pumping energy requirements may be approximated by using the following equation: kWh/yr = 1900 x Mgal/d x discharge head ft, assuming a wire-to-water efficiency of 60 percent. For the typical head requirement of 23 ft for this process, and assuming an average recirculation ratio of 2:1, an energy requirement of 131,000 kWh/yr/Mgal/d can be expected. Mgal = Influent Flow + Recirculation Flow.

Water Quality:	Filter Influent (mg/l)	Effluent (mg/l)
BOD_5	130	25
Suspended Solids	100	20

COSTS* - Assumptions: January 1979 dollars. ENR Index = 2872.

1. Construction costs shown are for carbonaceous oxidation and are based on: bed depth = 21 ft; hydraulic loading approximately 0.65 gal/min/ft^2 at an average recirculation ratio of 2:1; at organic loading = 20 lb BOD_5/1000 ft^3; concrete enclosures are precast concrete; foundations and supports are poured-in-place.
2. Construction cost includes plastic media, underdrains, distributors, and tower containment structures. Clarifiers and recirculation equipment not included.
3. Construction costs for single stage nitrification range 23-25% higher than those for carbonaceous oxidation.
4. O&M Costs shown are for carbonaceous oxidation and do not include energy requirements associated with recirculation. There is no energy requirement for the plastic media trickling filter itself.
5. Labor including fringes = $11/h.
6. O&M costs for nitrification are approximately 12-15% higher than those for carbonaceous oxidation.





REFERENCE - 259

*To convert construction cost to capital cost see Table A-2.

TRICKLING FILTER, HIGH RATE, ROCK MEDIA — FACT SHEET 2.2.7

Description - The process consists of a fixed bed of rock media over which wastewater is applied for aerobic biological treatment. Zoogleal slimes form on the media which assimilate and oxidize substances in the wastewater. The bed is dosed by a distributor system, and the treated wastewater is collected by an underdrain system. Primary treatment is normally required to optimize trickling filter performance, and post-treatment is often necessary to meet secondary standards or water quality limitations.

The rotary distributor has become the standard because of its reliability and ease of maintenance. It consists of two or more arms that are mounted on a pivot in the center of the filter. Nozzles distribute the wastewater as the arms rotate due to the dynamic action of the incoming primary effluent. Continuous recirculation of filter effluent is used to maintain a constant hydraulic loading to the distributor arms.

Underdrains are manufactured from specially designed vitrified-clay blocks that support the filter media and pass the treated wastewater to a collection sump for transfer to the final clarifier.

The filter media consists of 1- to 5-inch stone. The high rate trickling filter media bed generally is circular in plan, with a depth of 3 to 6 feet. Containment structures are normally made of reinforced concrete and installed in the ground to support the weight of the media.

The organic material present in the wastewater is degraded by a population of microorganisms attached to the filter media. As the microorganisms grow, the thickness of the slime layer increases. As the slime layer increases in thickness, the absorbed organic matter is metabolized before it can reach the microorganisms near the media face. As a result, the microorganisms near the media face enter into an endogenous phase of growth. In this phase, the microorganisms lose their ability to cling to the media surface. The liquid then washes the slime off the media, and a new slime layer will start to grow. This phenomenon of losing the slime layer is called sloughing and is primarily a function of the organic and hydraulic loadings on the filter. Filter effluent recirculation is vital with high rate trickling filters to promote the flushing action necessary for effective sloughing control, without which media clogging and anaerobic conditions could develop due to the high organic loading rates employed.

Common Modifications - Various recirculation methods, rate of recirculation, multistaging, electrically powered distributors, forced ventilation, and filter covers.

Technology Status - In widespread use since 1936. A modification of the low rate trickling filter process.

Applications - Treatment of domestic and compatible industrial wastewaters amenable to aerobic biological treatment in conjunction with suitable pre- and post-treatment. Industrial and joint wastewater treatment facilities may use the process as a roughing filter prior to activated sludge or other unit processes. The process is effective for removal of suspended or colloidal materials and is less effective for removal of soluble organics.

Limitations - Vulnerable to below freezing weather, recirculation may be restricted during cold weather due to cooling effects, marginal treatment capability in single stage operation. It is less effective in treatment of wastewater containing high concentrations of soluble organics. Has limited flexibility and control in comparison with competing processes, and has potential for vector and odor problems although they are not as prevalent as with low-rate trickling filters. Long recovery times with upsets. Limited to 60-80% BOD_5 removal.

Typical Equipment/No. of Mfrs. (23) - Underdrains/3; Distributors/10; Filter covers/2.

Performance - Single-stage configuration with filter effluent recirculation and primary and secondary clarification (percent removal).

BOD_5 - 60 to 80 percent   Phosphorus - 10 to 30 percent NH_4-N - 20 to 30 percent   SS - 60 to 80 percent

Chemicals Required - None

Residuals Generated - Sludge is withdrawn from the secondary clarifier at a rate of 2500 to 3000 gal/Mgal wastewater containing 400 to 500 lb dry solids.

Design Criteria -

Hydraulic loading (with recirculation) - 10 to 50 Mgal/acre/d
230 to 1150 gal/d/ft^2
Recirculation ratio - 0.5:1 to 4:1
Dosing interval - Not more than 15 sec (continuous)
Sloughing - continuous

Organic loading - 900 to 2600 lb BOD_5/d/acre ft
20 to 60 lb BOD_5/d/1000 ft^3
Bed Depth - 3 to 6 ft
Power requirements - 10 to 50 hp/Mgal
Underdrain minimum slope = 1 percent
Media - Rock, 1" to 5", (using square mesh screen. Must meet sodium sulfate soundness test)

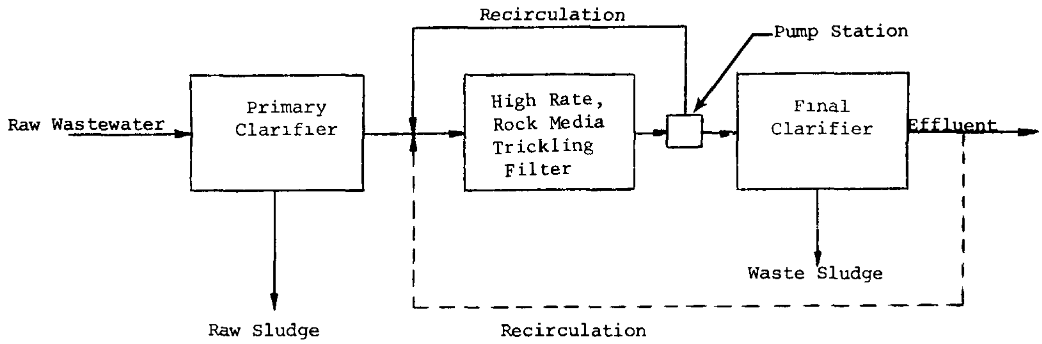
Process and Mechanical Reliability - The process can be expected to have a high degree of reliability if operating conditions minimize variability and the installation is in a climate where wastewater temperatures do not fall below 13°C for prolonged periods. Mechanical reliability is high. The process is simple to operate.

Environmental Impact - Air: Odor problems if improperly operated.

References - 7, 10, 22, 26, 27, 28, 29, 30, 31

TRICKLING FILTER, HIGH RATE, ROCK MEDIA — FACT SHEET 2.2.7

FLOW DIAGRAM -



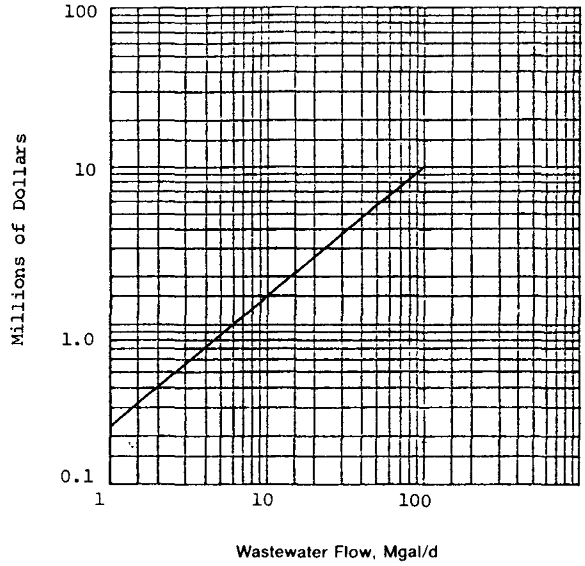
ENERGY NOTES - Pumping energy requirements may be approximated by using the following equation: kWh/yr = 1900 x Mgal/d x discharge head ft, assuming a wire-to-water efficiency of 60 percent. For the typical head requirement of 10 ft for this process and assuming an average recirculation ratio of 4:1, an energy requirement of 95,000 kWh/yr/Mgal/d can be expected. Mgal = Influent Flow + Recirculation Flow.

Water Quality:	Filter Influent (mg/l)	Effluent (mg/l)
BOD_5	130	45
Suspended Solids	100	40

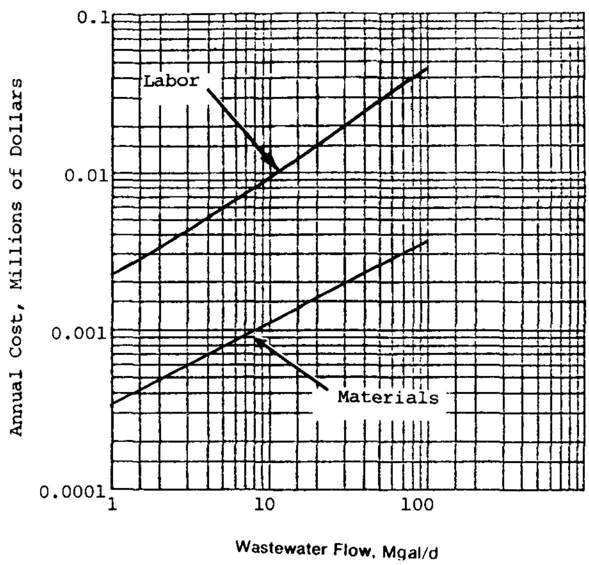
COSTS* Assumptions: ENR = 2494.

1. Construction cost (January 1977 dollars) based on: bed depth = 5 ft; organic loading = 20 lb BOD_5/d/1000 ft^3; recirculation ratio = 4.0 (@ average daily flow) to 0.4 (@ peak daily flow, assumed to equal 3.5 times average daily flow) to maintain average hydraulic loading=.75 gal/min/ft^2.
2. Cost includes rock media, underdrains, distributors, and reinforced concrete containment structures. Clarifier and recirculation equipment not included.
3. Operation and maintenance cost includes labor @ $7.50/h and materials. Does not include energy costs.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES - 207, 259

*To convert construction cost to capital cost see Table A-2.

TRICKLING FILTER, LOW RATE, ROCK MEDIA

FACT SHEET 2.2.8

Description - The process consists of a fixed bed of rock media over which wastewater is applied for aerobic biological treatment. Zoogleal slimes form on the media which assimilate and oxidize substances in the wastewater. The bed is dosed by a distributor system, and the treated wastewater is collected by an underdrain system. Recirculation is usually not used. Primary treatment is normally required to optimize trickling filter performance.

The rotary distributor has become the standard because of its reliability and ease of maintenance. In contrast to the high rate trickling filter which uses continuous recirculation of filter effluent to maintain a constant hydraulic loading to the distributor arms, either a suction-level controlled pump or a dosing siphon is employed for that purpose with a low rate filter. Nevertheless, programmed rest periods may be necessary at times because of inadequate influent flow.

Underdrains are manufactured from specially designed vitrified-clay blocks that support the filter media and pass the treated wastewater to a collection sump for transfer to the final clarifier. The filter media consists of 1- to 5-inch stone. Containment structures are normally made of reinforced concrete and installed in the ground to support the weight of the media.

The low rate trickling filter media bed generally is circular in plan, with a depth of 5 to 10 feet. Although filter effluent recirculation is generally not utilized, it can be provided as a standby tool to keep filter media wet during low flow periods.

The organic material present in the wastewater is degraded by a population of microorganisms attached to the filter media. As the microorganisms grow, the thickness of the slime layer increases. Periodically, wastewater washes the slime off the media, and a new slime layer will start to grow. This phenomenon of losing the slime layer is called sloughing and is primarily a function of the organic and hydraulic loadings on the filter.

Common Modifications - Addition of recirculation, multistaging, electrically powered distributors, forced venilation, filter covers, and use of various methods of pretreatment and post-treatment of wastewater.

Technology Status - In widespread use, this process is highly dependable in moderate climates. Use of after-treatment or multistaging has frequently been found necessary to insure uniform compliance with effluent limitations in colder regions. Being superseded by changes to plastic media systems.

Applications - Treatment of domestic and compatible industrial wastewaters amenable to aerobic biological treatment in conjunction with suitable pretreatment. This process is good for removal of suspended or colloidal materials and is somewhat less effective for removal of soluble organics. Can be used for nitrification following prior (first-stage) biological treatment or as a stand-alone process in warm climates if the organic loading is low enough.

Limitations - Vulnerable to climate changes and low temperatures, filter flies and odors are common, periods of inadequate moisture for slimes can be common, less effective in treatment of wastewater containing high concentrations of soluble organics, limited flexibility and process control in comparison with competing processes, high land and capital cost requirements, and recovery times of several weeks with upsets.

Typical Equipment/No. of Mfrs. (23) - Underdrains/3; Distributors/10; Filter covers/2.

Performance - Single-stage configuration with primary and secondary clarification and no recirculation (percent removal). BOD_5 - 75 to 90% Phosphorus - 10 to 30% NH_4-N - 20 to 40% SS - 75 to 90%

Residuals Generated - Sludge is withdrawn from the secondary clarifier at a rate of 3,000 to 4,000 gal/Mgal of wastewater, containing 500 to 700 lb dry solids.

Design Criteria -

Hydraulic Loading - 1 to 4 Mgal/acre/d; 25 to 90 gal/d/ft^2
Organic Loading - 200 to 900 lb BOD_5/d/acre ft; 5 to 20 lb BOD_5/d/1000 ft^3
Dosing interval - Continuous for majority of daily operating schedule, but may become intermittent (not more than 5 min) during low flow periods
Effluent channel minimum velocity = 2 ft/s at average daily flow
Media - Rock, 1" to 5", must meet sodium sulfate soundness test

Recirculation ratio - 0
Depth - 5 to 10 ft
Sloughing - Intermittent
Underdrain minimum slope = 1%

Process and Mechanical Reliability - Highly reliable under conditions of moderate climate. Mechanical reliability high. Process operation requires little skill.

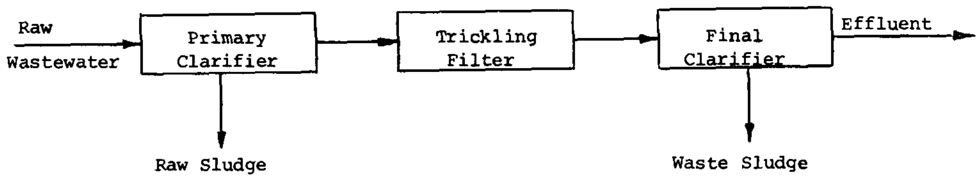
Environmental Impact - Odor problems; high land requirement relative to many alternative processes; and filter flies.

References- 7, 10, 22, 26, 27, 28, 29, 30, 31

TRICKLING FILTER, LOW RATE, ROCK MEDIA

FACT SHEET 2.2.8

FLOW DIAGRAM



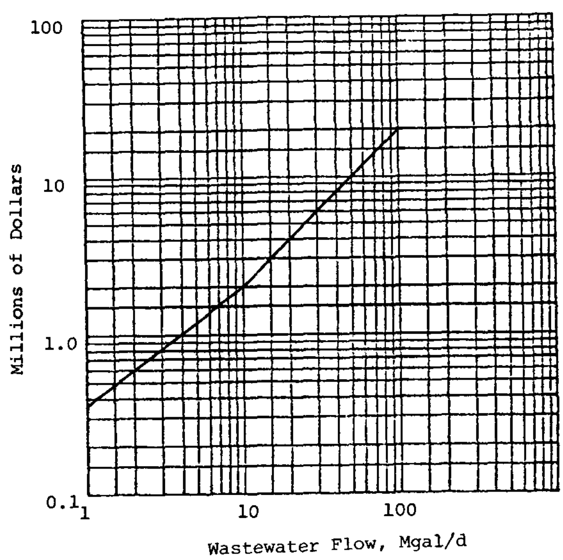
ENERGY NOTES - Assumptions: The process requires a hydraulic head for operation. Pumping energy requirements may be approximated by using the following eqution: kWh/yr = 1900 (Mgal/d) x (discharge head, ft), assuming a wire-to-water efficiency of 60 percent. For the typical head requirement of 10 ft for this process, an energy requirement of 19,000 kWh/yr/Mgal/d can be expected. Mgal = Influent flow + Recirculation flow (although recirculation flow is normally zero or intermittent).

Water Quality:	Filter Influent (mg/l)	Effluent (mg/l)
BOD_5	130	25
Suspended Solids	100	25

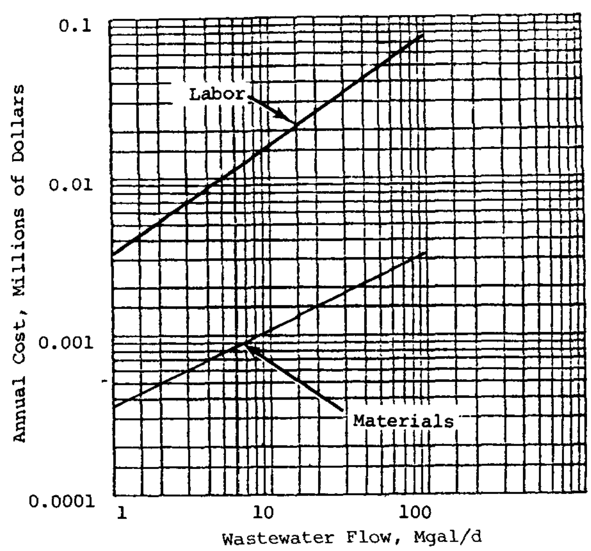
COSTS* - Assumptions: (January 1977 prices) ENR = 2494.

1. Construction cost based on: bed depth = 8 ft; organic loading = 10 lb BOD_5/d/1000 ft^3; hydraulic loading = 75 gal/d/ft^2; recirculation ratio = 0.
2. Construction cost includes reinforced concrete containment structures, rotating distributors, rock media, and underdrains. Clarifiers and recirculation equipment not included.
3. Operation and maintenance cost includes labor @ $7.50/h and materials. Does not include energy costs, if any.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCE - 207

*To convert construction cost to capital cost see Table A-2.

CLARIFIER, PRIMARY, CIRCULAR WITH PUMP — FACT SHEET 3.1.1

Description - Primary clarification involves a relatively long period of quiescence in a basin (depths of 10 to 15 ft) where most of the settleable solids fall out of suspension by gravity; a chemical coagulant may be added. The solids are mechanically collected on the bottom and pumped as a sludge underflow.

The conical bottom (1 in per ft slope) is equipped with a rotating mechanical scraper that plows sludge to a center hopper. An influent feed well located in the center distributes the influent radially, and a peripheral weir overflow system carries the effluent. Floating scum is trapped inside a peripheral scum baffle and squeegeed into a scum discharge box. The unit contains a center motor-driven turntable drive supported by a bridge spanning the top of the tank, or supported by a vertical steel center pier. The turntable gear rotates a vertical cage or torque tube, which in turn rotates the truss arms (preferably two long arms). The truss arms carry multiple flights (plows) on the bottom chord which are set at a 30^o angle of attack and literally "plow" heavy fractions of sludge and grit along the bottom slope toward the center blowdown hopper. An inner diffusion chamber receives influent flow and distributes this flow (by means of about 4-in H_2O head loss) inside of the large diameter feed-well skirt. Approximately three percent of the clarifier surface area is used for the feed well. The depth of the feed wells are generally about one-half of the tank depth. The center sludge hopper should be less than two ft deep and less than four ft^2 in cross section.

Common Modifications - Two short auxiliary scraper arms are added perpendicular to the two long arms on medium to large tanks. This makes practicable the use of deep spiral flights which aid in center region plowing where ordinary shallow straight plows (30^o angle of attack) are nearly useless. Peripheral feed systems are sometimes used in lieu of central feed. Also, central effluent weirs are used sometimes. Flocculating feed wells may also be provided if coagulants are to be added to assist sedimentation.

Technology Status - Very widely used.

Applications - Removal of readily settleable solids and floating material to reduce suspended solids content and BOD_5. Can accept high solids loading. Primary clarifiers are generally employed as a preliminary step to further processing.

Limitations - Maximum diameter is 200 ft. Larger tanks are subject to unbalanced radial diffusion and wind action, both of which can reduce efficiency. Horizontal velocities in the clarifier must be limited to prevent "scouring" of settled solids from the sludge bed and eventual escape in the effluent.

Typical Equipment/No. of Mfrs. (10) - Clarifier/35; Sludge Pumps/20

Performance - Efficiently designed and operated primary clarifiers should remove 50 to 65 percent of the TSS and 25 to 40 percent of the BOD_5 while producing an underflow sludge solids concentration of about 5 percent. Skimmings volumes rarely exceed 1.0 ft^3/Mgal.

Chemicals Required - Coagulants such as alum, ferrous sulfate and lime may be added to aid sedimentation. The dosage is determined from jar tests.

Design Criteria - Surface loading rates equal to 600 to 1200 gal/d/ft^2 for untreated wastewater; 360 to 600 for alum floc; 540 to 800 for iron floc; 540 to 1200 for lime floc. Detention times = 1.5 to 3.0 hours. Weir loadings = 10,000 to 30,000 gal/d/lin ft. Sludge collector tip speed = 10 to 15 ft/min. Heads of 2-3 ft H_2O are required to overcome losses at inlet and effluent controls and in connecting pipes. Forward velocity should be less than 9-15 times the particle settling velocity to avoid scour. Scum handling equipment should be sized for 6 ft^3/Mgal of free decanted water. Sludge pumping rates range between 2,500 to 20,000 gal/d/Mgal depending upon chemical addition and service.

Unit Process Reliability - Generally, reliability is high. However, clarification of solids into a packed central mass may cause collector arm stoppages. Attention to design of center area bottom slope, number of arms, and center area scraper blade design is required to prevent such problems.

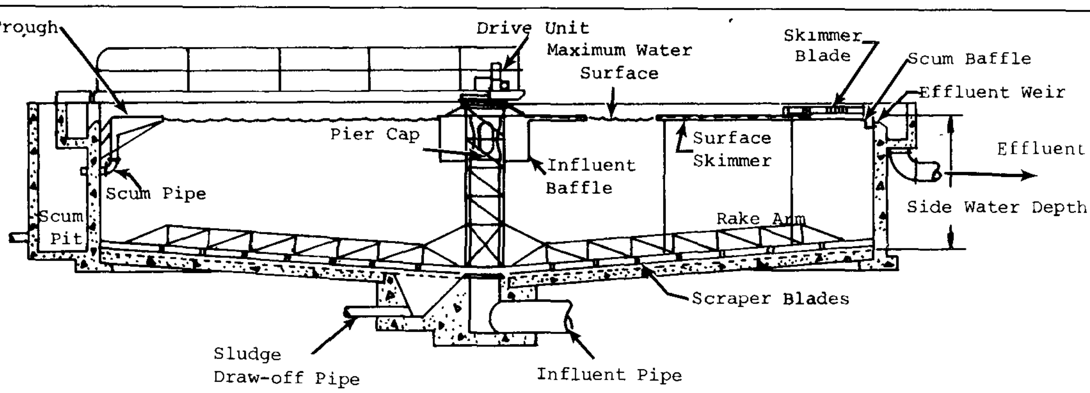
Environmental Impact - Scum on surface is a source of odors which can be controlled by masking with chemical additives and aerosols. Large land use requirement for degree of treatment imparted, even more so than rectangular units.

References - 3, 4, 7, 10, 64, 99

CLARIFIER, PRIMARY, CIRCULAR WITH PUMP

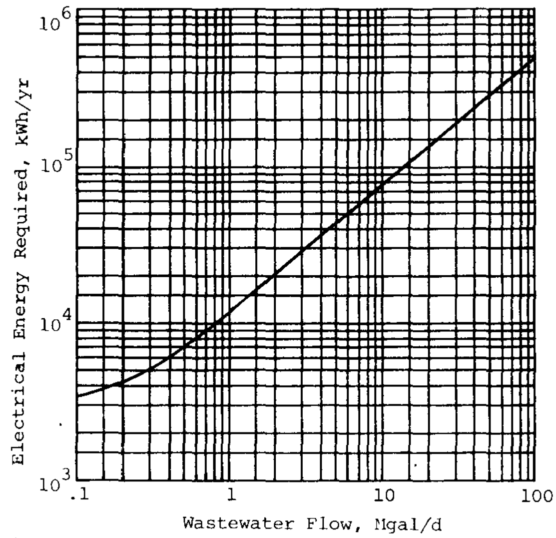
FACT SHEET 3.1.1

FLOW DIAGRAM -



ENERGY NOTES - Cost design assumptions applicable. Energy usage shown on energy curve is for sludge pumps, sludge scrapers and skimmers.

Energy required for providing the head loss of 2 to 3 ft through the clarifier can be approximated by the following equation: kWh/yr = 1625 (Mgal/d x TDH) at a wire-to water efficiency of 70 percent.

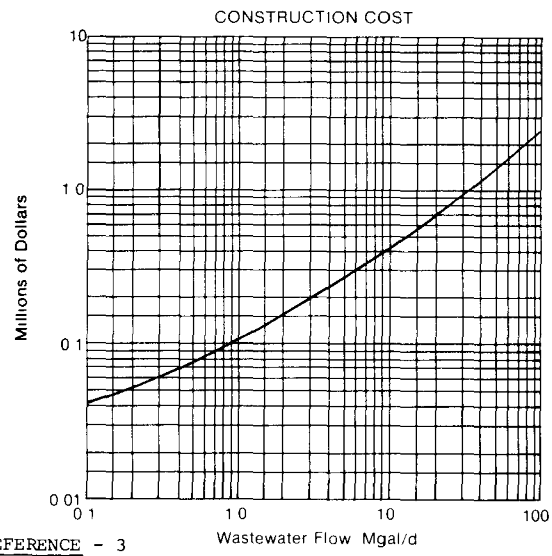


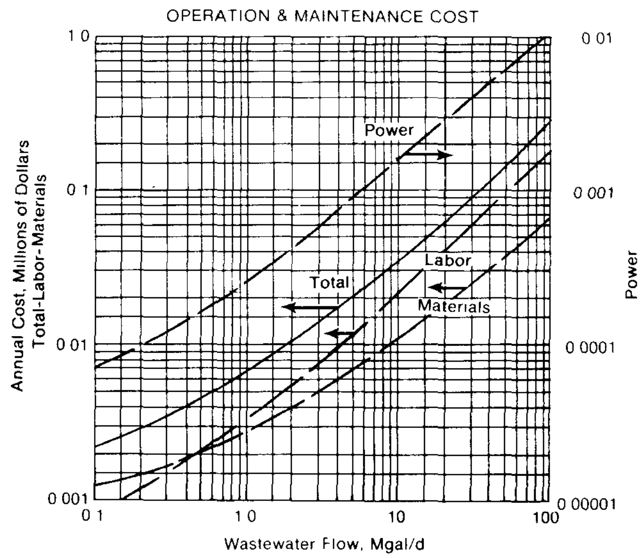
COSTS* - Assumptions: Service Life = 50 years; ENR = 2475.

Design Basis:

1. Clarifier designed for surface overflow rate of 800 gal/d/ft^2 (based on average Q).
2. Costs include primary sludge pumps; sludge concentration of 4 percent solids; pump head assumed as 10 ft TDH.
3. Power Cost = \$0.02/kWh
4. To adjust construction cost for alternative surface overflow rate, enter curve at effective flow (Q_E)

$$Q_E = Q_{DESIGN} \times \frac{800\ \text{gal/d/ft}^2}{\text{New Design Surface Overflow Rate}}$$





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

CLARIFIER, PRIMARY, RECTANGULAR WITH PUMP — FACT SHEET 3.1.2

Description - Primary clarification involves a relatively long period of quiescence in a basin (depths of 10 to 15 ft) where most of the settleable solids in a pretreated wastewater fall out of suspension by gravity. The solids are mechanically transported along the bottom of the tank by a scraper mechanism and pumped as a sludge underflow.

The maximum length of rectangular tanks has been approximately 300 ft. Where widths of greater than 20 ft are required, multiple bays with individual cleaning equipment may be employed, thus permitting tank widths up to 80 ft or more. Influent channels and effluent channels should be located at opposite ends of the tank.

Sludge removal equipment usually consists of a pair of endless conveyor chains. Attached to the chains at about 10-ft intervals are wooden crosspieces or flights, extending the full width of the tank or bay. Linear conveyor speeds of 2 to 4 ft/min are common. The settled solids are scraped to sludge hoppers in small tanks and to transverse troughs in large tanks. The troughs, in turn, are equipped with cross collectors, usually of the same type as the longitudinal collectors, which convey solids to one or more sludge hoppers. Screw conveyors have been used for the cross collectors.

Scum is usually collected at the effluent end of rectangular tanks by the flights returning at the liquid surface. The scum is moved by the flights to a point where it is trapped by baffles before removal or it can also be moved along the surface by water sprays. The scum is then scraped manually up an inclined apron, or it can be removed hydraulically or mechanically, and for this process a number of means have been developed (rotating slotted pipe, transverse rotating helical wiper, chain and flight collectors, scum rakes).

Common Modifications - Tanks may also be cleaned by a bridge-type mechanism which travels up and down the tank on rails supported on the sidewalls. Scraper blades are suspended from the bridge and are lifted clear of the sludge on the return travel. Chemical coagulants may be added to improve BOD_5 and SS removals and remove P.

Technology Status - Rectangular clarifiers are in widespread use.

Applications - Removal of readily settleable solids and floating material to reduce TSS and BOD_5. Can accept high solids loading. Primary clarifiers are generally employed as a preliminary step to further processing. Rectangular tanks also lend themselves to nesting with preaeration tanks and aeration tanks in activated sludge plants.

Limitations - Horizontal velocities in the clarifier must be limited to prevent "scouring" of settled solids from the sludge bed and their eventual escape in the effluent.

Typical Equipment/No. of Mfrs. (10) - Clarifiers/35; Sludge Pumps/20.

Performance - Efficiently designed and operated primary clarifiers should remove 50 to 65 percent of the TSS and 25 to 40 percent of the BOD_5 while producing a sludge solids concentration of about 5 percent. Skimmings volume rarely exceeds 1.0 ft^3/Mgal.

Chemicals Required - Coagulants such as alum, ferrous sulfate and lime may be added to aid sedimentation. The dosage is determined from jar tests.

Design Criteria - Average surface loading rates = 600 to 1200 gal/d/ft^2 for untreated wastewater. If chemicals are used, the ranges are 360 to 600 for alum, 540 to 800 for iron, 540 to 1200 for lime. Detention times = 1.5 to 3.0 hours. Weir loadings = 10,000 to 30,000 gal/d/lin ft. Individual bays of rectangular tanks should have a length to width ratio of at least 4. Forward velocities should be less than 9-15 times settling velocity to avoid scour. Scum handling equipment should be sized for 6 ft^3/Mgal of free decanted water. Sludge pumping rates range between 2500 to 20,000 gal/d/Mgal, depending upon chemical addition and service.

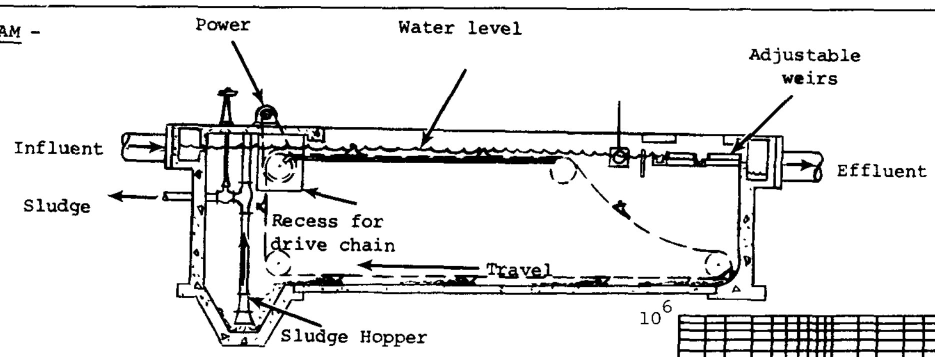
Unit Process Reliability - Generally, reliability is very high. However, broken links in collector drive chain can cause outages. Plugging of sludge hoppers has also been a problem when cross collectors are not provided.

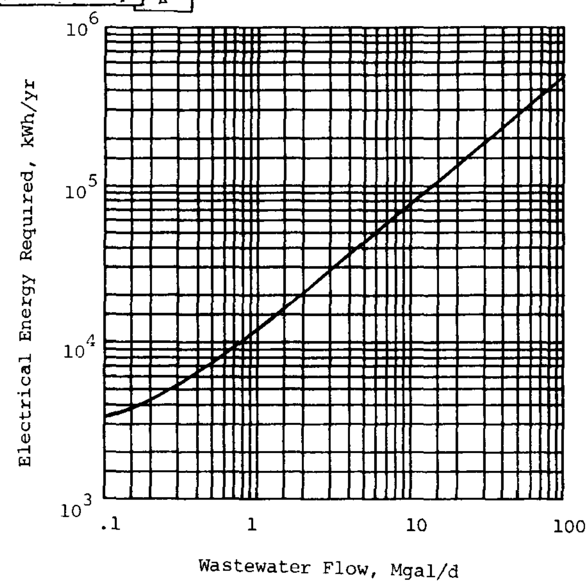
Environmental Impact - Multiple rectangular tanks require less area than multiple circular tanks and for this reason are used where ground area is at a premium. However, they require relatively large space for the level of treatment imparted.

References - 3, 7, 10, 64, 99

CLARIFIER, PRIMARY, RECTANGULAR WITH PUMP — FACT SHEET 3.1.2

FLOW DIAGRAM -





ENERGY NOTES - Cost design assumptions applicable. *Energy usage shown on the energy curve is for sludge pumps, sludge scrapers and skimmers.*

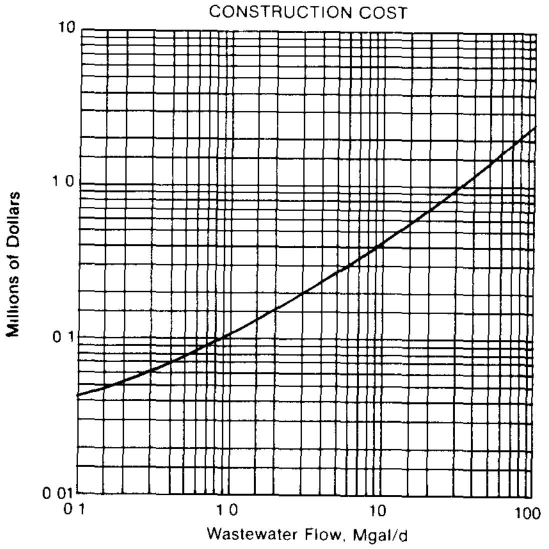
Energy required for providing the head loss of 2 to 3 ft through the clarifier can be approximated by the following equation: kWh/yr = 1625 (Mgal/d x TDH) at a wire-to-water efficiency of 70 percent.

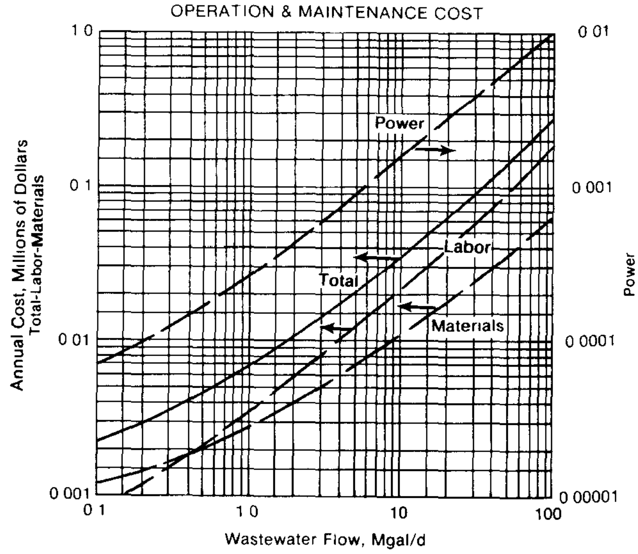
COSTS* - Assumptions: Service Life = 50 years; ENR = 2475.

Design Basis:

1. Clarifier designed for surface overflow rate of 800 gal/d/ft^2 (based on average Q).
2. Costs include primary sludge pumps; sludge concentration of 4 percent solids; pump head assumed as 10 ft TDH.
3. Power Cost = $0.02/kWh
4. To adjust construction cost for alternative surface overflow rate, enter curve at effective flow (Q_E)

$$Q_E = Q_{DESIGN} \times \frac{800\ \text{gal/d/ft}^2}{\text{New Design Surface Overflow Rate}}$$





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

CLARIFIER, SECONDARY, CIRCULAR — FACT SHEET 3.1.3

Description - Circular clarifiers have been constructed with diameters ranging from 12 to 200 ft, depths of 12 to 15 ft. There are two types to choose from: the center-feed and the rim-feed. Both utilize a revolving mechanism to transport and remove the sludge from the bottom of the clarifier. Mechanisms are of two types: those that scrape or plow the sludge to a center hopper similar to the types used in primary sedimentation tanks (see Fact Sheet 3.1.1), and those that remove the sludge directly from the tank bottom through suction orifices that serve the entire bottom of the tank in each revolution. In one type of the latter, the suction is maintained by reduced static head on the individual drawoff pipes. In another patented suction system, sludge is removed through a manifold either hydrostatically or by pumping.

Circular clarifiers are made with effluent overflow weirs located near the center or near the perimeter of the tank. Skimming facilities are now required on all federally funded projects.

While the design is similar to primary clarifiers, the large volume of flocculent solids in the mixed liquor requires that special consideration be given to the design of activated-sludge clarifiers. The sludge pump capacity and the size of the settling tank are larger. Further, the mixed liquor, on entering the tank, has a tendency to flow as a density current interfering with the separation of the solids and the thickening of the sludge. To cope successfully with these characteristics, factors that must be considered in the design of these tanks include: type of tank to be used, surface loading rate, solids loading rate, flow-through velocities, weir placement and loading rates, and scum removal.

Technology Status - Circular secondary clarifiers are in widespread use.

Applications - To separate the activated sludge solids from the mixed liquor, to produce the concentrated solids for the return flow required to sustain biological treatment, and to permit settling of solids resulting from low-rate trickling filter treatment.

Limitations - Must operate at relatively low hydraulic loadings (large space requirements). Maximum diameter is 200 ft. Larger tanks are subject to unbalanced radial diffusion and wind action, both of which can reduce efficiency. Horizontal velocities in the clarifier must be limited to prevent "scouring" of settled solids from the sludge bed and eventual escape with the effluent.

Typical Equipment/No. of Mfrs. (10) - Clarifier/35; Sludge Pumps/20

Performance - Underflow solids concentrations in activated sludge systems range from 0.5 to 2.0 percent depending on settling and compaction characteristics of sludge. Trickling filter (low-rate) underflows generally vary from 3 to 7 percent solids. Effluent SS have been measured at 11 to 14 mg/l (99), however, 20 to 30 mg/l are more likely.

Design Criteria - Inlet baffle diameter = 15 to 20 percent of tank diameter. (Baffle should not extend more than 3 ft below surface.) Weir loading rates = 10,000 to 30,000 gal/d/lin ft. Maximum upflow velocity in vicinity of weir = 12 to 24 ft/h. Other typical design parameters are as shown below:

Type of Treatment	Hydraulic Loading, gal/d/ft^2: Average	Hydraulic Loading, gal/d/ft^2: Peak	Solids Loading*, lb solids/d/ft^2: Average	Solids Loading*, lb solids/d/ft^2: Peak	Depth ft
Settling following trickling filtration	400-600	1000-1200	-	-	10-12
Settling following air activated sludge (excluding extended aeration)	400-800	1000-1200	20-30	50	12-15
Settling following extended aeration	200-400	800	20-30	50	12-15
Settling following oxygen activated sludge with primary settling	400-800	1000-1200	25-35	50	12-15

*Allowable solids loadings are generally governed by sludge thickening characteristics associated with cold weather operations.

The sludge recirculation rate in an activated sludge process ranges from 15 percent to 200 percent of the plant flow depending upon the modification employed.

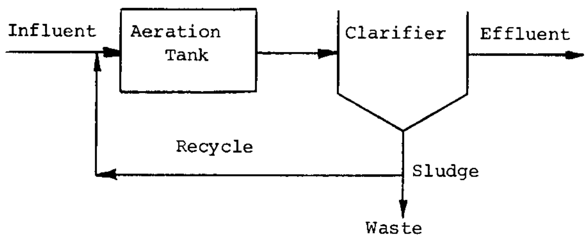
Unit Reliability - Generally, the reliability is very high. However, rising sludge due to denitrification and sludge bulking may cause problems, which may be overcome by proper operational techniques.

Environmental Impact - Circular units require greater land area than rectangular units.

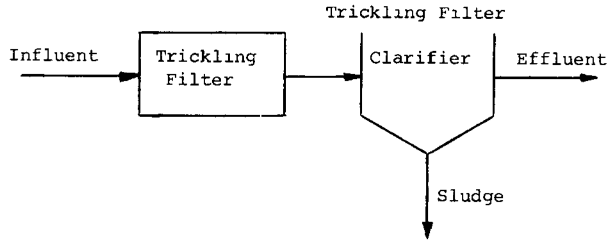
References - 3, 7, 10, 99

FLOW DIAGRAM -

Activated Sludge

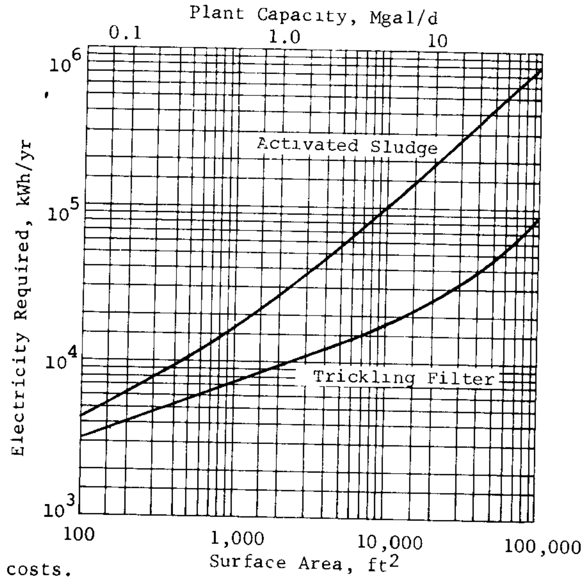


Trickling Filter



ENERGY NOTES - Cost design assumptions applicable. Energy usage is for sludge pumps, sludge scrapers and skimmers. In the activated sludge case, the sludge return pump energy is included.

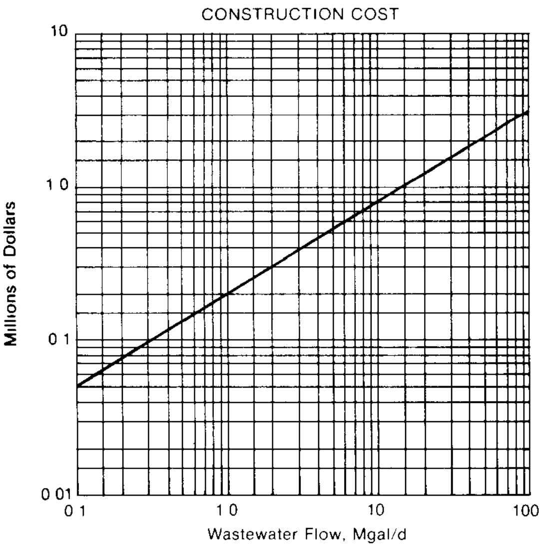
Energy required for providing the head loss of 2 to 3 ft through the clarifier can be approximated by the following equation: kWh/yr = 1625 (mgal/d plant flow + Mgal/d return sludge flow) TDH at a wire-to-water efficiency of 70 percent.

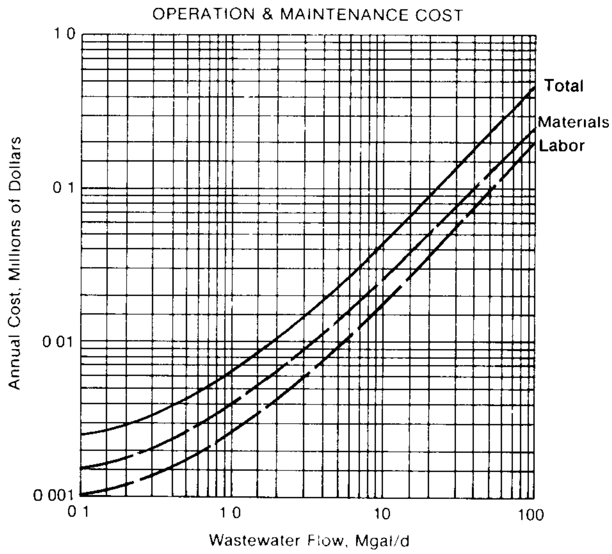


COSTS - Assumptions: Service Life = 40 years; ENR Index = 2475

1. Flocculator-type clarifier.
2. Overflow rate of 600 gal/d/ft^2 used for the development of costs.
3. Costs include sludge return and waste pumps. Sludge concentrations of 1 percent solids. Pump TDH at 10 ft. Spare pumps included as necessary. Pump capacity 350 gal/min/Mgal/d of plant capacity. Nonclog centrifugal pumps.
4. Maximum clarifier diameter = 200 ft.
5. To adjust for alternate overflow rates, enter the curve at effective flow.

$$(Q_E) = Q_{DESIGN} \times 600 \text{ gal/d/ft} \times \frac{1}{\text{NEW DESIGN FLOW RATE}}$$





REFERENCES - 3, 4

*To convert construction cost to capital cost see Table A-2.

CLARIFIER, SECONDARY, RECTANGULAR FACT SHEET 3.1.4

Description - The design of secondary clarifiers is similar to primary clarifiers except that the large volume of flocculant solids in the mixed liquor must be considered during the design of activated-sludge clarifiers and in sizing of sludge pumps. Further, the mixed liquor, on entering the tank, has a tendency to flow as a density current interfering with the separation of the solids and the thickening of the sludge. To cope successfully with these characteristics, factors that must be considered in the design of these tanks include: (1) type of tank to be used, (2) surface loading rate, (3) solids loading rate, (4) flow-through velocities, (5) weir placement and loading rates, and (6) scum removal.

Flow through rectangular tanks enters at one end, passes a baffle arrangement, and traverses the length of the tank to effluent weirs. The maximum length of rectangular tanks has been approximately 300 ft with depths of 12 to 15 ft. Where widths of greater than 20 ft are required, multiple bays with individual cleaning equipment may be employed, thus permitting tank widths up to 80 ft or more.

Sludge removal equipment usually consists of a pair of endless conveyor chains. Attached to the chains at 10 ft intervals are 2-in thick wooden crosspieces or flights, 6 to 8 in deep, extending the full width of the tank or bay. Linear conveyor speeds of 2 to 4 ft/min are common. The settled solids are scraped to sludge hoppers in small tanks and to transverse troughs in large tanks. The troughs, in turn, are equipped with cross collectors, usually of the same type as the longitudinal collectors, which convey solids to one or more sludge hoppers. Screw conveyors have also been used for the cross collectors. Tanks may also be cleaned by a bridge-type mechanism which travels up and down the tank on rails supported on the sidewalls. Scraper blades are suspended from the bridge and are lifted clear of the sludge on the return travel. For very long tanks, it is desirable to use two sets of chains and flights in tandem with a central hopper to receive the sludge. Tanks in which mechanisms that move the sludge toward the effluent end in the same direction as the density current have shown superior performance in some instances.

Scum is usually collected at the effluent end of rectangular tanks by the flights returning at the liquid surface. The scum is moved by the flights to a point where it is trapped by baffles before removal, or it can also be moved along the surface by water sprays. The scum is then scraped manually up an inclined apron, or it can be removed hydraulically or mechanically, and for this process a number of means have been developed (rotating transverse rotating helical wiper, chain and flight collectors, scum rakes).

Common Modifications - Multiple inlets with balanced flow at various spacings and with target baffles to reduce velocity of streams; hydraulic balancing between parallel clarifier units; Control of wind effects on water surface; Sludge hopper collection systems; Flocculation inlet structures; Use of traveling bridge sludge collectors and skimmers, as an alternate to chain and flight systems; Use of steeply inclined tube settlers to enhance SS removal in either new or rehabilitated clarifiers; Use of wedge wire settler panels at peak hydraulic loading of less than 800 gal/d/ft^2 for improved SS removal.

Technology Status - Rectangular clarifiers are in widespread use.

Applications - Secondary clarifiers are used for solids separation and for the production of a concentrated return sludge flow to sustain biological treatment. Multiple rectangular tanks require less area than multiple circular tanks and for this reason are used where ground area is at a premium. Rectangular tanks also lend themselves more readily to nesting with primary tanks and aeration tanks in activated sludge plants. They are also used generally where tank roofs or covers are required.

Limitations - Must operate at relatively low hydraulic loadings (large space requirements). The maximum length of tank has been about 300 ft. Horizontal velocities in the clarifier must be limited to prevent "scouring" of settled solids from the sludge bed and their eventual escape with the effluent.

Typical Equipment/No. of Mfrs. (10) - Clarifiers/35; Sludge Pumps/20.

Performance - Maximum practical solids concentrations of sludge from secondary clarifiers in activated sludge systems range from 0.5 to 2.0 percent depending on settling and compaction characteristics of the sludge (99). Effluent TSS = 20 to 30 mg/l (7).

Design Criteria - Average hydraulic loading in activated sludge systems varies from 400 to 800 gal/d/ft^2 and peak loadings range from 700 to 1200 gal/d/ft^2 depending on mixed liquor suspended solids concentration and percent sludge recycle. Average solids loadings of 0.6 to 1.2 lb/h/ft^2 and peak loadings of 1.25 to 2.0 lb/h/ft^2 have been suggested for activated sludge plants. Weir loading = 10,000 to 30,000 gal/d/lin ft. Maximum inflow velocity in vicinity of weir = 12 to 24 ft/h. Depths are normally 12 to 15 ft.

Unit Process Reliability - Mechanical reliability can be considered high provided suitable preventive maintenance and inspection procedures are observed. Plugging of sludge hoppers has been a problem when cross collectors are not provided. Process reliability is highly dependent upon the upstream performance of the aerator for the production of good settling sludge with acceptable compactability. Rising sludge caused by denitrification of the sludge is a problem in certain cases.

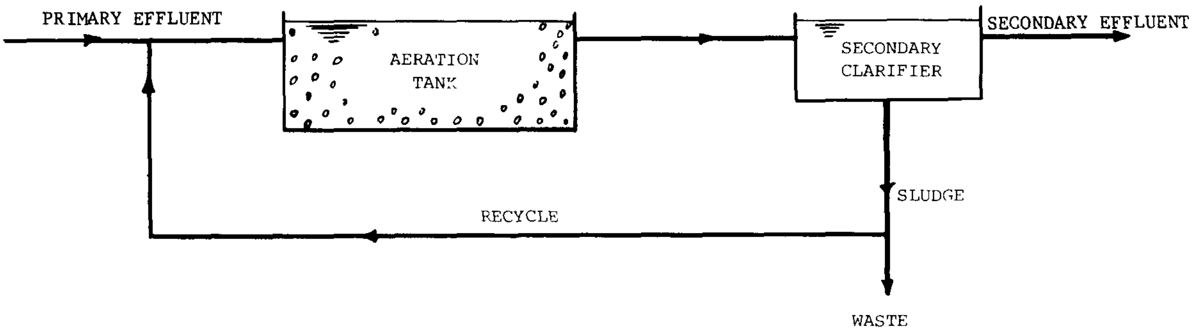
Environmental Impact - Although it requires large land areas, it offers a higher space efficiency than circular clarifiers.

References - 3, 7, 10, 99

CLARIFIER, SECONDARY, RECTANGULAR

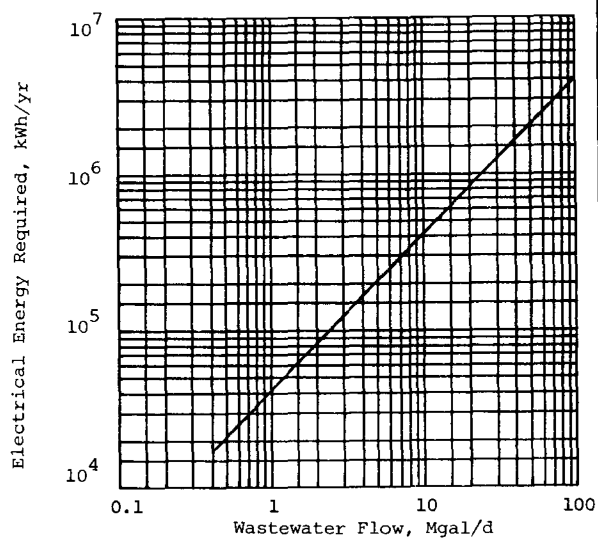
FACT SHEET 3.1.4

FLOW DIAGRAM -



ENERGY NOTES - Cost design assumptions applicable. Energy usage shown on energy curve is for sludge return and waste pumps, sludge scrapers and skimmers.

Energy required for providing the head loss for 2-3 ft through the clarifier can be approximated by the following equation: kWh/yr = 1625 (Mgal/d plant flow + Mgal/d return sludge flow)(TDH) at a wire to water efficiency of 70 percent.

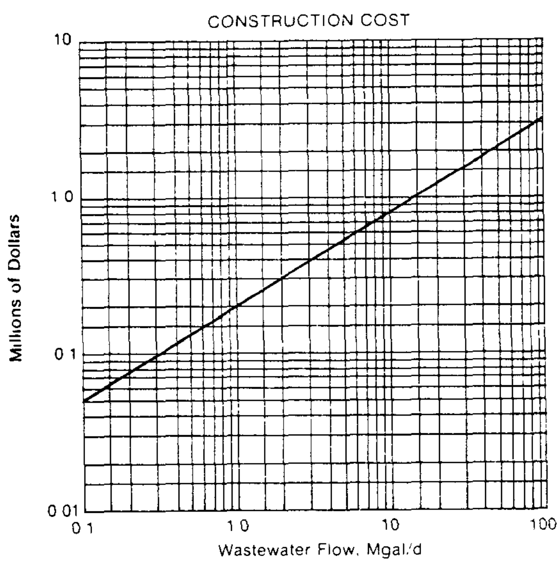


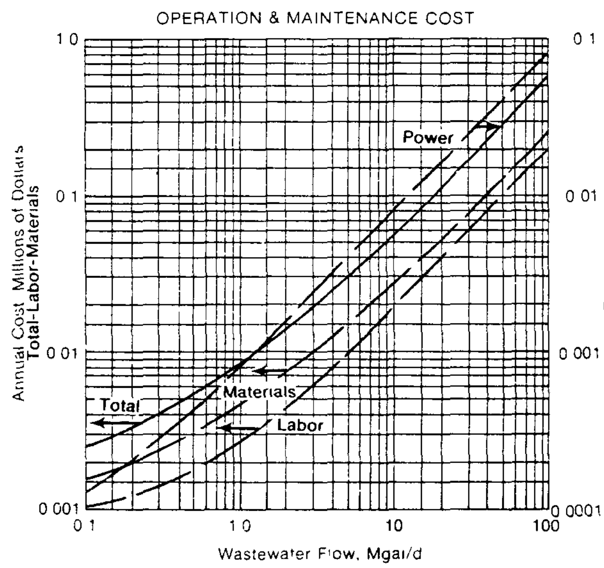
COSTS - *Assumptions:

Service Life: 40 years, ENR = 2475 (Sept. 1976), Power Cost: \$0.02/kWh.

Design Basis:

1. Flocculator-type clarifier: 600 gal/d/ft^2
2. Costs include sludge return and waste pumps. Sludge concentration of 1 percent solids. Pump TDH at 10 ft. Spare pumps included as necessary. (non-clog centrifugal pumps).
3. To adjust construction cost for alternative flow rates, enter the curve at effective flow (Q_E) = Q_{DESIGN} x 600 gal/d/ft^2 x (1/New Design Overflow Rate).





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

CLARIFIER, SECONDARY, HIGH RATE TRICKLING FILTER | FACT SHEET 3.1.5

Description (7, 99) - The design of clarifiers that follow high rate trickling filters is similar to that of primary clarifiers, (see Fact Sheets 3.1.1 and 3.1.2 for description) except that the surface loading rate is based on the plant flow plus the effluent recycle flow minus the underflow (often neglected). These clarifiers differ from secondary clarifiers following activated sludge processes in that the sludge recirculation is not used. Also, solids loading limits are not involved in the sizing. Recirculation of the supernatant from the clarifier to the trickling filter can range from one to four times the plant influent flow rate. See Fact Sheets 2.2.6 and 2.2.7 for further details on recirculation flow requirements. Under suitable trickling filter operating conditions it is more economical to recirculate the clarifier influent to reduce the flow sizing requirements in the clarifier.

Technology Status - In widespread use.

Applications - To control suspended solids levels in the effluent and to provide the recirculated water flow required to maintain the high rate trickling filter process.

Limitations - Effluent quality is limited by the performance of the trickling filter not that of the clarifier (99). See Fact Sheets 3.1.1 and 3.1.2 for other limitations.

Typical Equipment/No. of Mfrs. (10) - Clarifiers/35; Sludge Pumps/20; Recirculation Pumps/45

Performance - See predicted performance for trickling filters on Fact Sheets 2.2.6, 2.2.7, and 2.2.8.

Chemicals Required - None

Design Criteria (99) - Average hydraulic loading (including recirculated flow) = 800 gal/d/ft^2; peak hydraulic loading = 1000 to 1200 gal/d/ft^2; depth = 10 to 12 ft. Other criteria same as shown on Fact Sheets 3.1.1 and 3.1.2.

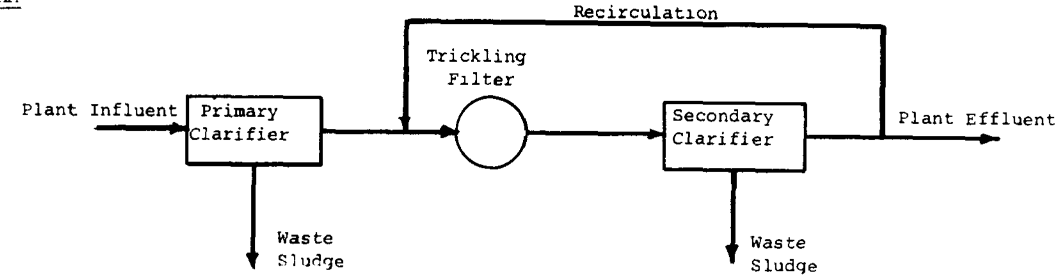
Unit Process Reliability - Generally, the reliability of the clarifier itself is very high. However, its performance is dependent upon the trickling filter.

Environmental Impact - Requires large land area. However, rectangular clarifiers are more space efficient than circular clarifiers.

References - 3, 7, 10, 99

CLARIFIER, SECONDARY, HIGH RATE TRICKLING FILTER — FACT SHEET 3.1.5

FLOW DIAGRAM -



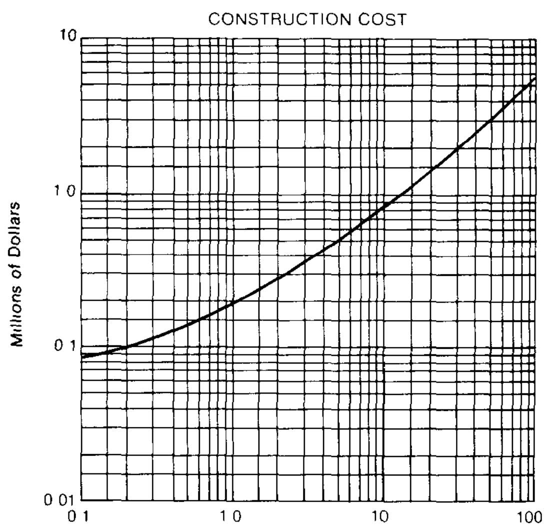
ENERGY NOTES (3) - Power required for operation = $P_{Sludge\ pumps} + P_{Recirculation} + P_{Skimmers\ \&\ Sludge\ Scrapers}$. At an effluent recycling rate of 3 times average plant wastewater flow, this power requirement can be estimated to be kWh/yr = 160,000 (Mgal/d plant flow). Clarifier head loss is 2 to 3 ft. Influent pumping energy can be estimated by the use of the following equation: kWh/yr = 1625 (Plant flow Mgal/d + effluent recycle flow Mgal/d) (TDH) at a wire-to-water efficiency of 70 percent.

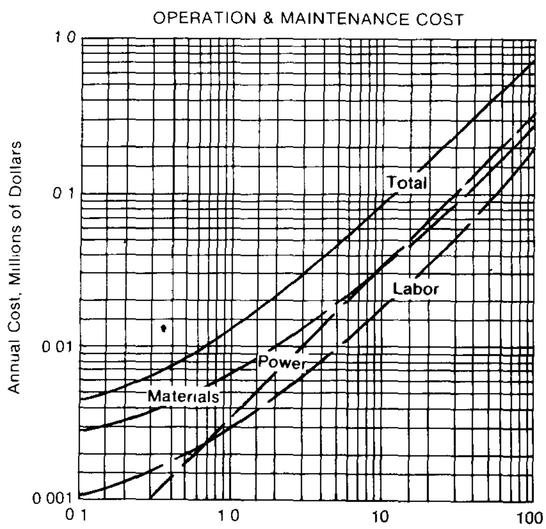
COSTS* - Assumptions: Service Life = 40 years; ENR = 2475.

Design Basis

1. Construction costs include sludge pumps, effluent recycle pumps, clarifier mechanisms and internal piping.
2. Overflow rate = 800 gal/d/ft^2 at average design flow.
3. Recycle pumping capacity = 3 times average wastewater flow.
4. Maximum clarifier diameter = 200 ft.
5. Power cost = $0.02/kWh
6. To adjust construction cost for alternative loading rates, enter curve at effective flow (Q_E)

$$Q_E = Q_{DESIGN} \times \frac{800\ \text{gal/d/ft}^2}{\text{New Design Overflow Rate}}$$





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

DISSOLVED AIR FLOTATION FACT SHEET 3.1.6

Description - Dissolved air flotation (DAF) is used to remove suspended solids by flotation (rising) by decreasing their apparent density. Dissolved air flotation consists of saturating a portion or all of the wastewater feed, or a portion of recycled effluent with air at a pressure of 25 to 70 lb/in^2g. The pressurized wastewater is held at this pressure for 0.5 to 3.0 minutes in a retention tank and then released to atmospheric pressure to the flotation chamber. The sudden reduction in pressure results in the release of microscopic air bubbles which attach themselves to oil and suspended particles in the wastewater in the flotation chamber. This results in agglomeration which, due to the entrained air, have greatly increased vertical rise rates of about 0.5 to 2.0 ft/min. The floated materials rise to the surface to form a froth layer. Specially designed flight scrapers or other skimming devices continuously remove the froth. The retention time in the flotation chambers is usually about 20 to 60 minutes. The effectiveness of dissolved air flotation depends upon the attachment of bubbles to the suspended oil and other particles which are to be removed from the waste stream. The attraction between the air bubble and particle is primarily a result of the particle surface charges and bubble-size distribution.

The more uniform the distribution of water and microbubbles, the shallower the flotation unit can be. Generally, the depth of effective flotation units is between 4 and 9 feet.

The surface sludge layer can in certain cases attain a thickness of many inches and can be relatively stable for a short period. The layer thickens with time, but undue delays in removal will cause a release of particulates back to the liquid.

Common Modifications - Units can be round, square or rectangular. In addition, gases other than air can be used. The petroleum industry has used nitrogen, with closed vessels, to reduce the possibilities of fire.

Technology Status - Dissolved air flotation has been used for many years to treat industrial wastewaters. It has commonly been used to treat sludges generated by municipal wastewaters (see Fact Sheet No. 6.3.6), however is not widely used to treat municipal wastewaters.

Typical Equipment/No. of Mfrs. (23) - Dissolved air flotation units/24; Air compressors/8; Skimmers/over 20.

Applications - DAF is used to remove lighter suspended materials whose specific gravity is only slightly in excess of 1.0. Usually used to remove oil and grease materials. Sometimes used when existing clarifiers are overloaded hydraulically by converting to DAF which requires less surface area.

Limitations - Will only be effective on particles with densities near or smaller than water.

Performance (99) -

	Percent Removal (w/o chemicals)	Percent Removal (w. chemicals)
Suspended Solids	40 to 65	80 to 93
Oil and Grease	60 to 80	85 to 99

Chemicals Required - Alum ($Al_2(SO_4)_3.14H_2O$), ferric chloride ($FeCl_3$), and polymers can be added to aid in the coagulation process prior to the actual flotation step.

Residuals Generated - A froth layer is generated, which is skimmed off the top of the unit and is generally denser than clarifier sludge.

Design Criteria (99) -

Parameter	Range
Pressure, lb/in^2g	25 to 70
Air to Solids Ratio, lb/lb	0.01 to 0.1
Float Detention, min	20 to 60
Surface Hydraulic Loading, $gal/d/ft^2$	500-8,000
Recycle, percent (where employed)	5 to 120

Unit Process Reliability - DAF systems have been found to be reliable. However chemical pretreatment is essential, without which DAF units are subject to variable influent conditions, resulting in widely varying performance.

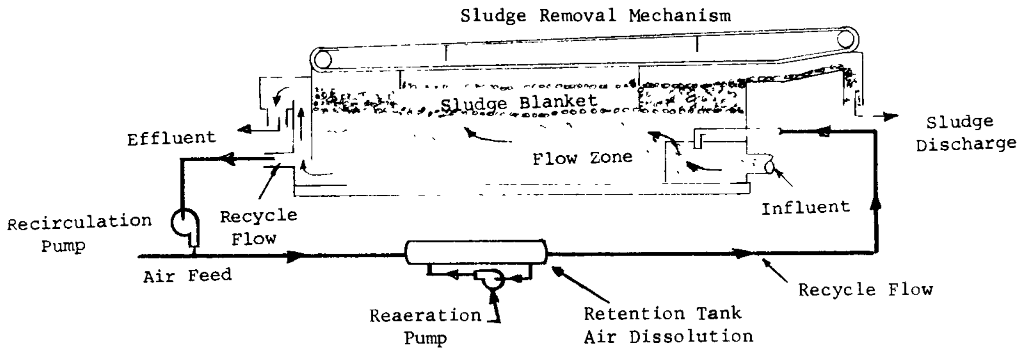
Environmental Impact - Requires very little use of land. The air released in the unit is unlikely to strip volatile organic material into the air. The air compressors will need silencers to control the noise generated. The sludge generated will need methods for disposal. This sludge will contain high levels of chemical coagulants used.

References - 23, 99, 108, 111

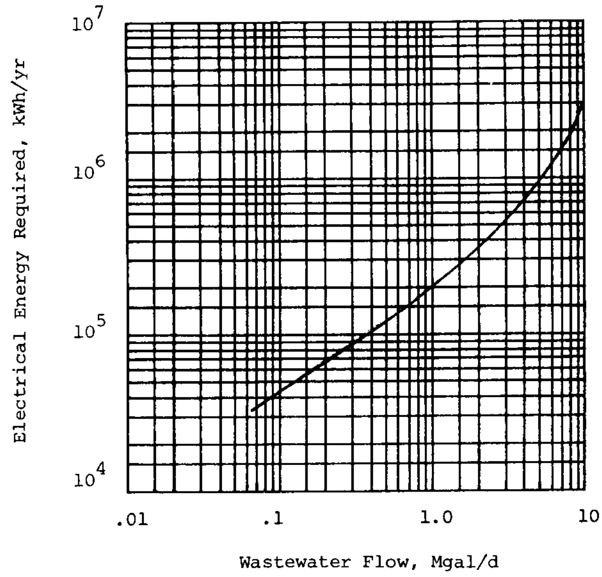
DISSOLVED AIR FLOTATION

FACT SHEET 3.1.6

FLOW DIAGRAM -



ENERGY NOTES - Assumptions: Energy consumption includes that required for wastewater recycle, air injection, and chemical feed pumping.

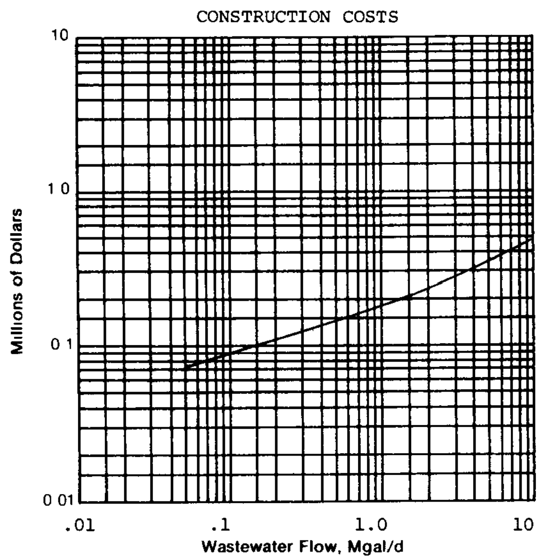


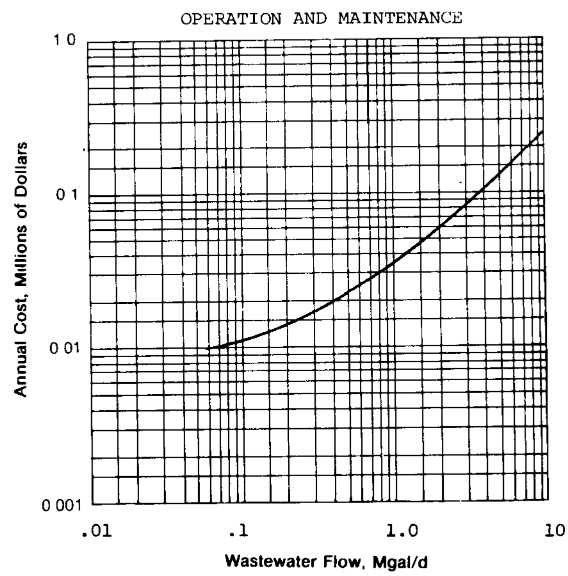
COSTS* - Assumptions: Costs are based on 1976 dollars; ENR Index = 2475.

1. Construction costs include DAF unit and chemical feed equipment.

2. Operating costs include chemical feed alum @ $72/t; polymer @ $1.50/lb, labor @ $20,000/my including fringes.

Design Basis:
Air Injection = 1.25 ft^3/1000 gal
33 percent recycle
Detention time = 25 min
Area flow rate = 2 to 3 gal/min/ft^2





REFERENCES - 99, 112

*To convert construction cost to capital cost see Table A-2.

FILTRATION, DUAL MEDIA

FACT SHEET 3.1.7

Description - Dual media filtration-gravity is one of the most economical forms of granular media filtration. Granular media filtration involves the passage of water through a bed of filter media with resulting deposition of solids. Eventually, the pressure drop across the bed becomes excessive or the ability of the bed to remove suspended solids is impaired. Cleaning is then necessary to restore operating head and effluent quality. The time in service between cleanings is termed the run length. The head loss at which filtration is interrupted for cleaning is called the terminal head loss, and this head loss is maximized by the judicious choice of media sizes.

Dual media filtration involves the use of both sand and anthracite as filter media, with anthracite being placed on top of the sand. Gravity filters operate by either using the available head from the previous treatment unit, or by pumping to a flow split box after which the wastewater flows by gravity to the filter cells. Pressure filters utilize pumping to increase the available head.

Normally filter systems include multiple filter compartments. This allows for the filtration system to continue to operate while one compartment is being backwashed.

A filter unit generally consists of a containing vessel, the filter media, structures to support the media, distribution and collection devices for influent, effluent and backwash water flows, supplemental cleaning devices (see "Common Modifications"), and necessary controls for flows, water levels and backwash sequencing.

Common Modifications - Filtration systems can be constructed out of concrete or steel, with single or multiple compartment units. Steel units can be either horizontal or vertical and are generally used for pressure filters. Systems can be manually or automatically operated.

Backwash sequences can include air scour or surface wash steps. Backwash water can be stored separately or in chambers that are integral parts of the filter unit. Backwash water can be pumped through the unit or can be supplied through gravity head tanks.

Technology Status - Has been used for many years in the potable water industry, and has been used in the wastewater treatment field for 10 to 15 years.

Typical Equipment/No. of Mfrs. (23) - Dual media filters/20; blowers/7; controls/29.

Applications - Removal of residual biological floc in settled effluents from secondary treatment and removal of residual chemical-biological floc after alum, iron, or lime precipitation in tertiary or independent physical-chemical waste treatment.

In these applications filtration may serve both as an intermediate process to prepare wastewater for further treatment (such as carbon adsorption, clinoptilolite ammonia exchange columns, or reverse osmosis) or as a final polishing step following other processes.

Limitations - Economics are highly dependent on consistent pretreatment quality and flow modulations. Increasing suspended solids loading will reduce run lengths, and large flow variations will deleteriously effect effluent quality in chemical treatment sequences.

Performance -

Filter Influent	Filter Effluent mg/l
High Rate Trickling Filter	10 to 20
2-Stage Trickling Filter	6 to 15
Contact Stabilization	6 to 15
Conventional Activated Sludge	3 to 10
Extended Aeration	1 to 5

Chemicals Required - Alum and iron salts, and polymers can be added as coagulant aids directly ahead of filtration units. This, however, will generally reduce run lengths.

Residuals Generated - Backwash water, which generally approximates two to ten percent of the throughput. Backwash water can be returned to the head of the plant.

Design Criteria (99) -
Filtration rate 2 to 8 gal/min/ft^2; bed depth 24 to 48 inches (depth ratios of 1:1-4:1 sand to anthracite); backwash rate 15 to 25 gal/min/ft^2; air scour rate 3 to 5 $stdft^3$/min/ft^2; filter run length 8 to 48 hours; terminal head loss 6 to 15 ft.

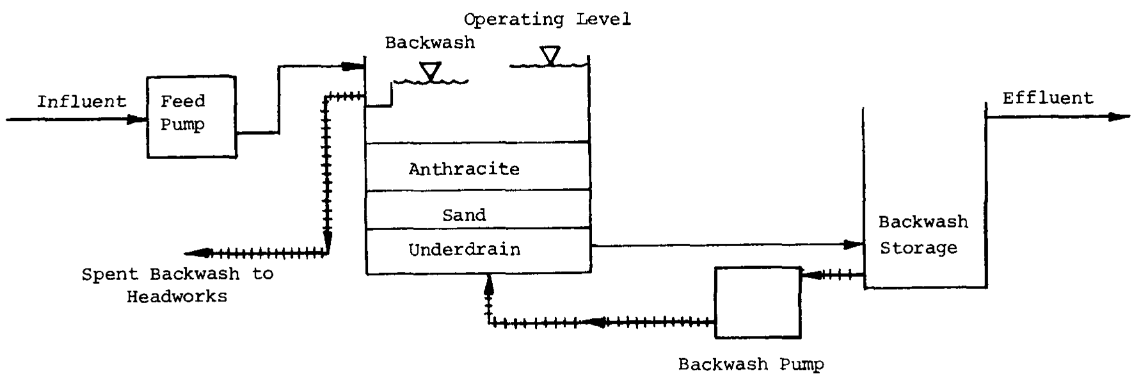
Unit Process Reliability- Dual media filtration systems are very reliable from both a process and unit standpoint.

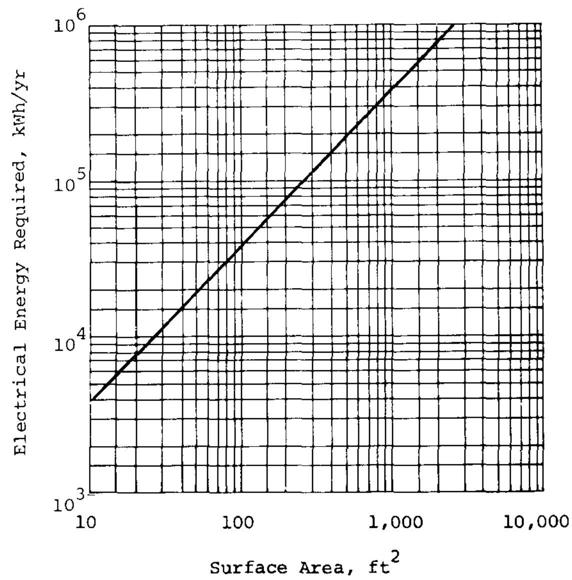
Environmental Impact - Requires relatively little use of land. Backwash water will need further treatment, with an ultimate production of solids which will need disposal. Air scour blowers usually need silencers to control noise. No air pollution generated.

References - 23, 26, 39, 44, 99

FILTRATION, DUAL MEDIA FACT SHEET 3.1.7

FLOW DIAGRAM -





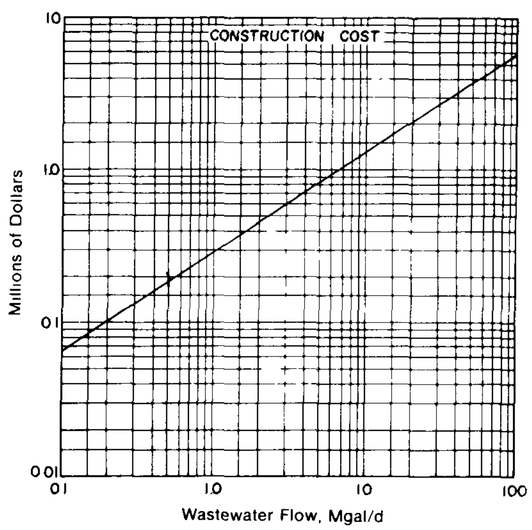
ENERGY NOTES - If sufficient head available, no influent pumping required. However, usually a feed pump is employed to provide necessary head.

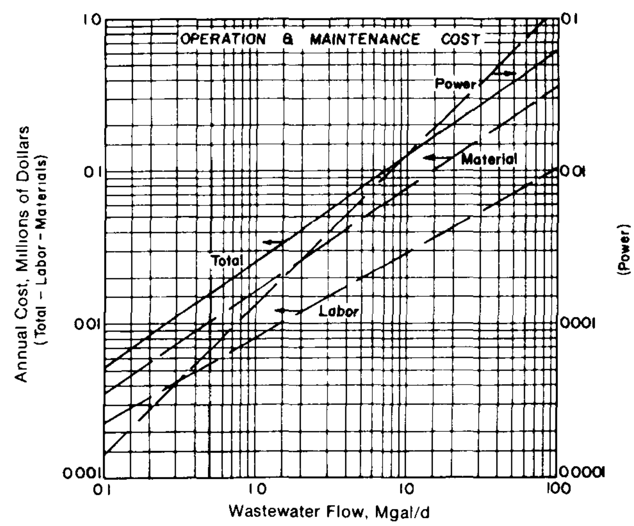
Assumptions:

1. Gravity filters @ 4 gal/min/ft^2
   a. TDH for backwash and feed pumps 14 ft
   b. Run length = 12 h; 15 min backwash @ 15 gal/min/ft^2
   c. Pump efficiency 70%; motor efficiency, 93%
2. Centrifugal pumps

COSTS* - Assumptions: ENR Index = 2475

1. Same as above, with air scour assist for backwash
2. Backwash holding tank = capacity of two backwash cycles.
3. Construction cost includes facilities for backwash storage, all feed and backwash pumps, piping, and building.
4. Power at $.02/kWh.
5. Labor at $7.50/h, including fringe benefits.





REFERENCES - 3, 4, 39

*To convert construction cost to capital cost see Table A-2.

FLOW EQUALIZATION FACT SHEET 3.1.9

Description - Wastewater flows into treatment facilities are subjected to diurnal and seasonal fluctuation in quality and in quantity. Most waste treatment processes are sensitive to such changes. An equalization basin serves to balance the extreme quality and quantity of these fluctuations to allow normal contact time in the treatment facility. This Fact Sheet addresses equalization basins that are used only to equalize flow; however, it should be noted that the quality of the wastewater will also equalize to some degree.

Equalization basins may be designed as either in-line or side-line units. In the in-line design, the basin receives the wastewater directly from the collection system, and the discharge from the basin through the treatment plant is kept essentially at a constant rate. In the side-line design, flows in excess of the average are diverted to the equalization basin and, when the plant flow falls below the average, wastewater from the basin is discharged to the plant to bring up the flow to the average level. The basins are sufficiently sized to hold the peak flows and to discharge at a constant rate.

Pump stations may or may not be required to discharge into or out of the equalization basin, depending upon the available head. Where pumping is found necessary, the energy requirements will be based on total flow for in-line basins and on excess flow for side-line basins.

Aeration of the wastewater in the equalization basin is normally required for mixing and maintaining aerobic conditions.

Common Modifications - There are various methods of aeration, pumping and flow control. Tanks or basins can be manufactured out of steel or concrete, or can be excavated and be of the lined or unlined earthen variety.

Technology Status - Has been used in the municipal and industrial sectors for many years. Over 200 municipal installations in the United States.

Typical Equipment/No. of Mfrs. (23) - Lift pumps/34; air compressors/8; basin liners/6; flow controllers/29; aerators/30.

Applications - Can be used to equalize the extremes of diurnal and wet weather flow fluctuations. The secondary benefits are equalization of quality and the potential for the protection from toxic upsets.

Limitations - Its application to equalize diurnal fluctuation is rather limited because the cost may be high when compared to the benefits. It may require substantial land area.

Performance - Flow equalization basins are easily designed to achieve the objective. Use of aeration, in combination with the relatively long detention times afforded can produce BOD_5 reductions of 10 to 20 percent.

Residuals Generated - Due to the settling characteristics of influent wastewater solids, some materials will collect at the bottom of the basin, and will need to be periodically discarded. Provisions must be made to accommodate this need.

Design Criteria (122) - Design of an equalization basin is highly site specific and dependent upon the type and magnitude of the input flow variations and facility configuration. The pumping/flow control mode, aeration, mixing and flushing methods are dependent upon the size and site conditions. Grit removal should be provided upstream of the basin. Mechanical mixing at 20 to 40 hp/Mgal of storage. Aeration at 1.25 to 2 ft^3/min/1,000 gal of storage.

Process Reliability - These units have been found to be reliable from both a unit and process standpoint and are used to increase the reliability of the flow-sensitive treatment processes that follow.

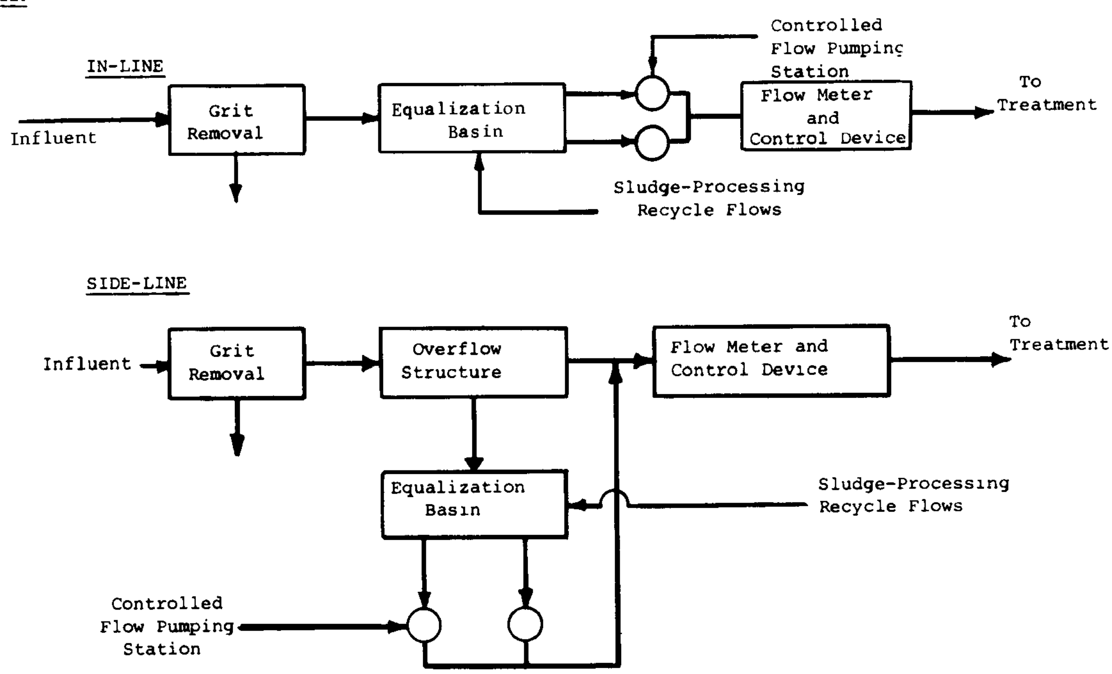
Environmental Impact - Can consume large land areas. Impact upon air quality and noise levels are minimal. There may be some sludge generated that will require disposal.

References - 23, 26, 113, 114, 122

FLOW EQUALIZATION

FACT SHEET 3.1.9

FLOW DIAGRAM -



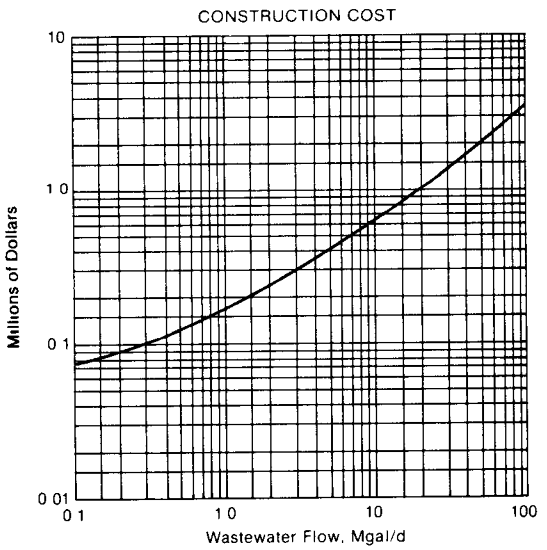
ENERGY NOTES - Pumping energy requirements may be approximated by using the following equation:

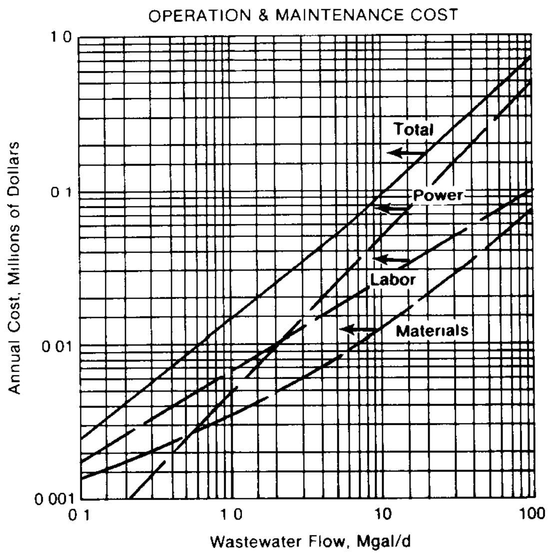
kWh/yr = 1900 X Mgal/d* X discharge head ft, assuming 60% wire to water efficiency

For the typical head requirements of 10 ft for this process, an energy requirement of 19,000 kWh/yr/Mgal/d can be expected.

*In the case of in-flow basins, the flow through the plant and in the case of side-line basins, the excess flow.

COSTS** - Assumptions: Construction costs are based on concrete basin for design flows less than 1 Mgal/d and 6-inch concrete lined earthen basin for design flows greater than 1 Mgal/d. Detention time = 1.0 d. Mixing requirements = 20 to 40 hp/Mgal of storage volume. Costs include basin and mechanical mixing equipment. Pumping is not included. ENR Index = 2475.





REFERENCE - 3

**To convert construction cost to capital cost see Table A-2.

MIXING/CHLORINE CONTACT, HIGH INTENSITY FACT SHEET 3.1.10

Description - Standard chlorine disinfection systems involve the addition of gaseous chlorine, followed by a baffled contact chamber which usually provides a 15 to 30 minute detention time. These contact chambers afford plug flow conditions, but do not encourage rapid contact between the chlorine and the microorganisms to be killed.

High intensity mixing systems have been under investigation for the past several years. These systems involve the use of mixing tanks with extremely high velocity gradients. These flash mixing devices cause the disinfectant to come into contact with many more microorganisms than standard contact devices. Therefore, small detention times can be used, on the order of 1 to 5 minutes.

High intensity mixing systems can be manufactured in two forms. One design uses standard mixing devices, with high energy input per unit volume. The second design involves the use of closely spaced baffles or static type mixers, with high energies supplied by pumping.

The effluent from the mixing chamber is generally checked for chlorine residual, which is used to adjust the rate of chlorine feed.

Common Modifications - Standard mixing devices, closely spaced baffles, or static mixers can be used, often in conjunction with (post) aeration. Various disinfecting agents, other than gaseous chlorine, can be used. These include hypochlorite, ozone, and chlorine dioxide.

Chemical feed rates can be adjusted automatically or manually.

Technology Status - The use of high intensity mixing devices for disinfection has been tested only on the pilot and bench scales.

Typical Equipment/No. Mfrs. (23) - Mixing devices/26.

Applications - For the purpose of this fact sheet, high intensity mixing devices are used for the application of chlorine to combined sewer overflows.

Limitations - Due to the simplicity of the process, and the use of proven equipment such as mixers, it is expected that there are few, and most likely minor, mechanical limitations.

In regard to the process of disinfection by chlorine, chlorinated hydrocarbons may be formed. Some of these compounds are known to be carcinogenic. The effectiveness of chlorination is greatly dependent upon pH and temperature of the wastewater being treated. Chlorine gas is hazardous material, and it requires sophisticated handling procedures. Chlorine will preferentially react with certain chemicals in the wastewater, leaving only the residual amounts of chlorine for disinfection. These compounds include ammonia, hydrogen sulfide and metals present in their reduced states.

Performance - High rate chlorination can result in 99.9 percent removal of viruses and over 99 percent removal of total and fecal coliforms.

Chemicals Required - Chlorine, sodium hypochlorite, or calcium hypochlorite.

Design Criteria - Detention times of 1 to 5 minutes are generally sufficient, with detentions up to 10 minutes possibly required in some applications. Velocity gradients of at least 300 s^{-1} are generally required. Mixing horsepower requirements are (at a 2-minute detention) approximately 1.25 hp/Mgal/d of throughput(wire to water).

Residuals - None

Process Reliability - Due to its lack of use on a full scale, the process reliability cannot be adequately determined. However, due to the simplicity of operation, and the use of proven equipment such as mixers, the reliability is expected to be high.

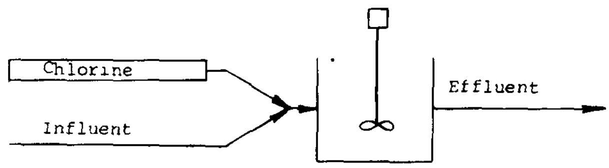
Environmental Impact - This process is designed to reduce the land-use and chemical requirements for disinfection processes. However, chlorination can cause the formation of chlorinated hydrocarbons. In addition, chlorine gas may be released to the atmosphere.

References - 154, 155, 163, 164, 165, 166

MIXING/CHLORINE CONTACT, HIGH INTENSITY

FACT SHEET 3.1.10

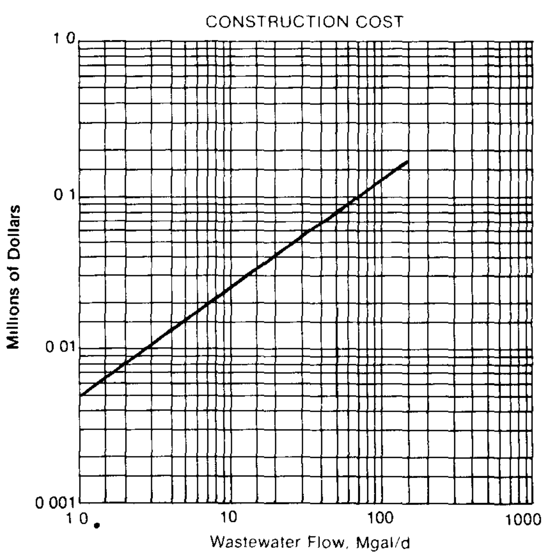
FLOW DIAGRAM -

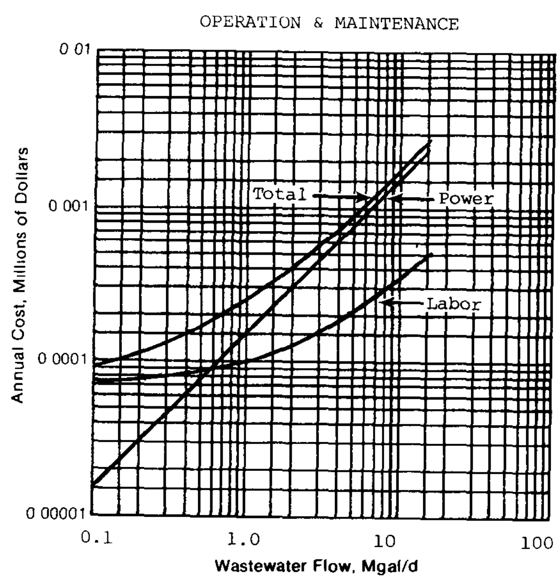


ENERGY NOTES - Energy required (kWh/yr) = 8750 X HP (wire to water)/1.339; for temperature = 15°C, detention time = 2 MIN, G = 300 sec^{-1}

COSTS -* Assumptions: ENR Index = 2475

1. Service life of mixer, approximately 10 yr.
2. Costs are based on 2 minute detention time and on velocity gradient (G) of 300 SEC^{-1}.
3. Construction costs include concrete mixing basin and stainless steel mixers.
4. Miscellaneous costs such as chlorine storage area, hoist and evaporator are not included.
5. Labor costs at $7.50/h and power at $.02/kWh.
6. Power requirement is 1.25 hp/Mgal/d (wire to water).





REFERENCES - 3,155

*To convert construction cost to capital cost see Table A-2.

POST AERATION FACT SHEET 3.1.11

Description - There are many regulations requiring the maintenance of minimum dissolved oxygen (DO) concentrations in wastewater treatment plant effluents. Plant effluents from secondary clarifiers normally contain 0.5 to 2.0 mg/l of DO. Many effluent quality standards, depending on the intended water use, specify a minimum DO concentration of 4.0 mg/l. Post aeration is designed to provide the additional oxygen to effluents prior to their discharge to receiving waters. There are at least four methods available for post aeration of treatment plant effluents:

Diffused Aeration - Diffused air aerators can be obtained in a number of variations, with all accomplishing the same goal. The purpose of diffused aerators is to carry the air supplied by blowers or compressors to a subsurface level in an aeration basin, distribute the air, and create as small a bubble as possible.

Mechanical Aeration - Mechanical aerators are generally grouped in two broad categories: turbine types and pump types. In both, oxygen transfer occurs through a vortexing action and/or from the interfacial exposure of large volumes of liquid sprayed over the surface. To optimize aeration and mixing, and to avoid interference between units, aerator manufacturers have developed criteria for minimum areas and depths, depending on the horsepower of the aerator and the configuration of the impeller.

Cascade Aeration - Cascade aeration generally takes advantage of effluent discharge head and employs a series of steps or weirs over which the flow moves in fairly thin layers. The objective is the maximization of turbulence to increase oxygen transfer. Head requirements vary from three to ten feet, depending upon the initial DO and the desired increase. If the necessary head is not available, effluent pumping is required.

U-Tube Aeration - The U-tube aerator consists of two basic components; a conduit to provide a vertical U-shaped flow path and a device for entraining air into the stream flow in the down leg of the conduit. The entrainment device is one of two types: (1) aspirator; or (2) compressor and diffuser. In either case, the entrained air is carried along the down flow leg of the tube because the water velocity exceeds the buoyant rising velocity of the air bubbles.

Technology Status - Except for U-tube aeration, post aeration systems have been widely used in both the municipal and industrial sectors. U-tube aeration has been utilized for sanitary force main aeration.

Typical Equipment/No. of Mfrs. (23) - Blowers/7; Aeration equipment/30.

Applications - Post aeration is used when the dissolved oxygen (DO) content in the effluent from the wastewater treatment plant does not meet effluent standards. The choice of an aeration method is dependent upon local conditions and economics.

Common Modifications - Post aeration can be accomplished in high-intensity mixing chlorination systems, which preclude the necessity of a separate post aeration system.

Limitations - Usually limited to secondary or tertiary effluents.

Performance - Post aeration systems can achieve oxygen concentrations in the effluent approaching the saturation concentration.

Chemicals Required - None

Residuals Generated - None

Design Criteria - Diffused Aeration - Post aeration systems are designed on the basis of required oxygen-transfer rate (26). General aeration requirements range from 0.5 to 5 Sft^3/min of air per square foot of tank area (26).

Mechanical Aeration - Mechanical aeration systems are also designed using oxygen-transfer rates which are then converted to horsepower ratings. Normal horsepower ratings can range from 0.03 to 0.1 hp/1000 gal of tank capacity (26).

Cascade Aeration - As mentioned above, cascade aeration takes advantage of water falling over a series of weirs. The cumulative height of these weirs is between 3 and 10 feet, depending on the DO increase required.

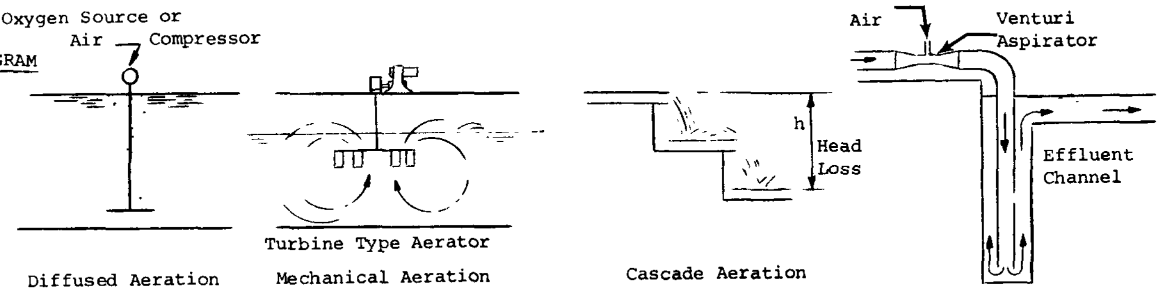
U-Tube Aeration - Various design considerations include air-to-water ratio, tube cross-sectional area, and depth. The hydraulic head requirements for plants of 5 Mgal/d or less should be less than five feet. If sufficient head is not available, the flow may be pumped through the U-tube.

Unit Process Reliability - Due to their inherent simplicity, post aeration systems are extremely reliable.

Environmental Impact - Degree of land usage required varies with type chosen, but generally, it is small. Volatiles remaining in the treated effluent may be stripped by the aeration process. There are no sludges generated.

Reference - 26

FLOW DIAGRAM



Diffused Aeration Mechanical Aeration Cascade Aeration U-Tube Aeration

ENERGY NOTES (26) - Energy consumption for post aeration systems is highly dependent upon basin geometry and the dissolved oxygen deficit. Diffused and mechanical aeration and power requirement can be calculated as follows:

$$\text{Power (kWh/yr)} = \frac{272\ (SOR)}{N_o F_g n}$$

with SOR = Standard oxygen-transfer rate, lb O_2/d
N_o = O_2 transfer efficiency under standard conditions in tap water, lb O_2/hph (See Appendix D)
F_g = Correction factor related to basin geometry
n = Aerator efficiency correction

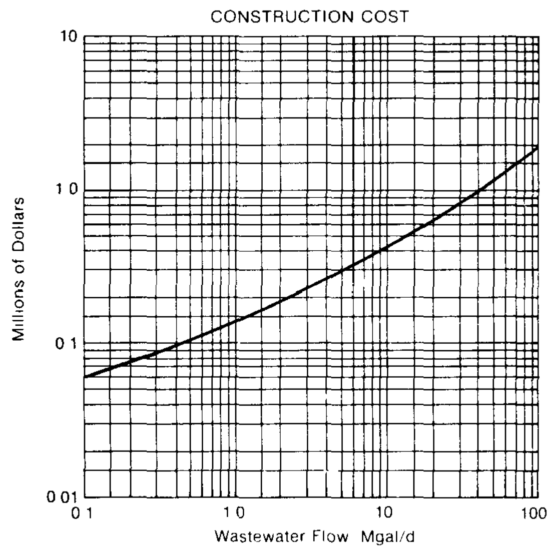
Cascade aerators consume power by the loss of head. The equivalent energy requirement can be calculated as follows:

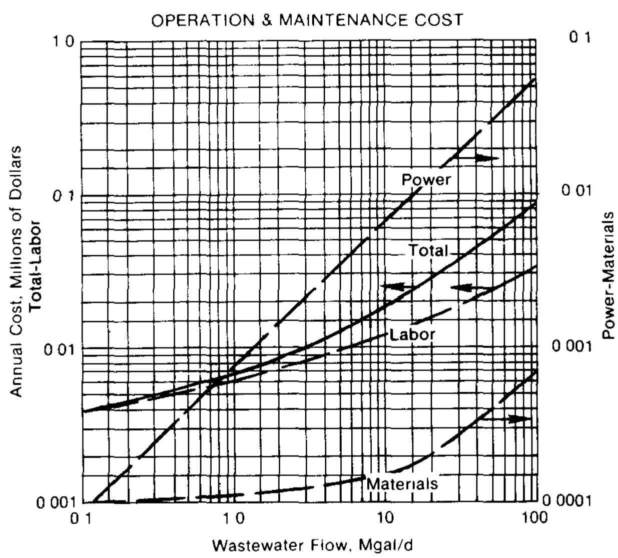
Energy (kWh/yr) = 1900 (Mgal/d X ft head loss), assuming a wire to water efficiency of 60 percent, with normal operating head loss at approximately 5 feet, Energy (kWh/y) = 9500 X (Mgal/d)

U-tube aerators:
Optimum U-tube (requiring pumping) designs require 0.9-1.3 kWh/lb D.O. added at 24° C

COSTS* (3) - Assumptions: ENR Index = 2475
1. Construction costs include aeration equipment and post aeration basin for mechanical aeration.
2. Designed to increase dissolved oxygen from 1 mg/l to 5 mg/l.
3. Detention time = 20 minutes.
4. Power information based on transfer of 34 lb of O_2/Mgal of wastewater treated.
5. Power @ $.02/kWh

Note: Total costs have been derived from the power, labor and materials costs given in reference 3.





REFERENCES - 3, 26

*To convert construction cost to capital cost see Table A-2.

Description - The purpose of preliminary treatment is to remove large objects, such as rocks, logs, and cans, as well as grit, in order to prevent damage to subsequent treatment and process equipment. Objects normally removed by preliminary treatment steps can be extremely harmful to pumps, and can increase downtime due to pipe clogging and clarifier scraper mechanism failures.

Preliminary treatment usually consists of two separate and distinct unit operations - bar screening and grit removal. There are two types of bar screens (or racks). The most commonly used, and oldest technology, consists of hand-cleaned bar racks. These are generally used in smaller treatment plants. The second type of bar screen is the type that is mechanically cleaned, which is commonly used in larger facilities.

Grit is most commonly removed in chambers, which are capable of settling out high density solid materials, such as sand, gravel and cinders. There are two types of grit chambers: (1) horizontal flow, and (2) aerated. In both types the settleables collect at the bottom of the unit. The horizontal units are designed to maintain a relatively constant velocity by use of proportional weirs or flumes in order to prevent settling of organic solids, while simultaneously obtaining relatively complete removal of inorganic particles (grit).

The aerated type produces spiral action whereby the heavier particles remain at the bottom of the tank to be removed, while organic particles are maintained in suspension by rising air bubbles. One main advantage of aerated units is that the amount of air can be regulated to control the grit/ organic solids separation, and less offensive odors are generated. The aeration process also facilitates cleaning of the grit. The grit removed from horizontal flow units usually needs additional cleaning steps prior to disposal.

Common Modifications - Many plants also use comminutors. These are mechanical devices that cut up the material normally removed in the screening process. Therefore, these solids remain in the wastewater to be removed in downstream unit operations, rather than being removed immediately from the wastewater.

In recent years, the use of static or rotating wedge-wire screens has increased to remove large organic particulates just prior to degritting. These units have been found to be superior to comminutors in that they remove the material immediately from the waste instead of creating additional loads downstream. Other grit chamber designs are available including swirl concentrators and square tanks.

Technology Status - Preliminary treatment has been widely used since the early days of municipal wastewater treatment. Wedge-wire screens are newer technology (approximately 13 years old).

Typical Equipment (23) - Screens/20; grinders/9; comminutors/12; sedimentation equipment/28; wedge-wire screens/2.

Applications - Should be used at all municipal wastewater treatment plants, and also are normally used prior to wastewater pumping stations.

Limitations - None for normal municipal wastes. Operational problems have been experienced with comminutors at certain installations due to heavy influx of plastic objects.

Performance - Bar screens are designed to remove all large debris, such as stones, wood, cans, etc. Grit chambers are designed to remove virtually all inorganic particles, such as sand and gravel. Wedge-wire screens remove up to 25 percent SS and associated BOD, and possibly reduce digester scum.

Chemicals Required - None

Residuals Generated - All unit operations, except for comminutors, will generate solids that will need disposal. Wedge-wire screens remove up to 1 yd^3 of 12 to 15 percent solids/Mgal. The grit and other solids are often landfilled.

Design Criteria - Bar Screens: Bar size, 1/4 to 5/8 in width by 1 to 3 in depth; spacing, 0.75 to 3 in; slope from vertical, 0 to 45°; velocity, 1.5 to 3 ft/s. Wedge-wire Screens: See Fact Sheet 3.1.17.

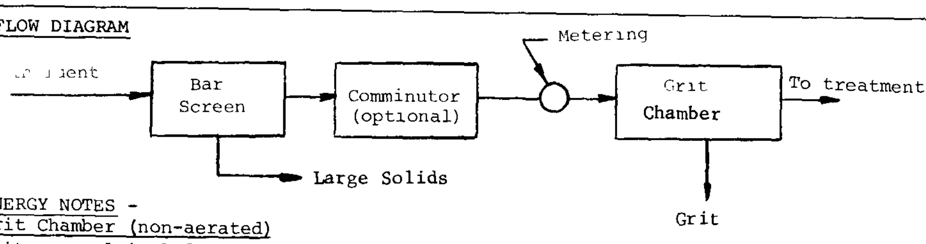
Grit Chambers: Horizontal velocities of 0.5 to 1.25 ft/s, sufficiently long to settle lightest and smallest (usually 0.2 mm) grit particles with an additional factor of safety (up to 50 percent). Weir crests are generally set 4 to 12 in above bottom.

Unit Process Reliability - Preliminary treatment systems are extremely reliable and, in fact, are designed to improve the reliability of downstream treatment systems.

Environmental Impact - Requires relatively little use of land. Requires minimal amounts of energy. Solids will be generated, requiring disposal. Odors are common when removed grit contains excess organic solids and is not disposed of within a short time after removal.

Reference - 7

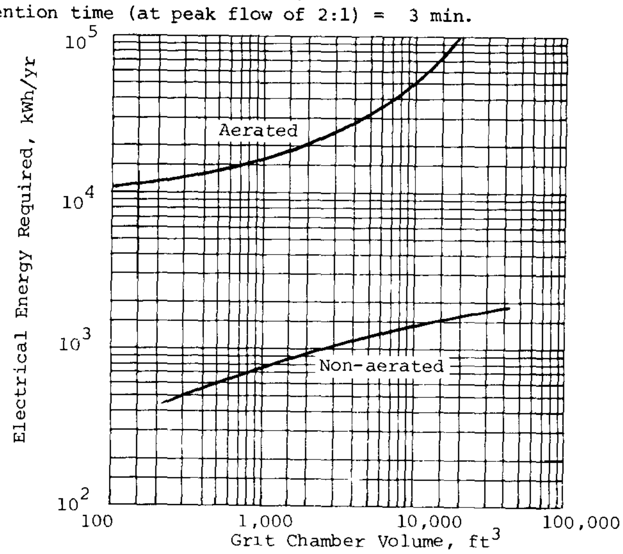
FLOW DIAGRAM



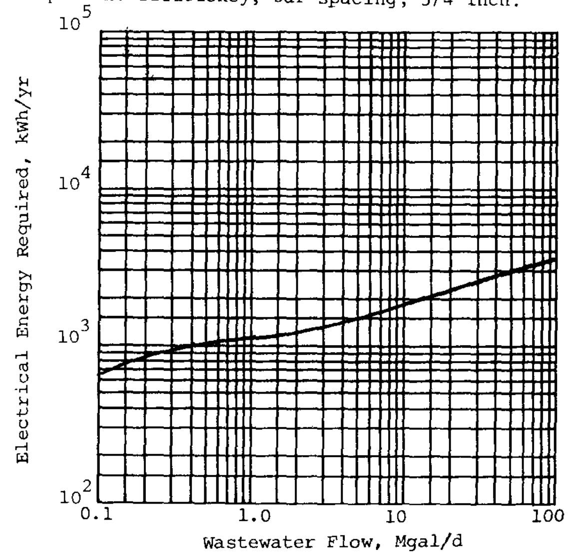
ENERGY NOTES -

Grit Chamber (non-aerated)
Grit removal includes screw pumps.
Velocity = 0.55 ft/s.
Detention time (at peak flow of 2:1) = 1 min.

Grit Chamber (aerated)
Grit removal includes screw pumps.
Air Rate = 3 ft^3/min/ft of length
Detention time (at peak flow of 2:1) = 3 min.

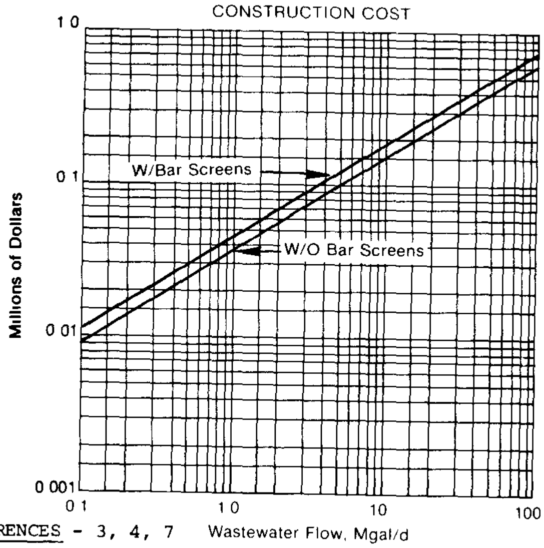


Mechanically Cleaned Bar Screen
Run time of 10 min/h; worm gear drive, 50 percent efficiency; bar spacing, 3/4 inch.

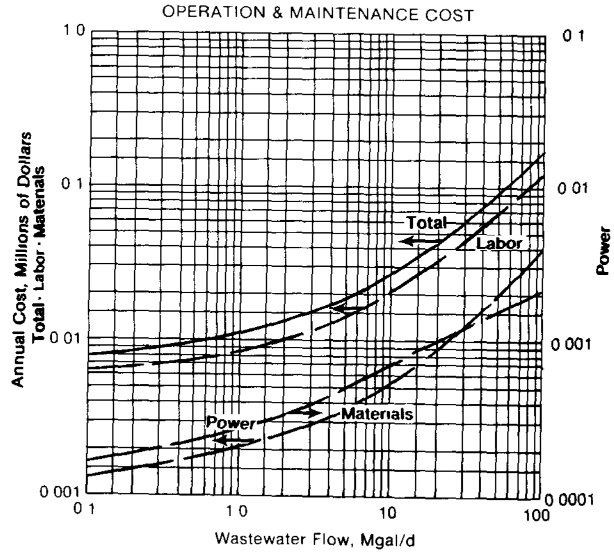


COSTS - Assumptions: ENR Index = 2475 *
Construction costs include: (a) Flow channels and superstructures; (b) bar screens (mechanical); (c) horizontal grit chamber with mechanical grit handling equipment; (d) Parshall flume and flow-recording equipment. Operation and maintenance costs do not include cost for grit disposal. Screenings 1 to 3 ft^3/Mgal. Grit 2 to 5 ft^3/Mgal. Power @ $.02/kWh.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES - 3, 4, 7

*To convert construction cost to capital cost see Table A-2.

PUMP STATIONS, IN-PLANT

FACT SHEET 3.1.13

Description - Due to terrain and design conditions, wastewater after partial treatment may require pumping to subsequent or previous treatment processes, and the final effluent after complete treatment may need pumping to the receiving body of water. These in-plant pump stations are usually less costly than those for raw wastewater due to the relatively clear water handled which requires neither screens nor comminutors; and to the use of relatively small wet wells. The assembly, installation, and testing of the station which includes pumps, motors, piping, valves, controls, and alarms are generally completed on the site.

Common Modifications - Some larger systems employ Archimedes screw pumps which may not require a wet well. Chemical addition equipment is sometimes needed according to the treatment requirements. Multiple pumps or variable-speed pumps are used to match the variations of flow.

Technology Status - Widespread use in wastewater application.

Application - Lifts wastewater when there is not sufficient head for gravity flow to a subsequent or a previous process, or to a receiving body of water.

Limitations - May need emergency power under certain conditions.

Typical Equipment/ No. of Mfrs. (23) - Pump sets/34; valves/39; ventilating fans/7; controls and alarms/29.

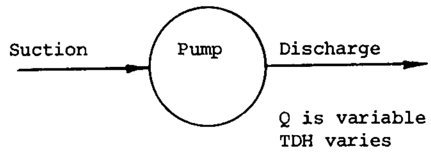
Design Criteria - Minimum slope wet well bottom 2:1; dry well and wet well must be ventilated; wet well floor should always remain covered with liquid to reduce odor problems; high water alarm; minimum number of pumps, 2; suitable water level controls for pump motor operation; emergency power provisions.

Reliability - Reliability is closely related to maintenance and power supply.

Environmental Impact - Low impact on air and water. Potential for water pollution and health risk under failure conditions. Potential for noise.

References - 3, 7, 22, 23, 30, 201

FLOW DIAGRAM -



ENERGY NOTES - Pumping energy requirements can be computed from the following equation:

$$\text{kWh/yr} = \frac{1140\ (\text{Mgal/d})(\text{ft of total head})}{\text{wire to water efficiency}}$$

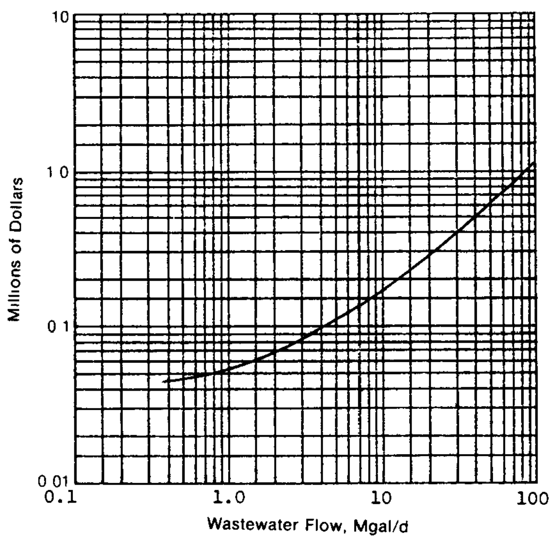
Using a wire to water efficiency of 67% and a TDH of 30 ft, about 51,000 kWh/yr are required for a 1 Mgal/d station.

COSTS*- Assumptions: ENR Index = 2475

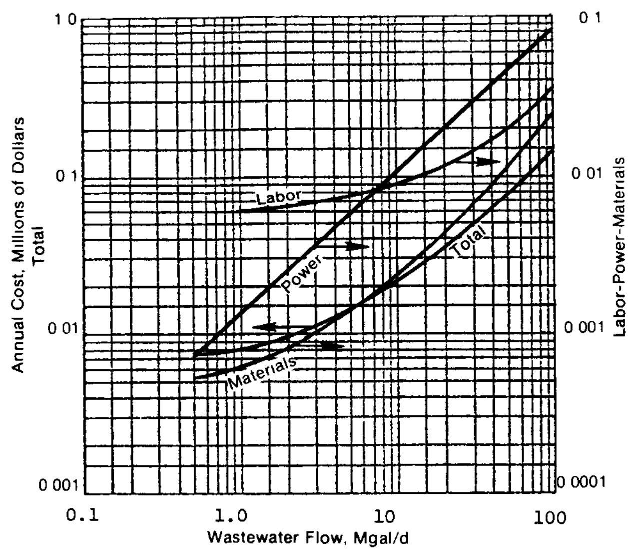
1. Costs are based on September 1976 figures.
2. Construction cost includes normal earthwork, structure, electrical, heating, ventilating, controls and other equipment essential to a complete pump station. TDH = 30 ft.
3. Power costs based on $0.02/kWh.

Note: Total cost has been derived from labor, materials and power costs provided in reference 201.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCE - 201

*To convert construction cost to capital cost see Table A-2.

SCREEN, HORIZONTAL SHAFT ROTARY

FACT SHEET 3.1.16

Description - An intermittently or continuously rotating drum covered with a plastic or stainless steel screen of uniform sized openings, installed and partially submerged in a chamber. The chamber is designed to permit the entry of wastewater to the interior of the drum and collection of filtered (or screened) wastewater from the exterior side of the drum. With each revolution, the solids are flushed by sprays from the exposed screen surface into a collecting trough. Coarse screens have openings of 1/4 inch or more; fine screens have openings of less than 1/4 inch. Screens with openings of 20 to 70 microns are called microscreens or microstrainers. Drum diameters are 3 to 5 ft with 4 to 12 ft lengths.

Common Modifications -

Tile chamber, reinforced concrete chamber, steel chamber.
Variable speed drive for drum.
Addition of backwash storage and pumping facilities.
Addition of ultra-violet light slime growth control equipment.
Addition of chlorinating equipment.

Technology Status - Widespread use for roughing pretreatment, and for secondary biological plant effluent polishing.

Applications - Removal of coarse wastewater solids from the wastewater treatment plant influent after bar screen treatment; screen openings 150 microns to 0.4 inches. For polishing activated sludge effluent, screen openings 20 to 70 microns.

Limitations - Dependence on pretreatment and inability to handle solids fluctuations in tertiary applications. Reducing the speed of rotation of the drum and less frequent flushing of the screen has resulted in increased removal efficiencies, but reduced capacities.

Typical Equipment/No. of Mfrs. (23) - Screens/20; mechanical equipment/at least 3.

Performance (3, 7, 22) - For tertiary applications with head loss of 0.3 to 2 ft:

Pollutant	Typical Percent Removals
BOD_5	40 to 60
SS	50 to 70

Note: Solids removed by fine screens have amounted to approximately 5 to 30 ft^3/Mgal of wastewater treated, equivalent to 5 to 15 percent of suspended matter.

Residuals Generated - Sidestream of solids accumulations backwashed from screen. (2 to 5 percent of influent with SS concentration of 200 to 500 mg/l).

Design Criteria -

Screen submergence 70 to 80 percent.
Loading Rate: 2 to 10 gal/min/ft^2 of submerged area depending on pretreatment and mesh size.
Screen openings: 150 microns to 0.4 inches for pretreatment; 20 to 70 microns for tertiary treatment.
Drum r/min: 0 to 7.
Screen Materials: Stainless steel or plastic cloth.
Washwater = 2 to 5 percent of flow being treated.
Performance of fine screen device varies considerably on influent solids type, concentration and loading patterns; mesh size; hydraulic head and degree of biological conditioning of solids.

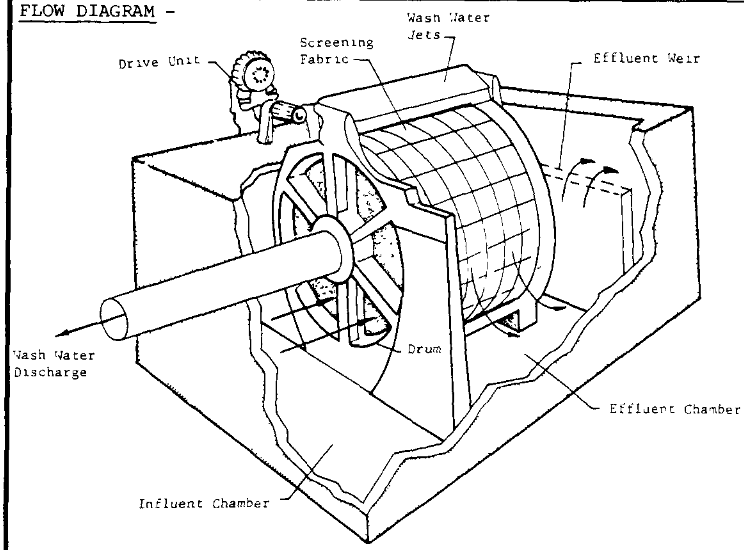
Unit Process Reliability - High degree of reliability for both the process and mechanical areas. The process is simple to operate. Mechanical equipment is generally simple and straightforward. Occasional problems may arise because of incomplete solids removal by flushing. Hand cleaning with acid solution may be required for stainless steel cloths. Blinding by grease can be a problem in pretreatment applications.

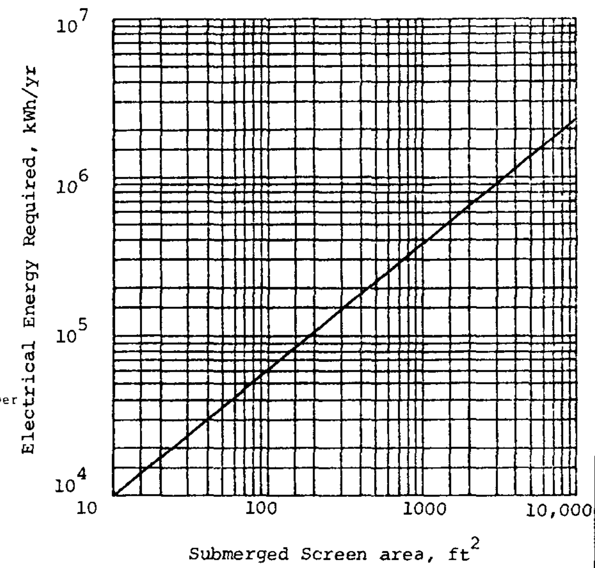
Environmental Impact - Air: odor problems around equipment may be created if solids are not flushed frequently enough from the screen (pretreatment). Disposal of solids by incineration can affect air quality. Land: Disposal of solids in landfill has neglibible impact. Water: None.

References - 3, 7, 22, 23, 39, 52, 99

SCREEN, HORIZONTAL SHAFT ROTARY — FACT SHEET 3.1.16

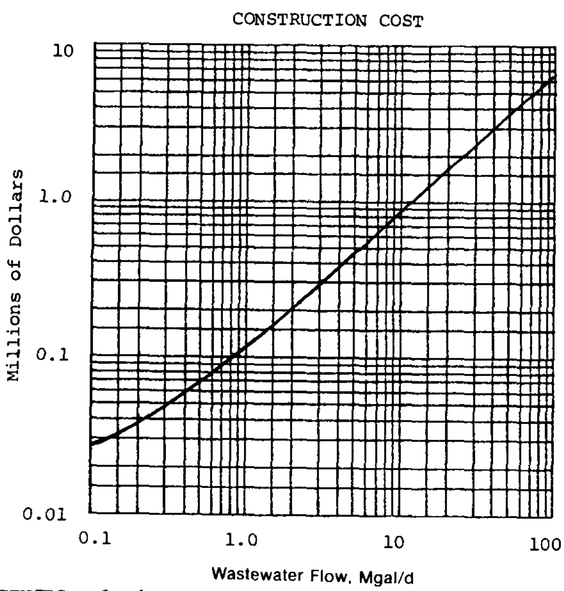
FLOW DIAGRAM -

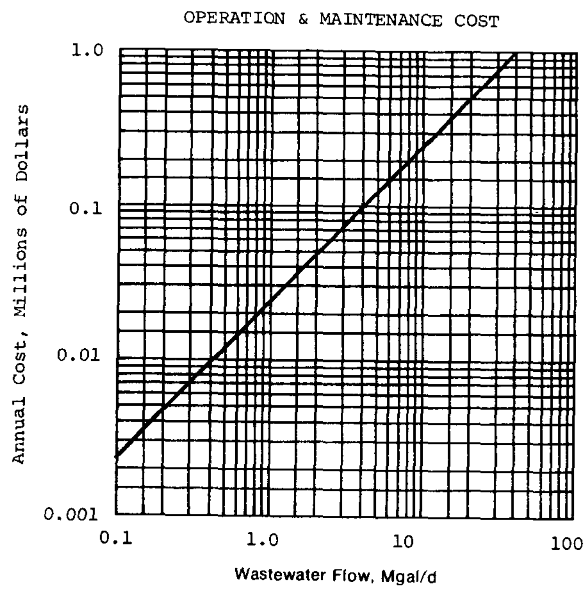




ENERGY NOTES (4) - Assumptions: Electrical energy requirements include backwash water pumping and screen drive.

COSTS* - Assumptions: ENR Index = 2475
Design Basis:
Construction costs include tanks, drums, screens, backwash equipment, drive motors, and building. Instrumentation for automatic operation is included. Hydraulic load = 2.5 gal/min/ft^2 at average flow. Screen mesh = 25 microns. Peripheral drum speed = 15 ft/min at 3 inch head loss. Backwash 3 percent of throughput at 35 psi.





REFERENCES - 3, 4

*To convert construction cost to capital cost see Table A-2.

SCREEN, WEDGEWIRE — FACT SHEET 3.1.17

Description - A device onto which wastewater is directed across an inclined stationary screen or a drum screen of uniform sized openings. Solids are trapped on the screen surface while the wastewater flows through the openings. The solids are moved either by gravity (stationary) or by mechanical means (rotating drum) to a collecting area for discharge. Stationary screens introduce the wastewater as a thin film flowing downward with a minimum of turbulence across the wedgewire screens, which is generally in three sections of progressively flatter slope. The drum screen employs the same type of wedgewire wound around its periphery. Wastewater is introduced as a thin film near the top of the drum and flows through the hollow drum and out the bottom. The solids retained by the peripheral screen follow the drum rotation until removed by a doctor blade located at about 120° from the introduction point.

Common Modifications - Wedgewire spacing can be varied to best suit the application. For municipal wastewater applications spacings are generally between 0.01 and 0.06 inches (0.25 to 1.5 mm). Inclined screens can be housed in stainless steel or fiberglass; wedgewires may be curved or straight; the screen face may be a single multi-angle unit, three separate multi-angle pieces, or a single curved unit. Rotary screens can have a single rotation speed drive or a variable speed drive.

Technology Status - In use in industry since 1965 and in municipal wastewater treatment since 1967. Over 100 installations to date.

Applications - Stationary and rotary drum screens are ideally suited and usually employed after bar screens and prior to grit chambers. They have also been employed for primary treatment, scum dewatering, sludge screening, and digester cleaning and for storm water overflow treatment. Generally, the rotary drum unit is preferred where grease problems are evident due to the increased frequency of cleaning required for stationary units.

Limitations - Require regular cleaning and prompt residuals disposal.

Typical Equipment/No. Mfrs. (23) - Screen systems/3

Performance - Screenings removed by fine screens (.01 to .06 in.) have amounted to approximately 1 to 2 yd^3/Mgal of wastewater treated. Head loss can be 4 to 8 ft. Pollutant removals are:

Pollutant	Typical Percent Removal
BOD	5 to 20
SS	5 to 25

Residuals Generated - Solids trapped on the screen surface (1 - 2 yd^3/Mgal)

Design Criteria - Screening of raw wastewater - (0.05 - 36 Mgal/d)

Parameter	Stationary	Rotary Drum
Screen opening	0.01 - 0.06 in	0.01 - 0.06 in
Head required	4 - 7 ft	2.5 - 4.5 ft
Space required	10 - 750 ft^2	10 - 100 ft^2
Motor size	-	0.5 - 3 hp

Unit Process Reliability - Very high reliability for process and mechanical areas when maintained.

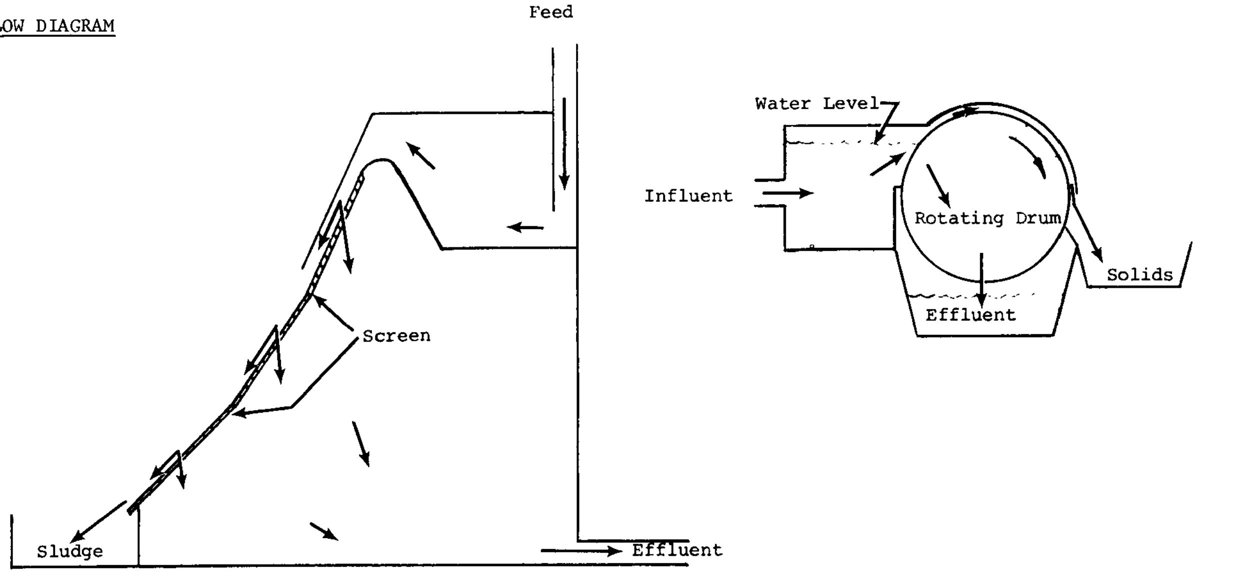
Environmental Impact - Air: Can create odors if screenings are not disposed of properly. Land: Practically nil. Screenings are generally disposed of in a landfill or by incineration. Water: None

References - 3, 7, 22, 27, 39, 52, 53, 99

SCREEN, WEDGEWIRE

FACT SHEET 3.1.17

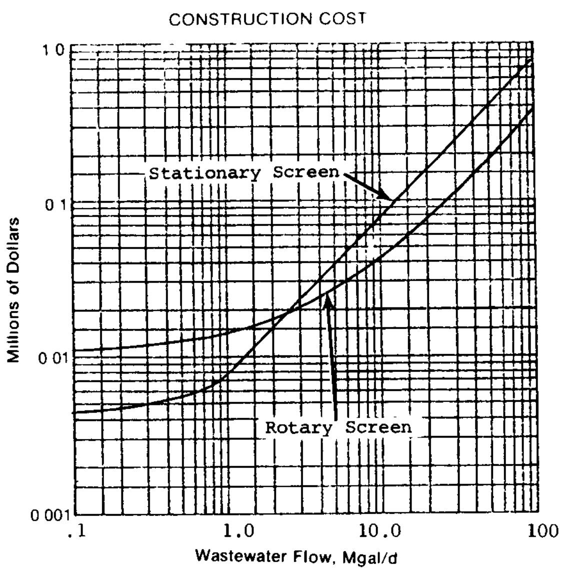
FLOW DIAGRAM

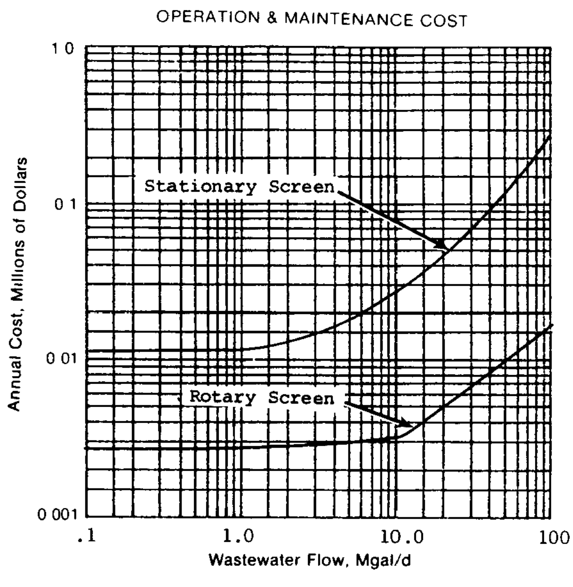


ENERGY NOTES - Energy requirements of the stationary screens are dependent upon the head loss through the screen system which may amount to 4 to 8 ft TDH. Energy requirements are kWh/yr = 1900 (Mgal/d X TDH) at a wire to water efficiency of 60 percent. With a representative head of 4.5 ft, 8,550 kWh/yr would be required per Mgal/d. Operation of rotary drum units requires about 3,300 kWh/yr for up to 1 Mgal/d; 5,000 kWh/yr for 1 to 6 Mgal/d; 10,000 to 20,000 kWh/yr for 6 to 8 Mgal/d; and about 2,000 kWh/yr/Mgal/d for higher flows in addition to pumping energy for 2.5 to 4.5 ft of static head.

COSTS* - Assumptions: Last quarter 1978 dollars. ENR Index = 2860

1. Construction cost includes wedgewire stainless steel screen 0.06 inch opening; equipment and installation, including electrical. Equipment provides suitable weirs for flow control.
2. Cost does not include flumes or piping for effluent or sludge, or pumping equipment.
3. Operation cost based on labor costs at $7.50/h; power at $0.02/kWh; pumping head for stationary screen 4.5 Ft.





REFERENCES - 3, 99

*To convert construction cost to capital cost see Table A-2.

AMMONIA STRIPPING FACT SHEET 4.1.1

Description - Ammonia Stripping is a simple desorption process used to lower the ammonia content of a wastewater stream. In the process, wastewater at elevated pH is pumped to the top of a packed tower with a countercurrent flow of air drawn through the bottom openings. Free ammonia (NH_3) is stripped from the falling water droplets into the air stream which is then discharged to the atmosphere.

Lime or caustic soda is added prior to the stripping to raise the pH of the wastewater to the range of 10.8 to 11.5 converting essentially all ammonium ions to ammonia gas which can be stripped by air. Process controls required for the operation are the proper pH adjustment of the influent wastewater, and maintenance of proper air and water flows.

Ammonia removal efficiency is highly dependent on air temperature and air/water ratios. As the air temperature decreases, the efficiency drops significantly. The most common operating problem of this process is the occasional formation of calcium carbonate scale. The influent should always be clarified before stripping.

Common Modifications - Tower packing materials, plastic and wood; operation of the stripping gas in a closed system with an ammonia absorption unit for removal of the CO_2 from the stripping gas stream to reduce scaling problems; reclamation of ammonia from the closed cycle absorption unit; use of high pH holding ponds, followed by a cross flow spray tower and final removal of the residual ammonia by breakpoint chlorination.

Technology Status - The process is considered fully demonstrated but not widely used.

Applications - Good for wastewater with high ammonia content (more than 10 mg/l). For higher ammonia content (more than 100 mg/l), it may be economical to use alternate ammonia removal techniques. See Fact Sheet No. 4.1.2.

Limitations - Poor efficiency in cold weather locations (0° - 10°C). Cannot operate in freezing conditions (unless sufficient heated air is available). Ammonia is discharged to atmosphere usually at low level (6 mg/m^3). This may be objectionable in certain locations. Nitrite, nitrate and organic nitrogen are not removed. Poor efficiency when ammonia concentration is low (less than 10 mg/l). Scale formation can be removed hydraulically in most cases but not in all, resulting in a need to pilot test at most locations.

Typical Equipment - Stripping tower closely resembles a conventional cooling tower, with 24 manufacturers (77).

Performance - The operation is unaffected by toxic compounds which can disrupt the performance of a biological system. However, volatile toxics will be stripped during the process. Operating efficiency is highly dependent on air temperature as follows:

Air Temperature	NH_3 Removal Efficiency
10°C	75 percent
20°C	90 to 95 percent

Efficiency may be reduced by severe scaling in the tower. However, under normal operating conditions, residual ammonia concentrations are in the 1 to 3 mg/l range.

Chemicals Required - Lime or caustic soda is needed to raise the pH of the wastewater to the range of 10.8 to 11.5. For wastewater with high calcium content, an inhibiting polymer may be added to ease the scaling problem. Effluent from the stripping may need pH readjustment to neutral condition with an acid (H_2SO_4 at 1.75 parts for one part of lime added) or recarbonation followed by clarification.

Design Criteria -

Wastewater loading: 1 to 2 gal/min/ft^2
Stripping air flow rate: 300 to 500 ft^3/gal

Packing depth: 20 to 25 ft
pH of wastewater: 10.8 to 11.5
Air pressure drop: 0.015" to 0.019" of water/ft

Packing material: plastic or wood
Packing spacing: approx. 2" horizontal and vertical
Providing: uniform water distribution
Providing: scale removal and clean-up
Land requirement: small

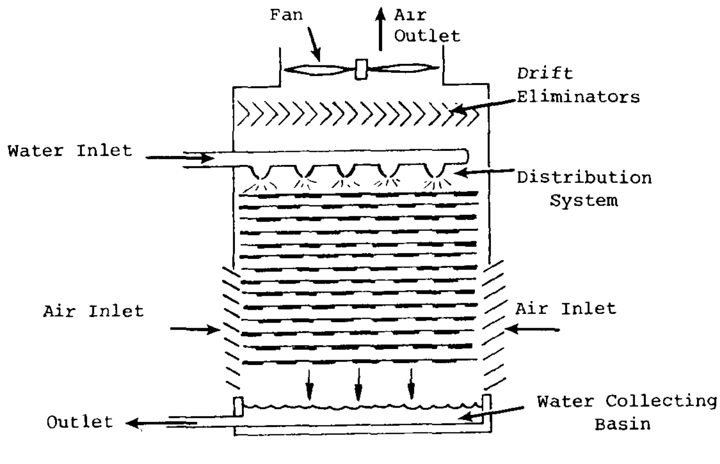
Reliability - The operation is simple and reliable, and not subject to upset by the wastewater fluctuation, if pH and air temperature are stable. Occasional clean-up of scale may be required.

Environmental Impact -

Air: Normal operational discharge of less than 6 mg/m^3 does not present an odor problem. NH_3 washout to downwind water bodies; minor noise pollution from motor, fan and water splashing.

References - 3, 4, 23, 28, 31, 39, 44, 47

FLOW DIAGRAM -



Countercurrent Tower

ENERGY NOTES (4) - Pumping energy requirements can be approximated by the use of the following equation:

$$kWh/yr = \frac{1140\ (Mgal/d \quad x\ ft\ of\ total\ head)}{Wire\ to\ water\ Efficiency}$$

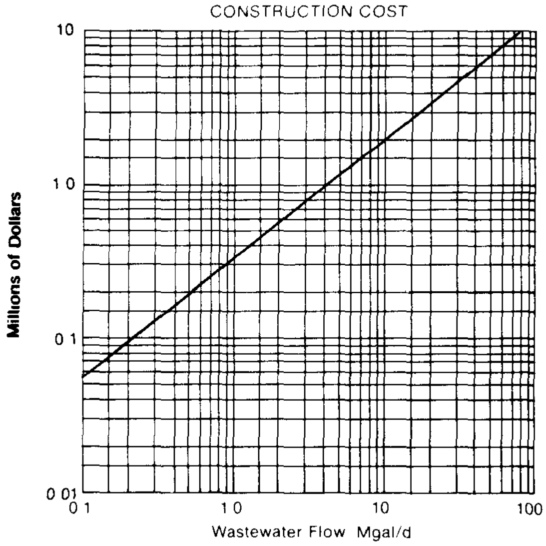
For a TDH of 50 feet, a wire to water efficiency of 60 percent and a 1 Mgal/d flow would amount to 95,000 kWh/yr. Assuming a fan energy requirement of 0.0765 hp/1,000 gal (400 ft^3/gal), a 1 Mgal/d facility would require 500,000 kWh/yr, resulting in a total energy requirement of 600,000 kWh/yr.

COSTS* - Assumptions: ENR 2475, Sept 1976

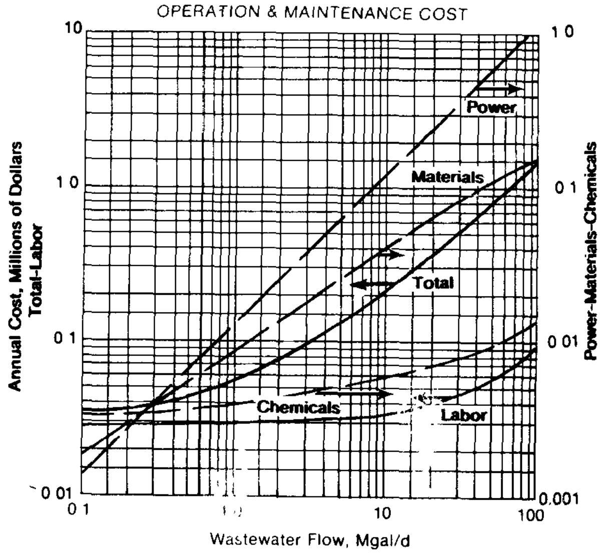
Design Assumptions: Tower, 20 ft high, packed with 1/2 in diameter Schedule 80 Pvc pipe at 3 in centers horizontally with alternate layers placed at right angles at 2 in centers vertically; Pump, 50 ft TDH; Loading, 1 gal/min/ft^2; Air Flow, 400 ft^3/gal; Concentration of NH_3, influent 18 mg/l, effluent 3 mg/l; pH to 11-11.5

Operation Assumptions: Labor, at $7.50/h, including benefits; Power, at $.02/kWh; Lime, at $30/ton
Note: Total O&M costs have been derived from the power, materials, chemicals and labor costs provided in Ref. 3.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES - 3, 4

*To convert construction cost to capital cost see Table A-2.

ARRP (AMMONIA REMOVAL AND RECOVERY PROCESS) FACT SHEET 4.1.2

Description - ARRP consists of two packed towers for stripping and absorption. In the stripping tower, wastewater flows downward against an upflow gas stream. Ammonia in the wastewater is stripped into the gas stream. The gas stream is then directed to the absorption tower, in which an absorption solution is sprayed downward. With good countercurrent contact, most of the ammonia transferred to the gas stream is absorbed by the solution. The gas stream is then recycled back to the stripping tower for reuse.

Lime or caustic soda is usually added to the wastewater prior to ARRP to convert the ammonium ion in the wastewater to free ammonia. Air is used as the stripping gas. Water or a dilute acid (sulfuric acid) is frequently selected as the absorption solution, so that the process produces an aqueous ammonia solution or an ammonium sulfate solution.

Common Modifications - For wastewaters with high ammonium ion concentrations (greater than 300 mg/l), steam may be economically used as the stripping gas. Steam is injected at the bottom of the stripping tower and is condensed as it exits. A wastewater feed-effluent heat exchanger is often used to minimize energy consumption.

Technology Status - Steam stripping and absorption operations are commonly used in chemical and fertilizer industries. In wastewater treatment, air stripping is considered fully demonstrated, but not widely used. ARRP is a relatively untried process.

Applications - Economically attractive for treatment of wastewater, with a high ammonium ion concentration (greater than 100 mg/l). This approach is being used for stripping ammonia from selective ion exchange regenerant. May produce a waste ammonia stream with some value.

Limitations - Less competitive as ammonium ion concentration decreases. Highly susceptible to the ammonia market to become cost effective.

Typical Equipment/No. of Mfrs. (77) - Stripping towers/28; absorption towers/46

Performance - Ammonia removal efficiency can be expected to be higher than with ambient air stripping towers in the colder climates, since the stripping gas temperature approximates the wastewater temperature. Removal efficiencies are projected to range from 90 to 95 percent with water temperatures of $20^\circ C$ to 75 percent at water temperatures of $10^\circ C$. Scaling problems are reduced when compared to NH_3 air stripping towers.

Chemicals Required -
Sulfuric acid (H_2SO_4): at 2.72 parts per one part of ammonium ion recovered, if an $(NH_4)_2SO_4$ solution is the desired product. No sulfuric acid is needed if water is used as the absorption solution.

Lime (CaO): Sufficient lime to raise pH to 10.8 to 11.5 (see Fact Sheet 4.2.2).

Acid for pH readjustment: may be needed for neutralization of the residual alkali.

Design Criteria (28, 47) -

Stripping Operation

Wastewater loading:	1 to 2 gal/min/ft^2 (air stripping)
	7 gal/min/ft^2 (steam stripping)
Gas flow rate:	300 to 500 ft^3/gal (air stripping)
	15 lb/1000 gal (steam stripping)
Packing depth:	20 to 25 ft
Wastewater pH:	10.8 to 11.5

Absorption Operation

Product solution:	1 to 30% (aqueous ammonia)
	to 50% ($(NH_4)_2SO_4$ solution)
Tower diameter:	50 to 75% flooding velocity
Degree of recovery:	about 90%
Packing depth:	15 to 20 ft
Gas pressure drop:	2 to 3" of water

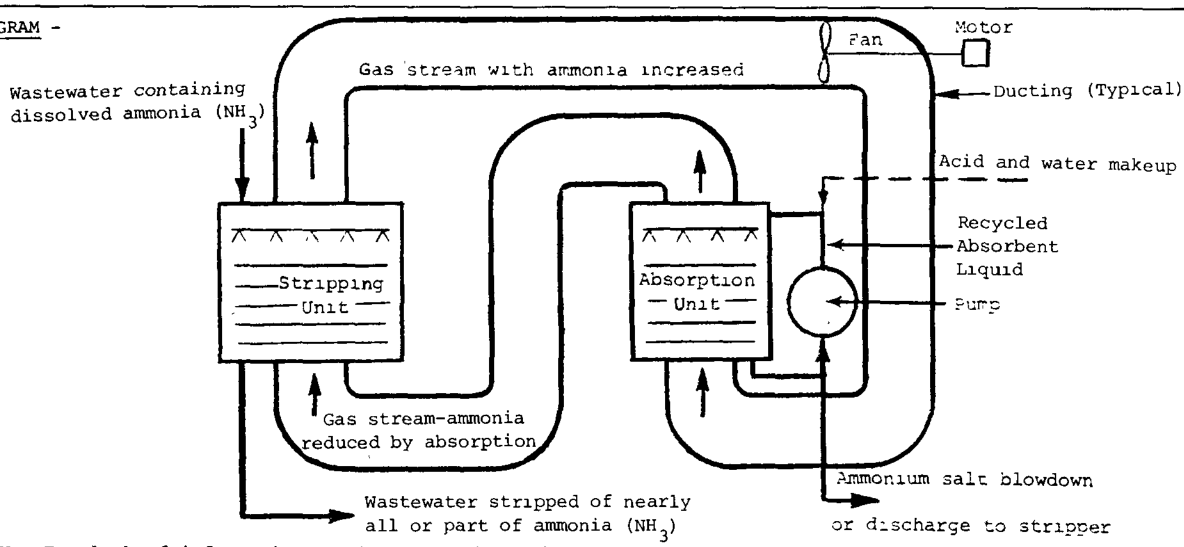
Tower diameter is set to a gas flow of 50 to 75 percent of flooding velocity for both the stripper and absorber.

Reliability - Can be expected to have a moderately high degree of reliability, as demonstrated in the chemical industry. Occasional clean-up of scale in the stripping tower and heat exchanger may be required.

Environmental Impact - Air: No impact without leakage.
Water: Effluent would have a slightly higher solids content due to pH adjustment.

References - 3, 28, 47, 77

FLOW DIAGRAM -



ASSUMPTION - For lack of information on the adsorption unit, it is assumed to be two-thirds the size of the stripping unit. A further assumption is that the construction cost, operation and maintenance cost, and energy requirements are also two-thirds of that for the stripping unit.

ENERGY NOTES -

Stripper: Pumping - kWh/yr = $\frac{1140 \text{ X Mgal/d X TDH}}{\text{wire to water efficiency}}$

Fan - kWh/yr = 76.5 hp/Mgal/d at 400 std. ft^3 air/gal of wastewater

Absorber: Pumping - kWh/yr = 0.67 X Energy Required for Stripper Pumping

Fan - kWh/yr = 0.67 X Energy Required for Stripper Fan

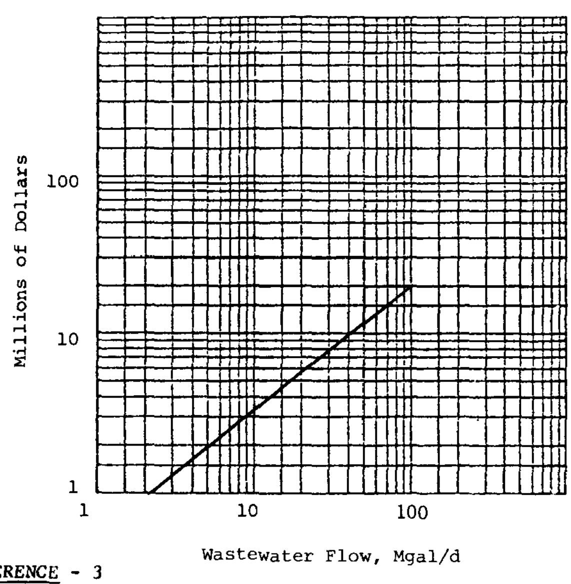
For wastewater flow of 1 Mgal/d, TDH of 50 ft and wire to water efficiency of 60 percent. The total energy required is: Pumping = 160,000 kWh/yr; Fan = 835,000 kWh/yr; Total = 995,000 kWh/yr

COSTS*- Assumptions: ENR Index = 2475

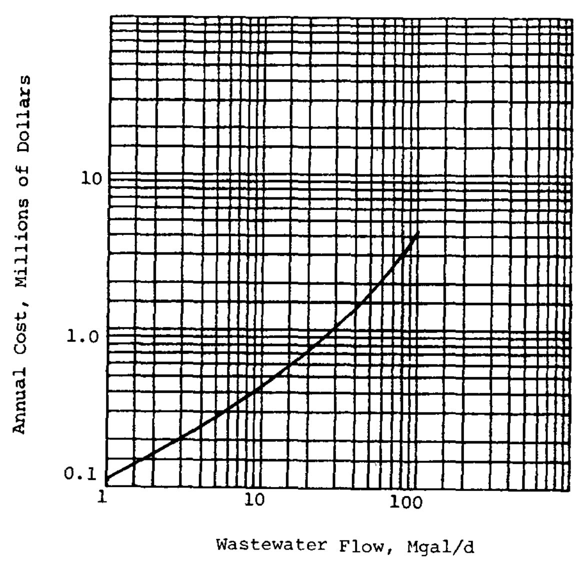
1. Construction cost includes ammonia stripping tower (20 ft high packed with 1/2 in. diameter schedule 80 PVC pipe at 3 in. centers horizontally with alternate layers placed at right angles at 2 in. centers vertically); pumps (50 ft TDH); lime feed facilities to raise pH to 11 to 11.5 and sulfuric acid facilities to subsequently neutralize the treated effluent. No credit for sale of NH_3.
2. Hydraulic loading: 1.0 gal/min/ft^2; Air/water ratio: 400 ft^3/gal.
3. Process performance:

	Wastewater Characteristics	
	In	Out
NH_3, mg/l	18	3

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

BREAKPOINT CHLORINATION FACT SHEET 4.1.3

Description - Breakpoint chlorination is a chemical treatment for ammonium ion removal. In the process, chlorine is added to a wastewater containing ammonium ion in a mixing tank, where practically all the ammonium ions are oxidized to nitrogen gas. Amount of chlorine addition is precisely adjusted to a level (the breakpoint) which is sufficient for the oxidation and results in minimal residual chlorine and by-product formation. Hydrochloric acid is co-produced during the oxidation and must be neutralized by adding lime or caustic soda. Equipment needs are relatively simple but control requirements for chlorine dosage and pH adjustment are sophisticated and important.

Common Modifications- A downstream de-chlorination step for the removal of residual chlorine is usually adopted. This can be a SO_2 addition (see Fact Sheet 4.5.2), or an activated carbon adsorption (see Fact Sheet 4.4.1). Sodium hypochlorite (NaOCl) may be used for the oxidation, instead of chlorine with no HCl co-production. In this case, no lime or caustic soda addition is needed.

Technology Status - Demonstrated on a large scale, but not widely used.

Applications - It is economically attractive for wastewater with low ammonium ion concentrations (less than 5 mg/l) and can be employed as a polishing step following other ammonium ion removal processes. It is especially attractive in a cold weather location.

Limitations - The process is rated low in capital costs, but high in operating costs, especially at ammonium ion concentrations above 16 mg/l. Potential for formation of chlorinated hydrocarbons in the effluent.

Typical Equipment/No. of Mfrs. (77) Chlorine analyzers/25; pH controllers/25; Control computers/42; Chemical feeders/27; Mixers/26.

Performance - Can reduce ammonium ion concentration to 0.1 mg/l or less, and convert to nitrogen gas and to insignificant amounts of by-products (nitrate at 0.2 to 0.45 mg/l and NCl_3 at 0 to 0.25 mg/l) under normal operation. Performance is not affected by temperature fluctuation or toxic compounds. However, pH and chlorine dosage have significant effects on by-product formations as follows:

pH	6	7	8
NCl_3, mg/l	0.33	0.05	
NO_3^-, mg/l	0.70		1.0

Cl_2 dosage	Breakpoint	50% excess
NCl_3, mg/l	Trace	0.63
NO_3^-, mg/l	0.15	0.6

Organic nitrogen compound is only slightly reduced.

Chemicals Required-
Chlorine (Cl_2): 8 to 13 parts per one part of ammonium ion (or NaOCl at 9 to 14 parts, instead of Cl_2)
Lime (CaO): 0.9 to 1.1 lb per one lb of Cl_2 or 1.5 lb of NaOH per one lb of Cl_2 (No need if NaOCl is used instead of Cl_2)
SO_2 for dechlorination: See Fact Sheet 4.5.2.

Design Criteria (28), (47) -

Chlorination
pH range: 6 to 7
Contact time: 1-2 min.
Cl_2 control: quick response

Activated Carbon Dechlorination
Loading rate: 1 to 2 gal/min/ft^2
Carbon charge: 0.3 to 2 ft^3/Mgal
Contact time: 10 min.

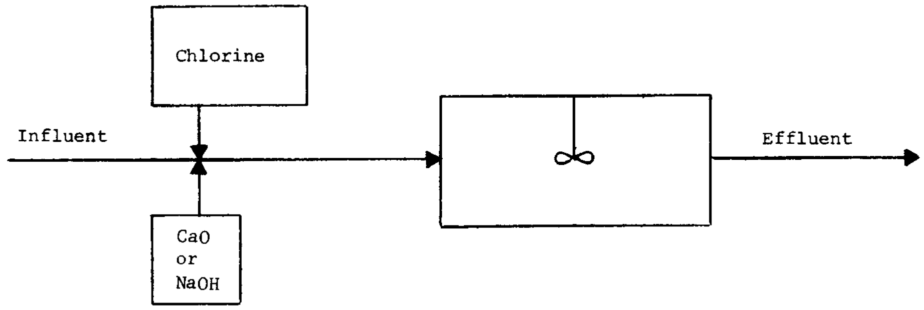
Reliability - Process reliability is medium. Computer control for quick and close dosage of chlorine and pH adjustment may be required to improve reliability and to minimize by-product formation.

Environmental Impact -
Air: Chlorine and by-products such as NCl_3 and H_2 may escape into the atmosphere, but the amounts are normally neglibible without process upset. Aeration operation for de-chlorination may not be acceptable in certain locations if the exit air is discharged directly into atmosphere.

Aqueous: Effluent TDS would increase significantly at 8.5, 12.2 or 14.8 times the amount of the ammonium ion reduced, depending on whether NaOCl, lime or caustic soda is used in the process.

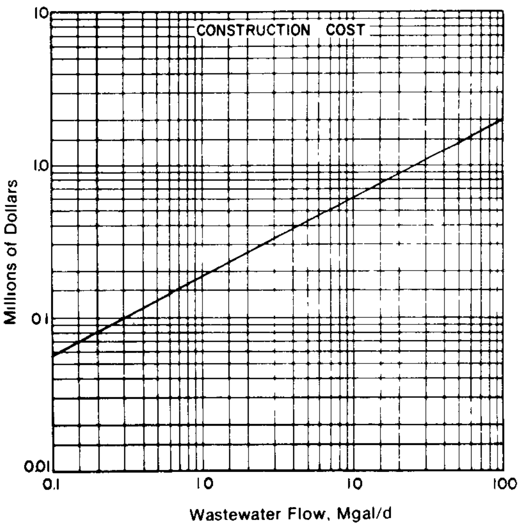
References - 3, 23, 28, 31, 47

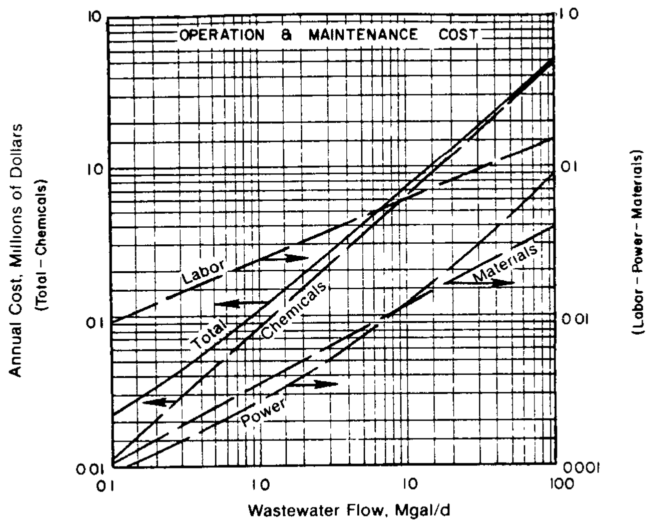
FLOW DIAGRAM -



ENERGY NOTES - Mixing energy - Approximately 135,000 kWh/yr/Mgal/d (Mixing power at 0.37 kWh/1000 gal)

COSTS* - Assumptions:
Service Life: 15 years
Equipment: Chlorine storage and feed system, lime storage and feed system, mixing tank (30 min)
Chemicals: Cl_2 (13 lb/lb of ammonium ion) at $160/ton
Lime (0.9 lb/lb of Cl_2) at $30/ton
Concentration: Ammonium ion input 23 mg/l, output 2.6 mg/l
Labor Rate: $7.50/h including benefits
Power Cost: $.02/kWh
Index: ENR 2475, Sept. 1976





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

ION EXCHANGE (FOR AMMONIA REMOVAL) FACT SHEET 4.1.4

Description - The ion exchange process can be utilized to reduce the ammonium ion concentration in wastewater. The medium is usually clinoptilolite, a natural ion exchange material. Wastewater, following filtration to reduce suspended solids, is passed downflow through the ion-exchange bed until the bed reaches the point of exhaustion. The bed is considered exhausted when the ammonia concentration in the effluent reaches a predetermined value. The exhausted bed can be regenerated with 2 percent NaCl solution. The effluent from the regeneration process is called spent regenerant, and it amounts to 2.5 to 5 percent of the wastewater stream and may contain more than 300 mg/l of ammonia. The key to the application of the ion exchange process is the method of handling of the spent regenerant.

The process for individual beds is batch but, by using multiple beds, continuous operation can be accomplished.

The spent regenerant requires some form of processing for separation of ammonia so that the regenerant can be reused. The alternative processes available for regenerant recovery are air stripping or steam stripping (Fact Sheet 4.1.2) at high pH and electrolysis treatment. The stripped ammonia can be vented to the atmosphere or absorbed in dilute acid solution and sold as fertilizer. Steam stripping produces a 1 percent aqueous ammonia solution as a waste product. Electrolysis converts chloride in the spent regenerant to chlorine which oxidizes ammonium to nitrogen gas.

Common Modifications - Any ion exchange material which has high selectivity for ammonium over other cations can be substituted for clinoptilolite.

Technology Status - The process is considered fully demonstrated, but not widely used.

Applications - The process may be employed for one or more of the following reasons: (1) Where cold weather limits the application of stripping as the sole process of ammonia removal (Fact Sheet 4.1.2), (2) reduction from a feed with low concentration of ammonium ion, 10 to 50 mg/l, (3) potential for the reduction of ammonia emission to atmosphere, (4) where limited increase in TDS is allowable.

Limitations - Relatively high capital cost compared to the other two ammonia removal processes, stripping or breakpoint chlorination. Nitrite, nitrate and organic nitrogen compounds are not removed.

Typical Equipment/No. of Mfrs. (77) - Ion exchangers/15; mixers/26; cycle controllers/36.

Performance - High ammonium ion removal efficiency, 93 to 97 percent, not significantly impaired by temperature fluctuation, and unaffected by toxic compounds. Residual ammonium ion concentrations are in the one to three mg/l range (down to 0.22 mg/l is possible at higher costs). Wastewater TDS would be increased by about 50 mg/l.

Chemicals Required -
Salt (NaCl): about 0.1 lb/1000 gallons of wastewater as makeup for purge and regenerant loss.
Caustic soda (NaOH): at 1.15 parts per one part of ammonium ion (or lime (CaO) at 1.6 parts per part of ammonium ion), if air or steam stripping is used for ammonia recovery.

Design Criteria -

Ion Exchange Operation
Clinoptilolite size = 20 x 50 mesh
Bed height = 4 to 6 ft
Wastewater suspended solids = 35 mg/l max.
Wastewater loading rate = 7.5 to 20 bed volume/h
Pressure drop = 8.4 in. of water/ft
Cycle time = 100 to 150 bed volumes for one 6 ft bed; 200 to 250 bed volumes for two 6 ft beds in series

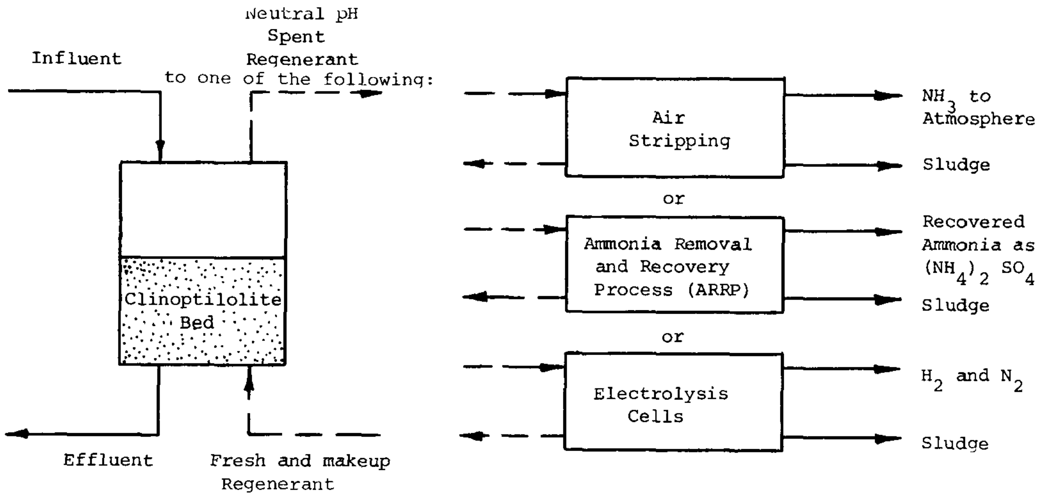
Regeneration
Solution = 2% NaCl
Solution flow rate = 4 to 10 bed volume/h or 4 to 8 $gal/min/ft^2$
Total solution volume = 2.5 to 5% of treated wastewater or 10 bed volumes
Cycle time = 1 to 3 hours
Backwash = 8 $gal/min/ft^2$

Reliability - Moderate. Operation is usually on automatic control, requiring occasional monitoring, inspection and maintenance. There is a potential scaling problem for wastewater with high magnesium and/or calcium contents.

Environmental Impact -
Air: None, unless regenerant air is stripped for NH_3 removal (see Fact Sheet 4.1.1).
Aqueous: A small purge stream (about 0.3 gal/1000 gal of wastewater), containing two percent NaCl, small amounts of calcium and magnesium salts and possibly some toxic metal ions (if any in the wastewater) must be disposed of. When a clarification step is employed, a low volume sludge stream, mainly $Mg(OH)_2$ and $CaCO_3$ must be disposed of. Effluent from the process would have a slightly higher solids content (addition of about 50 mg/l of salt).

References - 3, 23, 28, 47, 77

FLOW DIAGRAM -

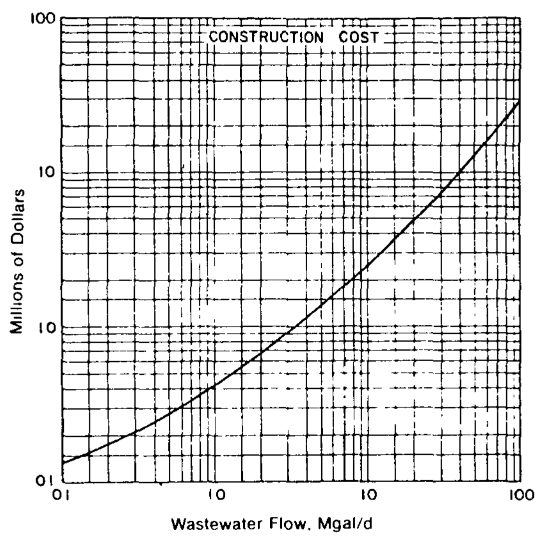


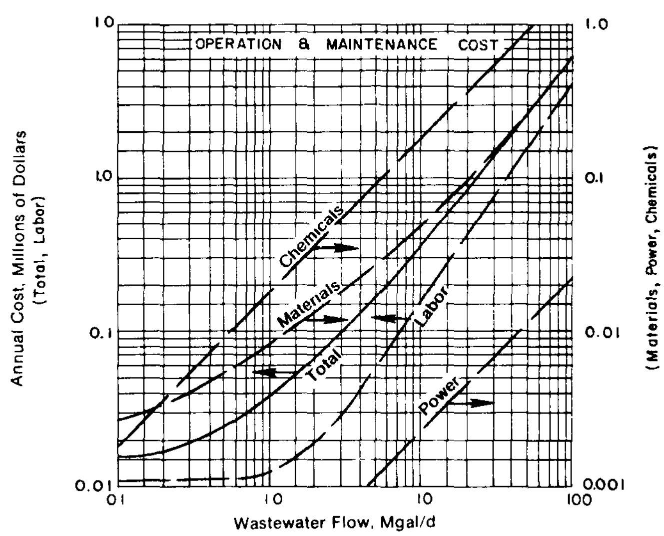
ENERGY NOTES - From the example below, power for operation of the regenerator amounts to 11,500 kWh/yr/Mgal/d.

COSTS * - Assumptions: ENR Index = 2475

1. Construction costs include:
   a. Gravity feed clinoptilolite beds with loading rate of 5.25 gal/min/ft^2 at 4 ft depth.
   b. Backwash regeneration facilities at 8 gal/min/ft^2.
   c. Sodium chloride regeneration facilities using 2 percent NaCl solution, 40 bed volumes/regeneration, and 1 regeneration/24 h.
   d. Closed-loop air stripping tower for regenerant recovery.
   e. Clarifier for spent regenerant.
2. Chemical costs include makeup clinoptilolite and makeup regenerant.
3. Ammonium sulfate produced by this system may be sold to offset operation and maintenance costs; however, it was not included in this cost estimate.

Note: Totals have been derived from the power, labor, materials and chemicals costs provided in reference 3.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

LIME RECALCINATION FACT SHEET 4.2.1

Description - In the recalcination process, lime sludge is subjected to thermal decomposition to produce quick lime (CaO) and CO_2. This process is very similar to the calcination process, except for the raw material, which is sludge. Primary or tertiary sludge where lime is used for coagulation can be recalcined. The application of the process reduces the volume for sludge disposal and for lime make-up requirements.

In a typical recalcination system, the lime sludges from chemical clarifiers and recarbonation reaction basins are thickened and centrifugally classified. The thickening process increases the solids concentration to 20 to 40 percent and the centrifugation reduces the inert content. The inert materials are made up largely of magnesium hydroxide and hydroxyapatite, and their presence will make the lime recovery and reuse more difficult. The cakes after centrifugation are ready for recalcination in the open hearth or fluidized bed furnace.

The tertiary plant serving South Lake Tahoe provides the most significant experience with open hearth furnace and the following details pertain to this plant. The cake after passing through solid bowl concurrent flow centrifuges is carried by a belt conveyor to a six-hearth furnace. The optimum temperature of operation appears to be 1900°F on the fourth and fifth hearths at 1.5 to 2.0 rabble rate. At this temperature, the available CaO increased by 5 percent as compared to a temperature of 1800°F. At a lower temperature, 1600°F, the product showed a tendency to agglomerate into particles of 1/4 to 3/4 inches in diameter with centers of unburned organic sludge in many of them. The recalcined lime is conveyed out of the furnace by gravity through a crusher to a thermal disc cooler where the lime temperature is lowered from 700°F to 100 to 150°F. From there it is conveyed to a rotary air lock and then to the storage bin. The product is in the form of lime dust. A portion of the stack gas is recycled to the recarbonation system to adjust the pH to about 7. The rest is scrubbed in a multiple tray scrubber before exhausting to the atmosphere. Although the cost of recalcined lime is slightly higher than new lime, the magnitude of sludge disposal reduced from 34 tons/d of liquid sludge to 1.5 tons/d of dry solids, thereby effecting a substantial cost saving.

A fluidized bed furnace may also be used. The filter cake is fed to a mixer along with dry recycled fines and quench water. From there it goes to a cage mill disintegrator where the pre-cooled calciner stack gas at 1000°F dries and disintegrates the moist solids. The resultant fine carbonate is conveyed by the exhaust gas to a cyclone separator. From the cyclone separator, a portion is recycled to the mixer and the other portion is fed to the calciner bin from where it enters the furnace. The furnace contains two compartments. The upper fluid bed is used for low temperature calcination (1500 to 1600°F) and the lower third bed to cool the product. The product is in the form of pelletized particles of 6 to 20 mesh size which is the primary advantage over the dusty product of open hearth furnace.

Commod Modifications - When large quantities of inert materials are involved, a dry classification device may be used after the recalcination furnace in addition to the wet centrifugal devices mentioned above.

Technology Status - At least six United States plants have utilized recalcination of lime sludge from treatment of wastewater.

Applications - Minimize makeup lime requirements and the amount of sludge for disposal.

Limitations - Economic feasibility of the process at a given site is dependent upon such factors as the quantity of lime used, sludge disposal costs and fuel costs and indirectly the expertise of the personnel available for satisfactory operation.

Typical Equipment/No. of Mfrs. (10, 23) - Calcination Reactor/12; Stack Gas scrubbers/3; Sludge cake conveyors/7; Sludge pumps/7; Air fans/42.

Performance - The recalcination of lime sludge reduces by a factor of 20 the amount of water and sludge for disposal. Seventy-two percent of the plant lime requirements can be obtained from the recovery process; 3.7 percent by weight of the usable calcium entering the furnace is lost as fly ash and captured in the wet scrubber.

Residuals Generated - Inerts from the centrifugal classifier in the form of magnesium hydroxide and hydroxyapatite and a portion of the lime. Wet scrubber sludge containing recalcined lime and particulates from combustion.

Design Criteria - Hearth loading rate = 5 $lb/ft^2/h$ of wet solids (approximately). Dry solids concentration = 20 to 40 percent. Excess air = 75 to 100 percent. Shaft cooling air flow = 1/3 to 1/2 of combustion air flow.

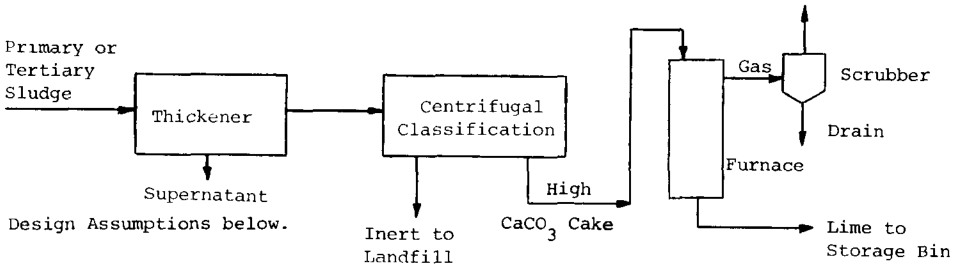
Environmental Impact - Particulate collection efficiencies of 96 to 97 percent are required to meet current EPA standards. Available data indicate that other air and water pollutant emissions are acceptable, however additional testing is required to confirm this.

References - 3, 8, 10, 23, 43, 77, 208

LIME RECALCINATION

FACT SHEET 4.2.1

FLOW DIAGRAM -



ENERGY NOTES - Based on Design Assumptions below.

Electrical energy -

Mgal/d	kWh/yr
1	150×10^3
10	650×10^3
100	$4,500 \times 10^3$

Fuel requirements 1.78×10^{10} Btu/Mgal/d/yr

To determine energy requirements for centrifuge operation see Fact Sheet 6.3.1 .

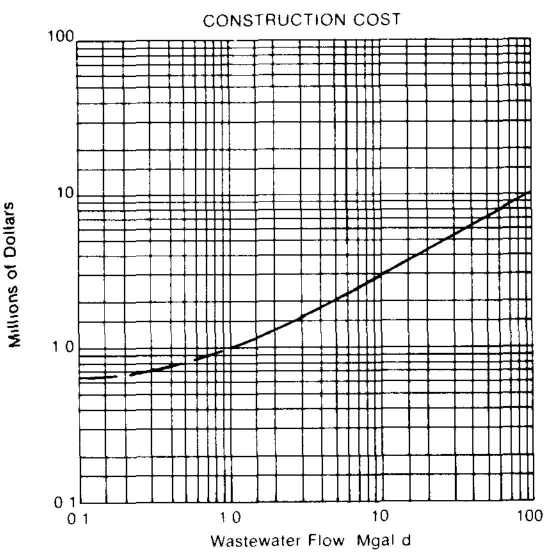
COSTS* - Assumptions: Service Life = 30 years; ENR Index = 2475

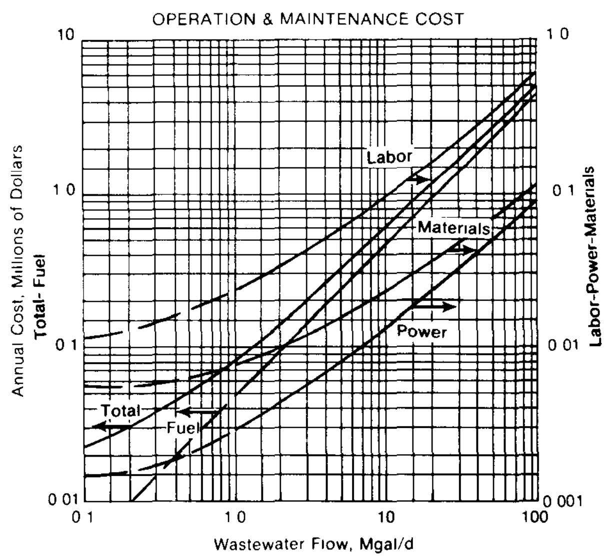
Design Basis:

1. Quantity of lime sludge: 4,500 lb/Mgal; 30 percent solids (from two-stage tertiary lime treatment).
2. Operations:

Flow Mgal/d	Wet Solids lb/h; 24 h/d	Days/Week Operating	Hours/Day Operating	Furnace Loading lb/h	Hearth Area ft^2
0.1	62.5	1	20	525	112
1.0	625	6	16	1,095	256
10.0	6,250	7	20	7,500	2 at 760
100.0	62,500	7	20	75,000	3 at 5,070

3. Fuel requirements (No. 2 fuel oil): 129,000 gal/yr/Mgal/d - 1.78×10^{10} Btu/Mgal/d/yr
4. Construction costs include recalcination furnace, sludge conveyors, storage, hoppers, building. Fuel cost = $2.66/$10^6$ Btu. Power cost = $0.02/kWh.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

TWO-STAGE TERTIARY LIME TREATMENT, WITHOUT RECALCINATION — FACT SHEET 4.2.2

Description - Lime treatment of secondary effluent for the removal of phosphorus and suspended solids is essentially the same process as high-lime clarification of raw wastewater. Calcium carbonate and magnesium hydroxide precipitate at high pH along with phosphorus hydroxyapatite and other suspended solids. In the two stage system, the first stage precipitation generally is controlled around a pH of 11, which is approximately one pH unit higher than that used in the single stage process. After precipitation and clarification in the first stage, the wastewater is recarbonated with carbon dioxide, forming a calcium carbonate precipitate which is removed in the second clarification stage.

Lime is generally added to a separate rapid-mixing tank or to the mixing zone of a solids contact or sludge blanket clarifier. After mixing, the wastewater is flocculated to allow for the particles to increase in size to aid in clarification. The clarified wastewater is recarbonated in a separate tank following the first clarifier, after which it is re-clarified in a second clarifier. Final pH adjustment may be required to meet allowable discharge limits.

Common Modifications - Treatment systems can consist of separate units for flash mixing, flocculation, and clarification; or they can consist of specially designed solids contact or sludge blanket units which contain flash mix, flocculation, and clarification zones in one unit. The calcium carbonate sludge formed in the second stage can be recalcined (see Fact Sheet No. 4.2.1). Final effluent can be neutralized with sulfuric acid, as well as other acids.

Technology Status - The use of these systems for water softening have been used for many decades, however their use for phosphorus removal has been prominant only since the mid-1960's. There are presently many large scale systems in operation.

Typical Equipment/No. of Mfrs. (23) - Clarifier equipment/38; chemical feeders/6; flocculators/32; mixers/26; instrumentation/9.

Applications - Used for the removal of phosphorus from wastewaters. Will also remove some BOD_5 and suspended solids as well as hardness present in the wastewater. Will also remove metals.

Limitations - Will generate relatively large amounts of chemical sludge. High operator skill required. In some cases polymer or coagulant is required to assist second-stage clarification.

Performance -

	Influent	Effluent
Phosphorus as P	Generally 15 to 40 mg/l, but not limiting in regard to effluent quality	0.01 to 1 mg/l

Chemicals Required - Lime (CaO), CO_2 or H_2SO_4, sometimes polymer or coagulant

Residuals Generated - First stage - Sludge containing hydroxyapatite, calcium carbonate, magnesium hydroxide, and organic solids - 1 to 1.5 pounds of dry solids per pound of lime added. Second stage - sludge may contain calcium carbonate, aluminum or ferric hydroxide, depending upon the coagulant used. The quantities generated are: 2.27 pounds $CaCo_3$ per pound of CO_2; 4 pounds per pound of Al in alum or 2.5 pounds per pound of Fe in ferric chloride.

Design Criteria - Clarifier settling rate - 1,000 to 1,400 gal/d/ft^2

Secondary Effluent Alkalinity (mg/l as $CaCO_3$)	Clarifier pH	Approximate Lime Dose (mg/l of CaO)
300	11.0	400-450
400	11.0	450-500

Carbon Dioxide - Feed tank - 5 to 15 minutes
Feed rate - 1.2 mg/l/mg/l of Ca to be precipitated

Unit Process Reliability - These systems are reliable from both a unit and process standpoint with skilled operator attention.

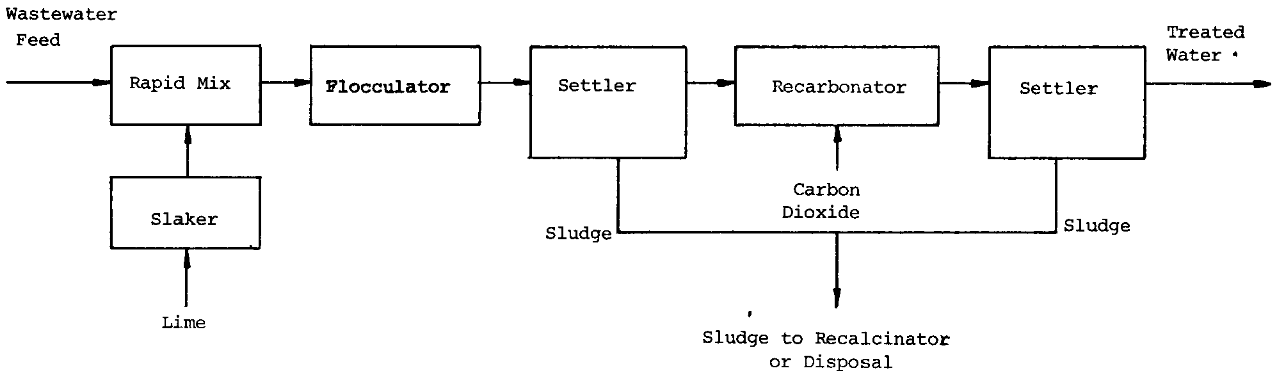
Environmental Impact - Will generate relatively large amounts of sludge which will need to be handled in some manner. Will have little or no effect on air pollution, noise levels, or odor. In comparison to secondary systems, little land use is required.

References - 29, 95

TWO-STAGE TERTIARY LIME TREATMENT, WITHOUT RECALCINATION

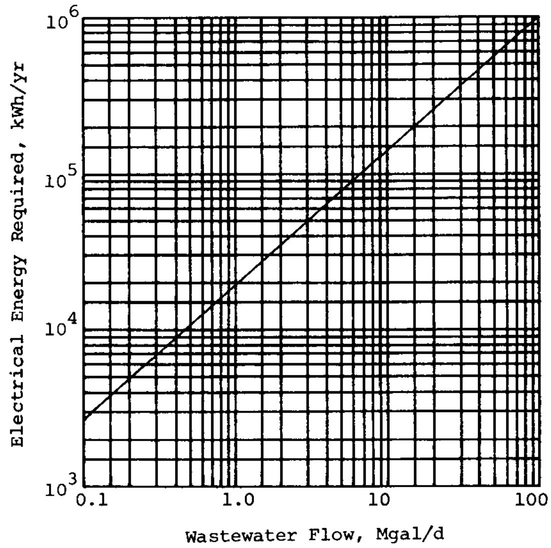
FACT SHEET 4.2.2

FLOW DIAGRAM -



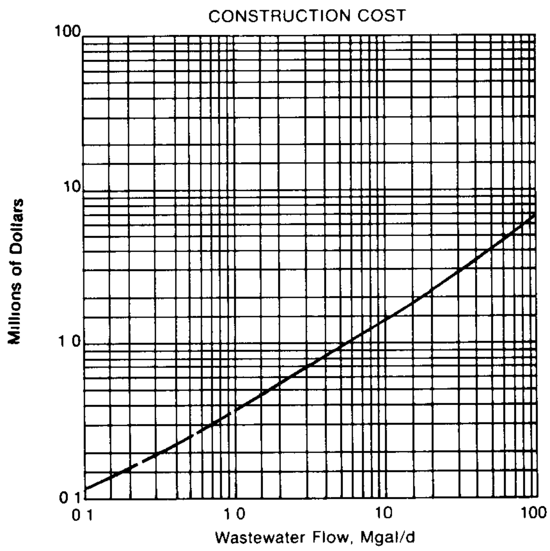
ENERGY NOTES -

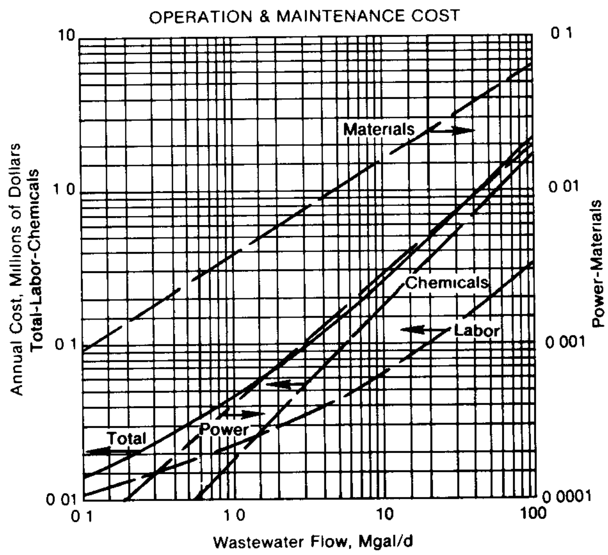
See design basis under COSTS.



COSTS - *Assumptions: ENR = 2475

1. Typical secondary effluent as feed to two-stage lime treatment.
2. Lime dosage rate = 400 mg/l or 3,340 lb/Mgal as CaO.
3. Clarifier overflow rate = 1,000 gal/d/ft^2.
4. Construction cost includes: lime storage and feed facilities, rapid-mix facilities, flocculator/clarifiers, flow and pH controls, and recarbonation facilities.
5. Costs do not include recalcination facilities.
6. Electric power = $.02/kWh
7. Lime costs = $25/ton, quick lime





REFERENCE - 3,

*To convert construction cost to capital cost see Table A-2.

INDEPENDENT PHYSICAL/CHEMICAL TREATMENT — FACT SHEET 4.3.1

Description - Independent Physical-Chemical Treatment (IPC) utilizes methods other than biological treatment to obtain secondary, or better, removals of BOD_5, COD and TSS. Typically, these systems use combinations of clarification with chemical addition, filtration, and activated carbon. This Fact Sheet includes nitrate addition to the activated carbon system to prevent H_2S formation by biological action in the carbon contactor.

Common Modifications - The following are some typical flow trains that can be used: Clarification, filtration, activated carbon (downflow); clarification, activated carbon (upflow), filtration. Additional treatment steps can be added to obtain better than secondary treatment levels, such as ammonia removal and part of phosphate clarification.

Technology Status - A number of full scale systems have been started up. Several mechanical problems have plagued operation. It has not been used on a wide scale.

Typical Equipment -
Clarification, filtration, preliminary treatment - See Fact Sheets 3.1.1 through 3.1.5.
Chemical addition - See Fact Sheets in Section 5.
Thickening and dewatering - See Fact Sheets 6.3.1 through 6.3.9.
Activated Carbon - See Fact Sheets 4.4.1, and 4.4.2.
Chlorination - See Fact Sheet 4.5.1.
Transportation and disposal - See Fact Sheets 6.1.1 through 6.1.11.

Applications - IPC can be used in some applications where standard biological treatment applies, namely typical municipal wastewater. IPC is a very flexible process and can be tailored to specific pollutant problems, such as high background levels of metals or refractory organic materials. Phosphorus and some toxic chemicals will also be removed. (See Fact Sheet 4.4.1.)

Limitations - The large quantities of sludge produced by the process may result in disposal problems.

Performance (50) - Application of screened degritted wastewater can result in the following estimated process effluent quality:

Unit Process Combinations	BOD_5 (mg/l)	COD (mg/l)	TURB (JTU)	PO_4 (mg/l)	SS (mg/l)	Color (Units)	NH_3-N (mg/l)
C,S	50-100	80-180	5-20	1-4	10-30	30-60	20-30
C,S,F	30-70	50-150	1-2	0.5-2	2-10	30-60	20-30
C,S,F,AC	10-30	25-45	1-2	0.5-2	2-10	5-20	20-30
C,S,NS,F,AC	5-10	25-45	1-2	0.5-2	2-10	5-20	1-10

C,S = coagulation and sedimentation; F = mixed-media filtration;
AC = activated carbon adsorption; NS = ammonia stripping.
Lower effluent NH_3 value at 18°C; upper value at 13°C.

Chemicals Required - $NaNO_3$ for H_2S control. In addition, chemicals are used to aid in suspended solids removal in the first stage clarification process. These include alum ($Al_2(SO_4)_3\ 14H_2O$), ferric chloride ($FeCl_3$), polymers, and lime (CaO). In small plants carbon dominates chemical costs.

Residuals Generated - Sludge will be generated in the preliminary clarification step. This sludge is quite voluminous (see Fact Sheet 5.1.5 for lime and 4.2.2 for alum and ferric chloride). Filter backwash water (see Fact Sheets 3.1.7 and 3.1.8) and spent activated carbon and carbon backwash water (see Fact Sheet 4.4.1) will also be generated. Carbon from regeneration will be recycled within the plant and the ash fines must be disposed of in an acceptable manner.

Design Criteria - See associated Fact Sheets for individual pieces of equipment. (Refer to listing of processes under "Typical Equipment" as shown above.)

Unit Process Reliability - Because this process is a combination of many processes, the reliability is a function of the individual unit process reliabilities. See individual Fact Sheets as indicated above.

Toxics Management - Removes many, but not all, non-degradable organic compounds. Most effective for non-polar, high molecular weight, slightly soluble compounds.

EPA has developed activated carbon adsorption isotherms for 60 toxic organic materials (86). The isotherms demonstrate removal of 51 of these organic compounds by activated carbon technology. Another study (87) demonstrated that PCB levels can be reduced from 50 micrograms per liter to less than 1 microgram per liter, and other work showed that aldrin, dieldrin, endrin, DDE, DDT, DDD, toxaphene, and Aroclors 1242 and 1254 can be removed to values less than 1 microgram per liter (88). Toxicity measured by bioassays was also significantly reduced.

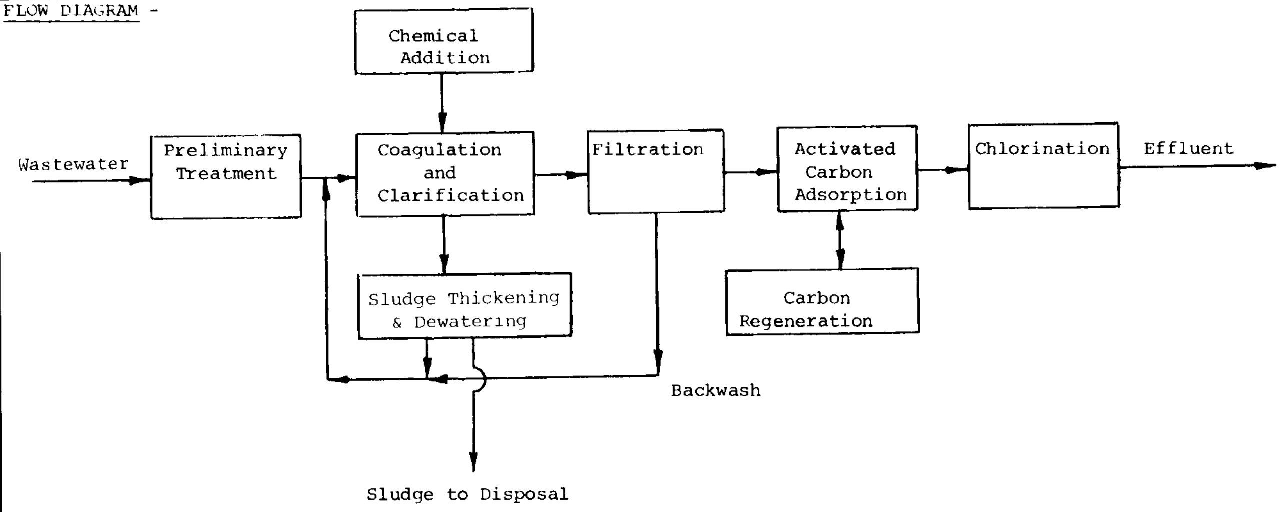
Environmental Impact- See Fact Sheets for individual processes. In general, however, this process requires much less land area than conventional biological secondary treatment systems. Phosphorus removal is inherent in this system.

References - 50, 86, 87, 88, 95

INDEPENDENT PHYSICAL/CHEMICAL TREATMENT

FACT SHEET 4.3.1

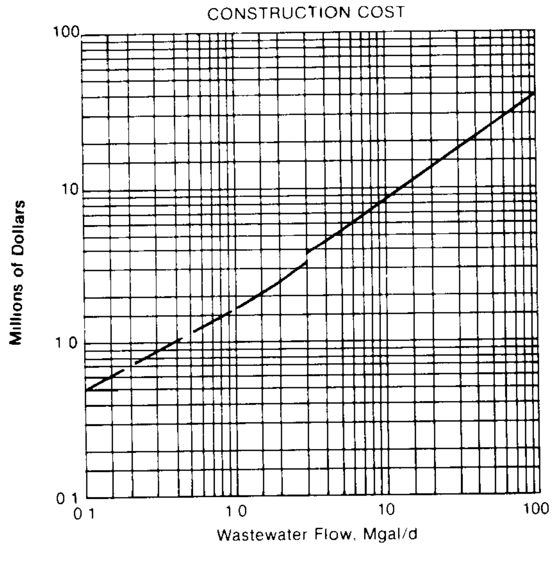
FLOW DIAGRAM -

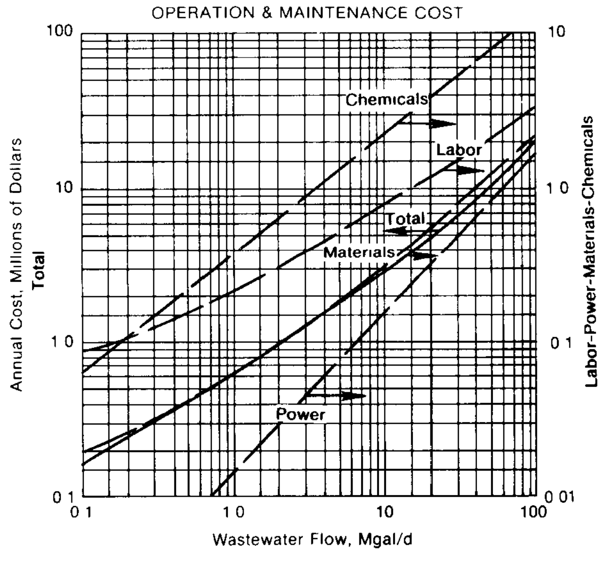


ENERGY NOTES - Energy (kWh/yr) = 7,500,000 (Mgal/d).

COSTS -*(ENR Index = 2475) Assumptions:

1. Processes include lift pumps, preliminary treatment, two-stage lime, gravity filtration, interstage pumping, carbon adsorption, chlorination, gravity thickener, vacuum filters, miscellaneous structures, support personnel.
2 Lime dosage at 400 mg/l as CaO.
3. Carbon adsorption without regeneration at plant sizes less than 3 Mgal/d; carbon adsorption with regeneration at plant size greater than 3 Mgal/d.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

TERTIARY GRANULAR ACTIVATED CARBON ADSORPTION FACT SHEET 4.4.1

Description - Granular activated carbon is used in wastewater treatment to adsorb soluble organic materials. Granular carbon systems generally consist of vessels in which the carbon is placed, forming a "filter" bed. These systems can also include carbon storage vessels and thermal regeneration facilities. Vessels are usually circular for pressure systems or rectangular for gravity flow systems. Once the carbon adsorptive capacity has been fully utilized, it must be disposed of or regenerated. Usually multiple carbon vessels are used to allow continuous operation. Columns can be operated in series or parallel modes. All vessels must be equipped with carbon removal and loading mechanisms to allow for the removal of spent carbon and the addition of new material. Flow can be either upward or downward through the carbon bed. Vessels are backwashed periodically. Surface wash and air scour systems can also be used as part of the backwash cycle.

Small systems usually dispose of spent carbon or regenerate it offsite. Systems above about 3 to 5 Mgal/d usually provide on-site regeneration of carbon for economic reasons. (See Fact Sheet No.4.4.2)

Technology Status - Has been used for municipal wastewater treatment on a limited basis since the mid-1960's.

Applications - Used directly following secondary clarifier, primarily when nitrification obtained in secondary treatment. Often preceded by chemical clarification of secondary effluent. In either case, a high quality influent is sought.

Limitations - Wastewater should be filtered prior to treatment to remove suspended solids. Requires more sophisticated operation than standard secondary treatment systems. Under certain conditions, granular carbon beds provide favorable conditions for the production of hydrogen sulfide, creating odors, and corrosion problems. More mechanical operations - difficult corrosion control - materials handling. Most applicable to low strength or toxic wastewaters.

Typical Equipment/No. of Mfrs. (23) - Activated carbon material/5 (90), granular carbon systems/15

Performance

	Influent (mg/l)	Effluent (mg/l)
BOD	10 to 50	5 to 20
COD	20 to 100	10 to 50
TSS	5 to 10	2 to 10

Side Streams:
Spent Carbon - 3 to 10 lb/lb of COD removed for Tertiary treatment
Backwash Water - 1 to 5 percent of wastewater throughput, TSS 100 to 250 mg/l

Design Criteria -

Size - Vessels 2 to 12 ft diameter commonly used
Area Loading - 2 to 10 gal/min/ft^2
Organic Loading - 0.1 to 0.3 lb BOD_5 or COD/lb carbon
Backwash - 12 to 20 gal/min/ft^2
Air Scour - 3 to 5 ft^3/min/ft^2
Bed Depth - 5 to 30 ft
Contact Time - 10 to 50 min.
Land Area - minimal

Reliability - Moderately reliable both mechanically and operationally depending on design construction and manufactured equipment quality.

Toxics Management - Removes many, but not all, non-degradable organic compounds. Most effective for non-polar, high molecular weight, slightly soluble compounds.

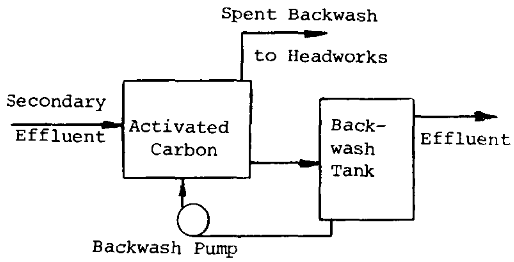
EPA has developed activated carbon adsorption isotherms for 60 toxic organic materials (86). The isotherms demonstrate removal of 51 of these organic compounds by activated carbon technology. Another study (87) demonstrated that PCB levels can be reduced from 50 micrograms per liter to less than 1 microgram per liter, and other work showed that aldrin, dieldrin, endrin, DDE, DDT, DDD, Toxaphene, and Aroclors 1242 and 1254 can be removed to values less than 1 microgram per liter(88). Toxicity measured by bioassays was also significantly reduced.

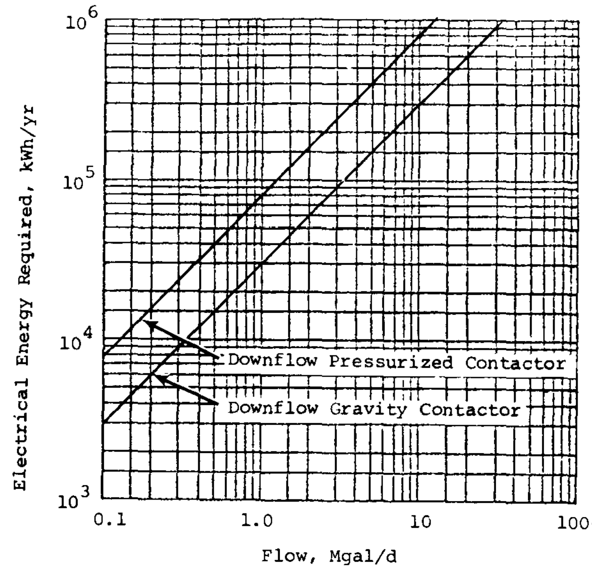
Environmental Impact - Very little use of land. There is air pollution generated as a result of regeneration. Under certain conditions, granular activated carbon beds may generate hydrogen sulfide which has an unpleasant odor. $NaNO_3$ or chlorine may be applied to the influent to inhibit or control these conditions. Spent carbon may be a land disposal problem, unless regenerated.

Improved Joint Treatment Potential - Will remove pollutants discharged by industrial sources that are generally not treated by normal secondary systems such as refractory organic materials and some metals.

References - 4, 23, 50, 84, 85, 86, 87, 88, 89, 90

FLOW DIAGRAM -



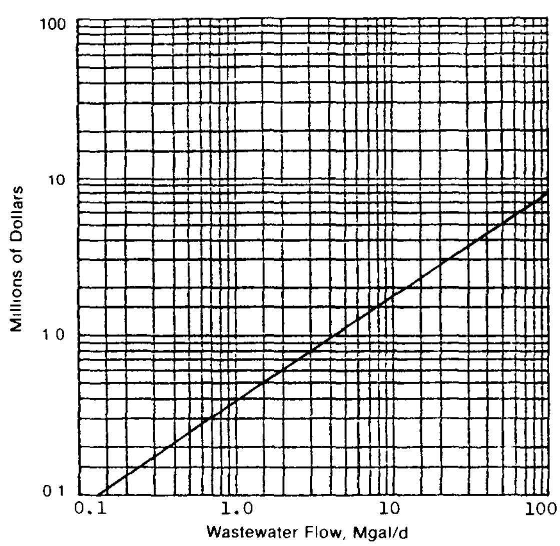


ENERGY NOTES - The energy consumption curve gives the energy required for pumping only. See Fact Sheet 4.4.2 for regeneration energy requirement. Carbon: 8 to 30 mesh size.
Downflow Pressure - Headloss = 37 ft; hydraulic load = 7 gal/min/ft^2; backwash rate = 18 gal/min/ft^2; terminal headloss = 20 ft; backwash time = 15 min; backwash frequency = 1/d.
Downflow Gravity - Hydraulic load 3.5 gal/min/ft^2; terminal headloss = 6 ft; backwash rate = 18 gal/min/ft^2; backwash time = 15 min; backwash frequency = 1/d; backwash pump headloss = 23 ft; pump and motor efficiency = 70 percent.

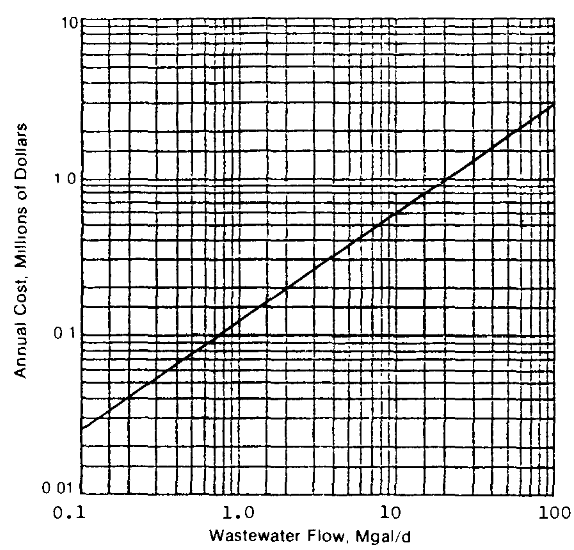
COSTS* - Assumptions: ENR Index = 2475

1. Construction cost includes vessels, media, pumps, carbon storage tanks, controls, and operations building; loading rate = 30 lb carbon per Mgal; contact time = 30 min; disposal costs not included.
2. O/M cost includes pumping (\$.02/kWh), labor (\$7.50/h, including fringes) and maintenance.
3. No regeneration is included.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES - 3, 84

*To convert construction cost to capital cost see Table A-2.

ACTIVATED CARBON THERMAL REGENERATION | FACT SHEET 4.4.2

Description - To make granular activated carbon economically feasible for wastewater treatment in most applications, the exhausted carbon must be regenerated and reused. When the plant effluent quality reaches the minimum effluent quality standards or when a predetermined carbon dosage is achieved, spent carbon is removed from the columns to be regenerated. The most common method of thermal regeneration of carbon is with the use of multiple hearth furnaces. Rotary kiln furnaces are also in use. In either case, a typical sequence for thermal regeneration of carbon is as follows:

The granular carbon is hydraulically transported (pumped) in a water slurry to the regeneration station for dewatering.
After dewatering, the carbon is fed to a furnace which requires an external source of steam and is heated to 1500 to 1700°F in a controlled atmosphere which volatilizes and oxidizes the adsorbed impurities.
The hot regenerated carbon is quenched in water.
The cooled regenerated carbon is washed to remove carbon fines and hydraulically transported to the adsorption equipment or to storage.
The furnace off-gases are scrubbed, (the scrubber water is returned to the plant for processing) and may also pass through an afterburner.

The thermal regeneration process itself involves four steps. The first step is drying, which occurs by evaporation at temperatures up to 300°F. The second step involves volatilization of light organic materials. This occurs at 300 to 600°F. Those organic compounds which are not removed by volatilization are thermally decomposed at temperatures of 600 to 1200°F. The last step involves reactivation, which is the removal of char from the pores of the carbon. The total regeneration process requires approximately 30 minutes. Regeneration systems usually require spent carbon holding tanks, regenerated carbon holding tanks, dewatering screws, quench tanks, steam generators, and air pollution control equipment.

Common Modifications - Multiple hearth furnaces, rotary kiln furnaces.

Technology Status - Thermal regeneration of carbon is a well-established and demonstrated technology.

Typical Equipment/No. of Mfrs. (23, 100) - Carbon regeneration furnaces/3; conveyors/4; air scrubbers/over 50.

Applications - Can be used whenever disposal of carbon is uneconomical or environmentally impractical, generally at large facilities.

Limitations - Is usually not practical for small activated carbon systems. Should generally be operated on a 24 h/d basis, which requires around-the-clock operator attention.

Performance - The quality of the carbon exiting the regeneration system will not equal that of virgin carbon. However, the actual amount of degradation is greatly dependent upon the carbon used and the organic materials removed. In general, there will be a reduction in iodine number, molasses index, with an associated increase in ash content. In addition, there will be a loss in carbon due to oxidation and crushing. This generally totals 2 to 10 percent of the carbon being regenerated, with 5 percent being the general average value.

Chemicals Required - Acid may be used to strip metals from regenerated carbon, in special cases.

Residuals Generated - Some amount of ash and carbon fines will be generated, which will greatly depend upon the quality of carbon and the type of wastewater treated. Exhaust air from the furnace will require scrubber treatment, resulting in the recycling of solids to the plant and eventual inclusion in sludges.

Design Criteria - The theoretically required furnace capacity can be determined by multiplying the carbon dosage (in lb carbon/Mgal) by the daily flow rate in Mgal/d. This will determine the lb carbon/d that must be regenerated. An allowance of 40 percent downtime should then be included. Multiple hearth furnaces used for regenerating carbon generally include a hearth area of about 1 ft^2/40 lb carbon/d to be regenerated. A storage tank should be sized to hold all of the carbon contained in the largest carbon adsorber. This tank would be used to hold the carbon prior to regeneration. A tank of equal size is needed to hold the regenerated carbon prior to its use in a previously emptied adsorber. A steam generator (0.4 to 1.0 lb steam/lb carbon) is also required in conjunction with the furnace. All ancillary equipment, such as conveyors and quenchers, should be designed for the maximum throughput of the furnace.

Unit Process Reliability - Carbon regeneration systems are reliable from a process standpoint. However, they are subject to more mechanical failures than other wastewater treatment processes. Therefore, high maintenance costs, relative to the unit's construction cost, can be expected.

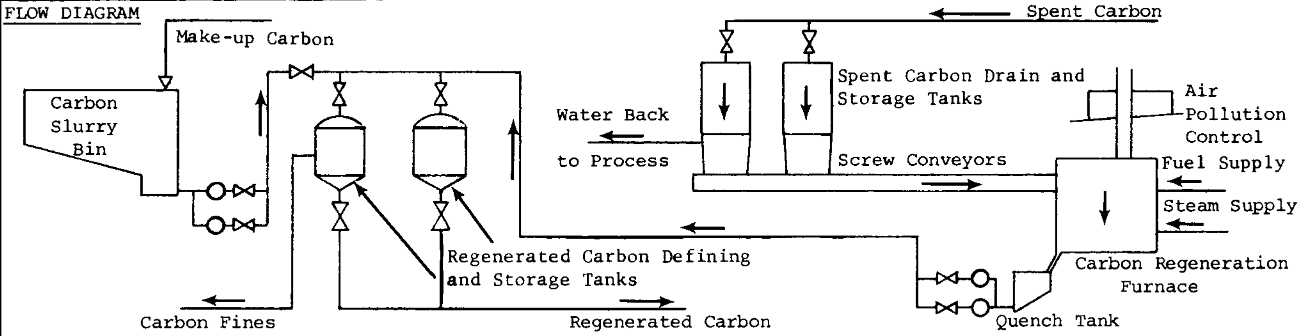
Environmental Impact - Very little use of land is required. Air emissions from the furnace will be polluted with volatiles stripped from the carbon and with carbon monoxide formed from incomplete combustion. Therefore, afterburners and scrubbers are usually required to treat the exhaust gases. The induced draft fan of a MHF could produce a noise problem, if not controlled. It should be noted that carbon regeneration will eliminate a solids handling problem caused by the spent carbon (See Fact Sheet 4.4.1).

References 50, 115

ACTIVATED CARBON THERMAL REGENERATION

FACT SHEET 4.4.2

FLOW DIAGRAM

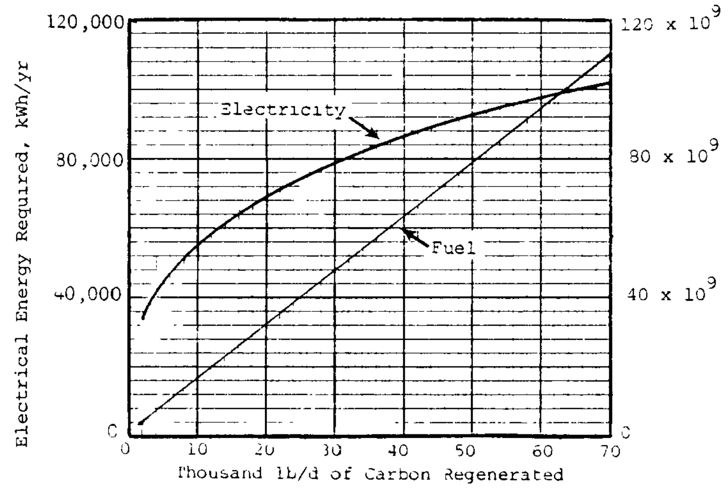


ENERGY NOTES (116) -

Electricity = 0.004-0.046 kWh/lb of carbon regenerated. Rate decreases with increasing scale.

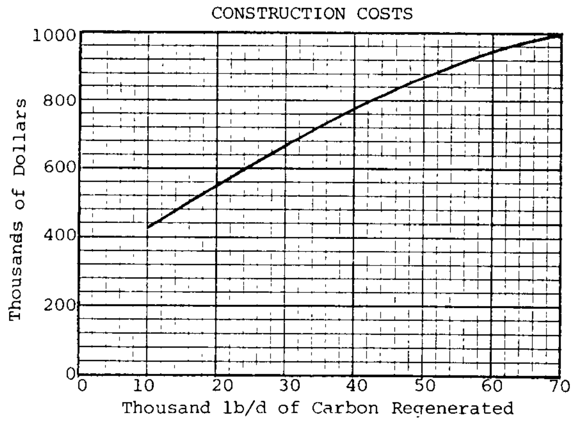
Fuel = 4300-6800 Btu/lb. Rate decreases with increasing scale.

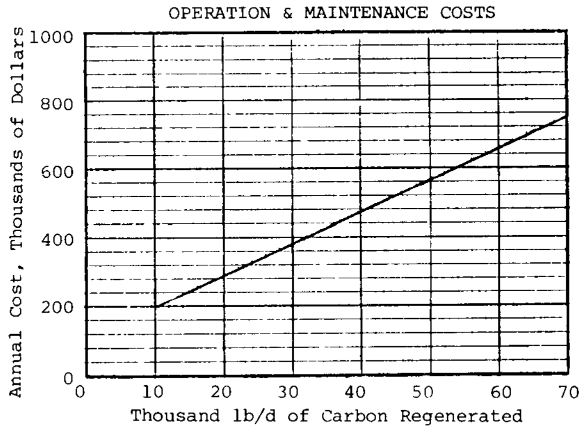
Steam = 0.6 lb/lb



COSTS* (116) - Assumptions: 1977 dollars; ENR Index = 2577

1. Carbon loss 5 percent per regeneration.
2. Equipment includes dewatering feed screw, quench tank, afterburner, scrubber, furnace and controls, two storage tanks and steam generator.
3. Operating costs are based on maintenance costs of 15 percent of constructed costs/yr. Carbon make-up - $.50/lb.





REFERENCES - 50, 116

*To convert construction cost to capital cost see Table A-2.

OZONE OXIDATION (AIR AND OXYGEN) FACT SHEET 4.4.3

Description - Ozone (O_3) is a very strong oxidant. At dosages of 10 to 300 mg/l, ozone may be used to remove residual dissolved organics in secondary effluent. Ozone has also been experimentally used to treat raw wastewater and wastewater after various stages of treatment. The rate of oxidation is both temperature and pH dependent. Reaction rates increase with increasing temperature. Because there is a wide range of ozone reactivity with the diverse organic content of wastewater, both the required ozone dose and reaction time are dependent on the quality of the influent to the ozonation process. Generally, higher doses and longer contact times are required for ozone oxidation reactions than are required for wastewater disinfection using ozone. Ozone tertiary treatment may eliminate the need for a final disinfection step. Ozone breaks down to elemental oxygen in a relatively short period of time (half life about 20 minutes). Consequently, it must be generated on site using either air or oxygen as the feed gas. Ozone generation utilizes a silent electric arc or corona through which air or oxygen passes, and yields an ozone in air/oxygen mixture, the percentage of ozone being a function of voltage, frequency, gas flow rate and moisture. Automatic devices are commonly applied to control and adjust the ozone generation rate.

Common Modifications - Systems have been designed which utilize staged contactors (injection type) with recycle of the ozone/oxygen off-gas. On these systems, provision must be made for the removal of nitrogen gas from the influent wastewater stream and for the removal of reaction-produced carbon dioxide from the off-gas stream in those situations that warrant it.

Technology Status - It is a developing technology. Recent developments and cost reduction in ozone generation and ozone dissolution technology make the process more competitive. A full scale application is currently in the start-up stage.

Applications - The process is feasible as a tertiary treatment for oxidation of residual dissolved organics, cyanides, organic N compounds and other toxics susceptible to the highly active oxidation characteristics of ozone. If oxygen-activated sludge is employed in the system, ozone treatment may be economically attractive, since a source of pure oxygen is available facilitating ozone production.

Limitations - For poor quality wastewater with high COD, BOD_5 and/or TOC contents (greater than 300 mg/l), ozone treatment may be uneconomical due to high ozone consumption. COD removal is generally limited to around 70 percent. May not be effective in oxidizing some halogenated hydrocarbons.

Typical Equipment/No. of Mfrs. (77, 130) - Oxygen generator/5; Columns-towers/60; Ozone auxiliary equipment/8; Ozone generator/10.

Performance - The following table shows the reduction of overall COD, BOD_5, and TOC, achieved in laboratory tests after a 90 minute contact time with ozone (128).

	COD, mg/l		BOD_5, mg/l		TOC, mg/l	
Ozone Dosage, mg/l	Influent	Effluent	Influent	Effluent	Influent	Effluent
50	318	262	142	110	93	80
100	318	245	142	100	93	77
200	318	200	142	95	93	80
325	318	159	142	60	93	50
50	45	27	13	7	20.5	15.5
100	45	11	13	3	20.5	9
200	45	5.5	13	1.5	20.5	5

Beyond the 70 percent COD removal level, the oxidation rate is significantly slowed. In laboratory tests, COD removal never reaches 100 percent even at a high ozone dose of 300 mg/l.

Chemicals Required - Air or pure oxygen may be used as the feed gas to the ozone generator.

Design Criteria -

Contact time:	1 to 90 min	Ozone production	4.5 kWh/lb from oxygen, 7.5 kWh/lb from air
Dosage rate:	10 to 300 mg/l	pH range:	5 to 11 (6 to 8 optimum)

Reliability - Mechanical reliability is good.

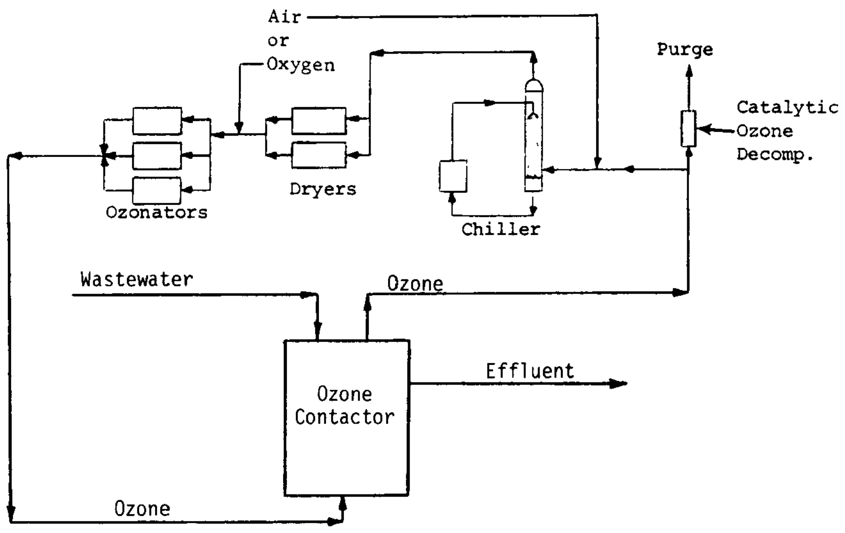
Environmental Impact - Ozone in off gases which are not destroyed is an air pollutant in the lower atmosphere which can discolor or kill vegetation coming in contact with it. Inhalation toxicology of ozone is both exposure duration and concentration dependent.

Toxics Management - Ozone has been found to be a good oxidant for removal of cyanide, phenol and other dissolved toxic organic materials.

References - 77, 95, 128, 130, 132, 172

OZONE OXIDATION (AIR AND OXYGEN) FACT SHEET 4.4.3

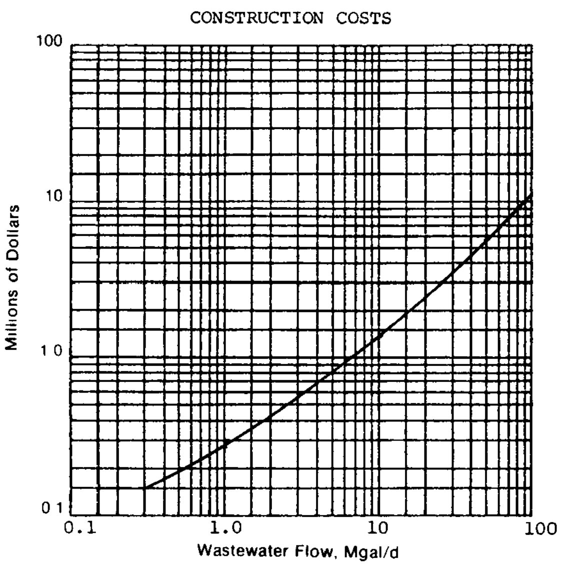
FLOW DIAGRAM -

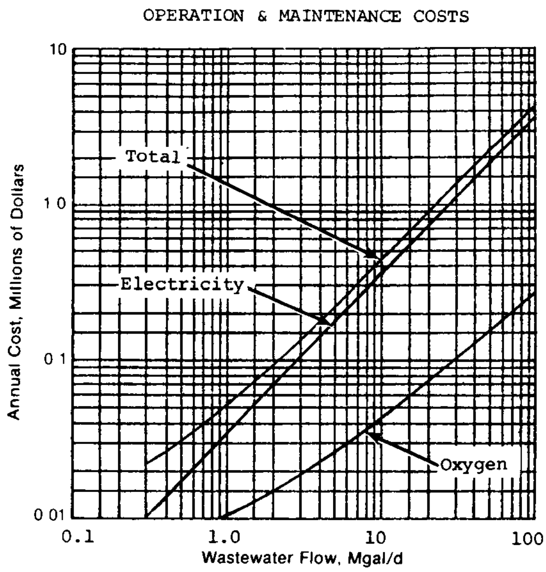


ENERGY NOTES - 1,927,200 kWh/yr/Mgal/d are the estimated energy requirements for a 75 mg/l ozone dosage derived from an oxygen feed.

COSTS* - Assumptions: 1971 prices; ENR Index = 1581

1. Construction costs are based on an ozone dosage of 75 mg/l derived from an oxygen feed.
2. Construction costs include deaerators, process pumps, injector and mixers, reactors and holding tanks, oxygen compressors, dryers, ozone generators, sumps and draws, ozone decomposer.
3. Total operation and maintenance costs include electricity, oxygen, maintenance and labor.
4. Labor = $5/hr plus 30 percent for overhead and supervision; electricity = $.02/kWh.





REFERENCES - 3, 95, 172

*To convert construction cost to capital cost see Table A-2.

CHLORINATION (DISINFECTION) — FACT SHEET 4.5.1

Description - Chlorination is the most commonly used wastewater disinfection process. This process involves the addition of elemental chlorine or hypochlorite to the wastewater. When chlorine is used, it combines with water to form hypochlorous (HOCl) and hydrochloric (HCl) acids. Hydrolysis goes virtually to completion at pH values and concentrations normally experienced in municipal wastewater applications. Hypochlorous acid will ionize to hypochlorite (OCl) ion, with the amount greatly affected by pH. However, hypochlorous acid is the primary disinfectant in water. In wastewater, the primary disinfectant species is monochloramine. Therefore, the tendency of hypochlorous acid to dissociate to hypochlorite ion should be discouraged by maintaining a pH below 7.5.

The amount of chlorine added is determined by cylinder weight loss. Chlorine demand is determined by the difference between the chlorine added and the measured residual concentration after a certain period has passed from the time of addition. This is usually 15-30 minutes. The chlorine or hypochlorite is rapidly mixed with the wastewater, after which it passes through a detention tank, which normally contains baffled zones to prevent short circuiting of wastewater.

Common Modifications - Chlorine or hypochlorite salts can be used. The two most common hypochlorite salts are calcium and sodium hypochlorite. Dechlorination may be used, which generally involves the addition of sulfur dioxide (see Fact Sheet 4.5.2), aeration, or even activated carbon, when chlorine residual standards are strict.

Technology Status - Chlorination of water supplies on an emergency basis has been practiced since about 1850. Presently, chlorination of both water supplies and wastewaters is an extremely wide-spread practice.

Typical Equipment/No. of Mfrs. (77) - Chlorine analyzers/25; pH controllers/25; Chemical feeders/27; Mixers/26.

Applications - Chlorination for disinfection is used to prevent the spread of waterborne diseases and to control algae growth and odors.

Limitations - May cause the formation of chlorinated hydrocarbons, some of which are known to be carcinogenic compounds. The effectiveness of chlorination is greatly dependent on pH and temperature of the wastewater. Chlorine gas is a hazardous material, and requires sophisticated handling procedures. Chlorine will react with certain chemicals in the wastewater, leaving only the residual amounts of chlorine for disinfection. Chlorine will oxidize ammonia, hydrogen sulfide, as well as metals present in their reduced states.

Performance - It should be noted that disinfection is designed to kill harmful organisms, and generally does not result in a sterile water (free of all microorganisms). The following table presents coliform remaining after 30 minutes of chlorine contact time assuming primary effluent contains 35 x 10^6 total coliform/100 ml prior to disinfection, and secondary effluent contains 1 x 10^6 total coliform/100 ml prior to disinfection. The values given are dependent upon good mixing in a highly turbulent regime followed by ideal plug flow conditions in the contact chamber. If these conditions do not exist, a definitive relation between Cl_2 residual and coliform reduction cannot be expected. Predictability of results from chlorination is also affected by wastewater characteristics and treatment processes used.

	Total Coliform MPN/100 ml	
Chlorine Residual, mg/l	Primary Effluent	Secondary Effluent
0.5 - 1.5	24,000 - 400,000	1,000 - 12,000
1.5 - 2.5	6,000 - 24,000	200 - 1,000
2.5 - 3.5	2,000 - 6,000	60 - 200
3.5 - 4.5	1,000 - 2,000	30 - 60

In normal low dose disinfection treatment, the COD, BOD_5, and TOC of the treated wastewater are not measurably changed.

Chemicals Required - Chlorine, sodium hypochlorite, or calcium hypochlorite.

Design Criteria - Generally a contact period of 15-30 minutes at peak flow is required. Detention tanks should be designed to prevent short circuiting. This usually involves the use of baffling. Baffles can either be the over-and-under or the end-around varieties. Residuals of at least 0.5 mg/l are generally required. The following table presents typical dosages for disinfection:

Effluent From	Dosage range, mg/l
Untreated wastewater (prechlorination)	6-25
Primary sedimentation	5-20
Chemical-precipitation plant	3-10
Trickling-filter plant	3-10
Activated-sludge plant	2-8
Multimedia filter following activated-sludge plant	1-5

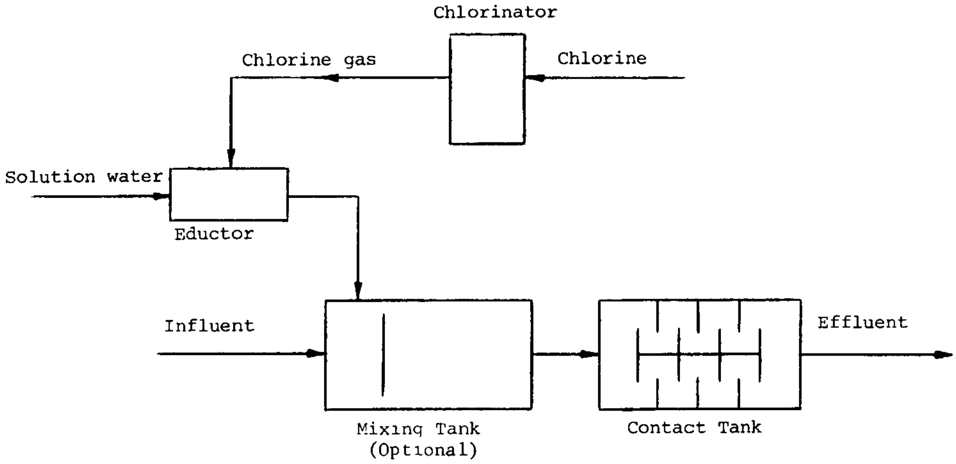
Unit Process Reliability - Extremely reliable.

Environmental Impact - Can cause the formation of chlorinated hydrocarbons. Chlorine gas may be released to the atmosphere. Relatively small land requirements.

References - 3, 26, 7, 11, 77, 126, 127, 129, 140, 146.

CHLORINATION (DISINFECTION) FACT SHEET 4.5.1

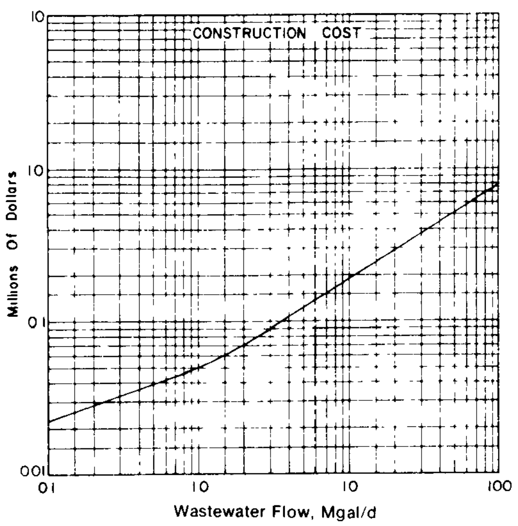
FLOW DIAGRAM -

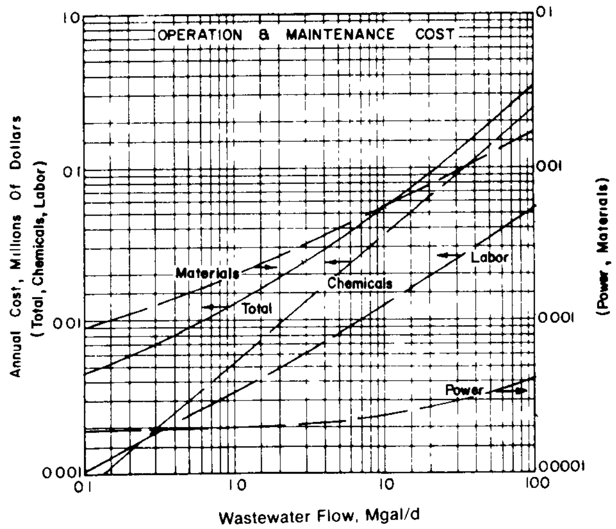


ENERGY NOTES - Energy requirements for chlorination are derived principally from water used for the vacuum eductors and the evaporators when used. For the example below, total energy requirements are 10,000 kWh/yr/Mgal/d, 1,200 kWh/yr/Mgal/d and 200 kWh/yr/Mgal/d, respectively, for a 1 Mgal/d, 10 Mgal/d and 100 Mgal/d facility. Eductor water requirements can vary widely from site to site. Facilities using more than 1,000 lb chlorine/d generally use electrically heated evaporators for conversion of the liquid chlorine to gas. The heat of vaporization of chlorine is 111 Btu/lb @ 60°F. Approximate energy required for the evaporator can be computed by the following equation: kWh/yr = 11.8 X lb chlorine/d. Mixing is not included.

COSTS* - Assumptions:

1. Service life: 15 years
2. Equipment: Including chlorine supply, chlorinator, and contact chamber
3. Dosage = 10 mg/l; contact time = 30 minutes for average flow
4. Labor rate = $7.50/h, including benefits
5. Power cost = $.02/kWh; chlorine cost = $160/ton
6. Index: ENR = 2475, September 1976.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

DECHLORINATION (SULFUR DIOXIDE) FACT SHEET 4.5.2

Description - Since about 1970, much attention has been focused on the toxic effects of chlorinated effluents. Both free chlorine and chloramine residuals are toxic to fish and other aquatic organisms. Dechlorination involves the addition of sulfur dioxide to the wastewater, whereby the following reactions occur:

$$SO_2 + HOCl + H_2O = SO_4^{+2} + Cl^- + 3H^+ \quad \text{(For free chlorine)}$$

$$SO_2 + NH_2Cl + 2H_2O = SO_4^{+2} + Cl^- + 2H^+ + NH_4^+ \quad \text{(For combined chlorine)}$$

As can be seen, small amounts of sulfuric and hydrochloric acids are formed; however, they are generally neutralized by the buffering capacity of the wastewater. Dechlorination can also be used in conjunction with superchlorination. Since superchlorination involves the addition of excess chlorine, dechlorination is required to eliminate this residual. Sulfur dioxide is the most common chemical used. It is fed as a gas, using the same equipment as chlorine systems. Because the reaction of sulfur dioxide with free or combined chlorine is practically instantaneous, the design of contact systems are less critical than that of chlorine contact systems. Detention of less than 5 minutes is quite adequate, and in-line feed arrangements may also be acceptable under certain conditions.

Common Modifications - Metabisulfite, bisulfite, or sulfite salts can be used. Automatic or manually fed systems can also be used. If chlorine is used at the site, sulfur dioxide is preferred, since identical equipment can be used for the addition of both chemicals. Alternative dechlorination systems include activated carbon, H_2O_2, and ponds (sunlight and aeration).

Technology Status - The technology of dechlorination with sulfur dixoide is established, but is not in widespread use. A few plants in California and at least one in New York are known to be practicing effluent dechlorination with SO_2 on either a continuous or intermittant basis.

Typical Equipment/No. of Mfrs. (23) - Chemical feeders/27; mixers/26; Automatic controls/over 50.

Applications - Can be used whenever a chlorine residual is undesirable. This usually occurs when the receiving water contains aquatic life sensitive to free chlorine. Is generally required when superchlorination is practiced or stringent effluent chlorine residuals are dictated.

Limitations - Will not destroy chlorinated hydrocarbons already formed in the wastewater. It has been reported that about 1 percent of the chlorine ends up in a variety of stable organic compounds when municipal wastes are chlorinated.

Performance - Available chlorine residuals can be reduced to essentially zero by sulfur dioxide dechlorination.

Chemicals Required - Sulfur dioxide (SO_2) and Sulfite salts are the most common chemicals used. Sodium metabisulfite ($Na_2S_2O_5$) can also be used, but is much less common. In fact, any reducing agent can be considered, depending on cost and availability.

Residuals Generated - None

Design Criteria - Contact Time: 1-5 minutes; Sulfur Dixoide Feed Rate: 1.1 pounds per pound of residual chlorine; Sodium Sulfite Feed Rate: 0.57 pound per pound of chlorine; Sodium Bisulfite Feed Rate: 0.68 pound per pound of chlorine; Sodium Thiosulfate Feed Rate: 1.43 pounds per pound of chlorine.

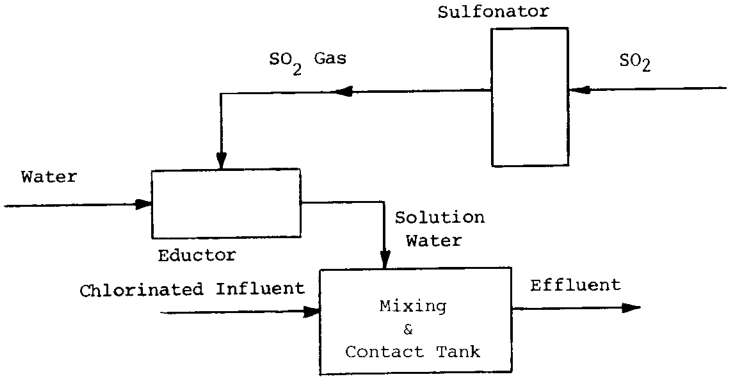
Unit Process Reliability - Sulfur dioxide addition for dechlorination purposes is reasonably reliable from a mechanical standpoint. The greatest problems are experienced with analytical control which may lower the process reliability.

Environmental Impact - Requires very little use of land, and no residuals are generated. It is used to eliminate the environmental impact of chlorine residuals. Overdosing can result in low pH and low DO effluents, however.

References - 7, 48

DECHLORINATION (SULFUR DIOXIDE) FACT SHEET 4.5.2

FLOW DIAGRAM -



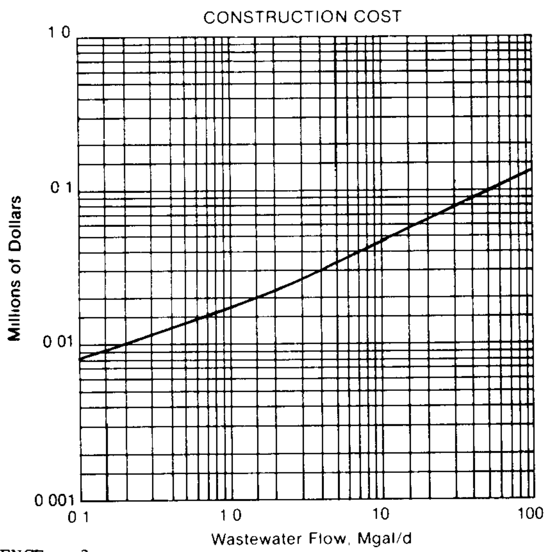
ENERGY NOTES - Energy requirements for SO_2 dechlorination are derived principally from water used for the vacuum eductors and the evaporators when used. For the example below, total energy requirements are 10,000 kWh/yr/Mgal/d, 1,200 kWh/yr/Mgal/d and 200 kWh/yr/Mgal/d, respectively, for a 1 Mgal/d, 10 Mgal/d and 100 Mgal/d facility. Eductor water requirements can vary widely from site to site. Facilities using more than 1,000 lb SO_2/d generally use electrically heated evaporators for conversion of the liquid SO_2 to gas. The heat of vaporization of SO_2 is 158 Btu/lb @ 60°F. Approximate energy required for the evaporator can be computed by the following equation: kWh/yr = 16.8 X lb SO_2/d. Mixing is not included

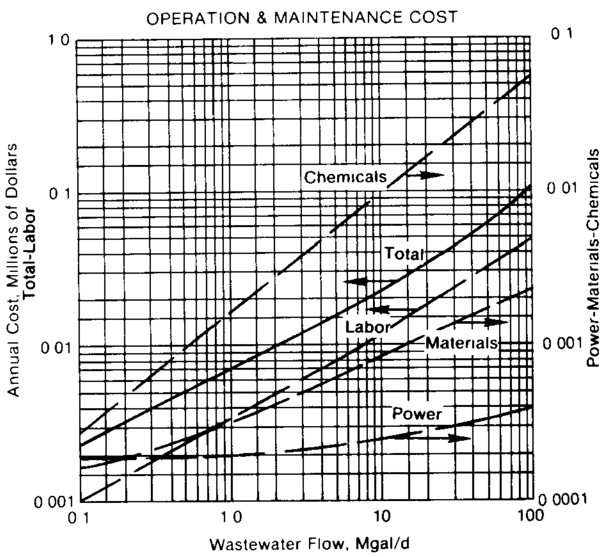
COSTS* - Design Basis: Assumptions: ENR Index - 2475

1. Construction costs include SO_2 feed facilities, reaction tank (1 minute detention time), mixer, and storage facilities; building space not included.
2. SO_2 costs are based on 20 lb/Mgal (1.1 mg/l of SO_2 required per mg/l of chlorine residual).
3. No control instrumentation included.

SO_2 Costs -

150 lb cylinder	$450/t
2,000 lb. cylinder	215/t
Tank Car	155/t





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

OZONE DISINFECTION (AIR AND OXYGEN) — FACT SHEET 4.5.3

Description and Common Modifications - Ozone (O_3) may be used for the final disinfection step in a wastewater treatment process. As a disinfectant (dosages of 3 to 10 mg/l are common), ozone is an effective agent for deactivating common forms of bacteria, bacterial spores and vegetative microorganisms found in wastewater, as well as eliminating harmful viruses. Additionally, ozone acts to chemically oxidize materials found in the wastewater and can reduce the BOD_5 and COD, forming oxygenated organic intermediates and end products. Further, ozone treatment reduces wastewater color and odor.

Ozone breaks down to elemental oxygen in a relatively short period of time (half life about twenty minutes). Consequently, it is generated on site using either air or oxygen as the raw material. The ozone generation process utilizes a silent electric arc or corona through which air or oxygen passes yielding a certain percentage of ozone. Automatic devices are commonly applied to control voltage treatment, frequency, gas flow and moisture, all of which influence the ozone generation rate. Ozone injection into the wastewater flow may be accomplished via mechanical mixing devices, countercurrent or co-current flow columns, porous diffusers or jet injectors. Ozone acts quickly and consequently requires a relatively short contact time. Ozonation as a tertiary treatment process to reduce BOD_5 and COD is covered in Fact Sheet 4.4.3.

Technology Status - Fully demonstrated but not widely used in the United States because of relatively high cost of ozone. Recent developments in ozone generation have lowered the cost and thus make it more competitive with other disinfection methods.

Applications - Applicable in cases where chlorine disinfection may produce potentially harmful chlorinated organic compounds. If oxygen-activated sludge is employed in the system, ozone disinfection is economically attractive, since a source of pure oxygen is available facilitating ozone production.

Limitations - Ozone disinfection does not form a residual that will persist and can be easily measured to assure adequate dosage. Ozonation may not be economically competitive with chlorination under non-restrictive local conditions.

Effluents containing high levels of suspended solids may require filtration to make ozone disinfection more cost-effective.

Typical Equipment/No. of Mfrs. (77, 130) - Oxygen Generator/5; Columns-Towers/60; Ozonation auxiliary equipment/8; Ozone Generator/10.

Performance - Easily oxidizable wastewater organic materials consume ozone at a faster rate than disinfection; therefore, effectiveness of disinfection is inversely correlated with effluent quality but directly proportional to ozone dosage. When sufficient ozone is introduced, ozone is a more complete disinfectant than chlorine.

Results of disinfection by ozonation have been reported by various sources as follows (11):

Influent	Dose, mg/l	Contact Time, minutes	Effluent Residual
Secondary effluent	5.5-6.0	Less than or equal to 1	Less than 2 fecal coliforms/100 ml
Secondary effluent	10	3	99% inactivation of fecal coliform
Secondary effluent	1.75-3.5	13.5	Less than 200 fecal coliform/100 ml
Drinking water	4	8	Sterilization of virus

Chemicals Required - Air or pure oxygen may be used as the raw material for the ozone generation.

Design Criteria (131) -
Contact time: 1 to 16 minutes
Dosage: 5 to 10 mg/l

Reliability - Mechanically highly reliable. Highly reliable in deactivating microorganisms.

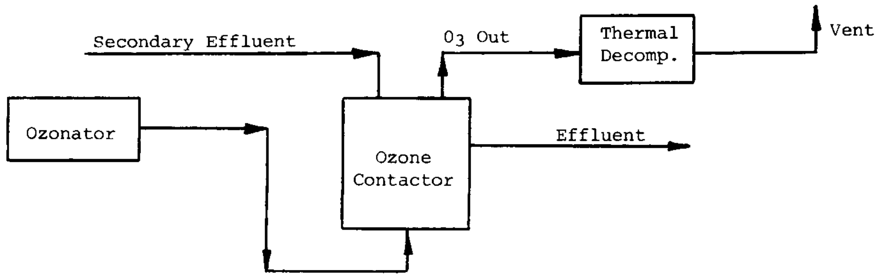
Toxics Management (132) - Ozone has been found to be a good oxidant for removal of cyanide, phenol and other dissolved toxic organic materials. Combination of ozonation and activated carbon treatment can achieve 95 percent chloroform and other trihalomethanes removals.

Environmental Impact - Ozone is an air pollutant which can discolor or kill vegetation coming in contact with it. Residual ozone in off-gas streams must be processed for ozone decomposition prior to release. Ozone is toxic when inhaled in sufficient concentration.

References - 3, 10, 11, 39, 77, 126, 128, 129, 130, 131, 132

OZONATION DISINFECTION (AIR AND OXYGEN) FACT SHEET 4.5.3

FLOW DIAGRAM -



ENERGY NOTES - The energy requirement is 750 kWh/Mgal of wastewater treated if ozone is generated from air and 550 kWh/Mgal if ozone is generated from oxygen. These requirements are based on the assumption that the energy required for the production of ozone is 7.5 kWh/lb of ozone when generated from air and 4.5 kWh/lb when generated from oxygen.

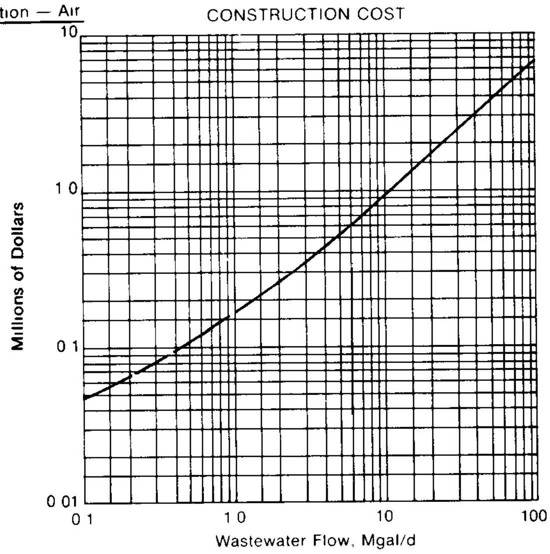
COSTS* - Assumptions: Service Life = 30 years

Design Basis:

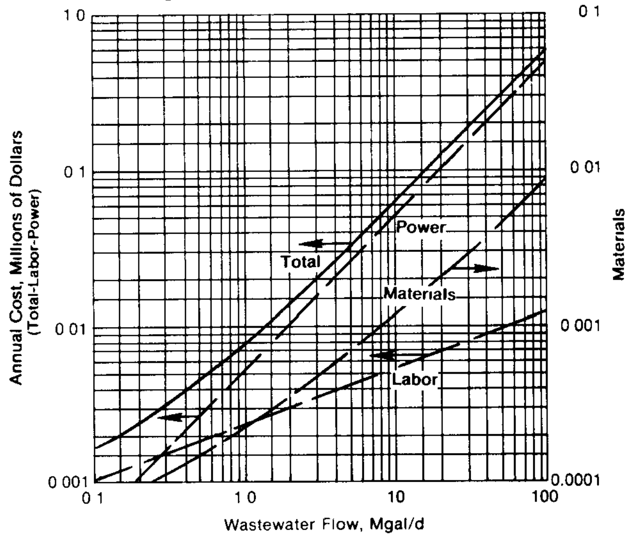
1. Equipment: O_2 storage or air supply ozonator, injector, contact chamber, aeration chamber.
2. O_2 requirements: 3 lb/lb of O_3, ozone dosage: 8 mg/l.
3. Labor rate: $7.50/h, including benefits, power cost: $.02/kWh.
4. Index: ENR = 2475, September 1976.

Ozonation — Air

CONSTRUCTION COST

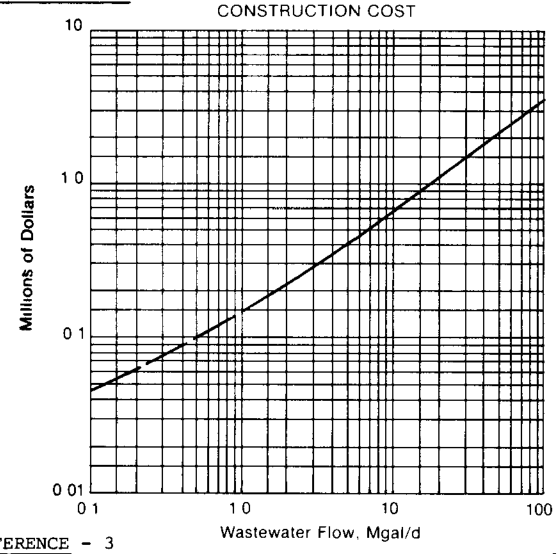


OPERATION & MAINTENANCE COST

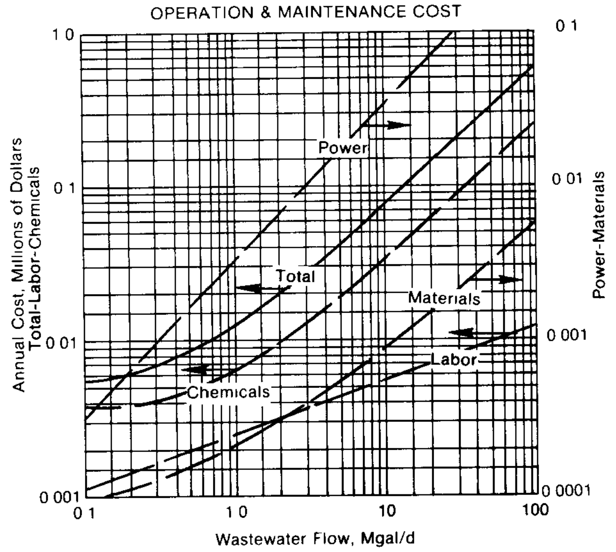


Ozonation — Oxygen

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

ALUM ADDITION FACT SHEET 5.1.1

Description and Common Modifications - Alum or filter alum, $Al_2(SO_4)_3 \cdot 14H_2O$, is a coagulant which when added to wastewater reacts with available alkalinity (carbonate, bicarbonate and hydroxide) and phosphate to form insoluble aluminum salts. The combination of alum with alkalinity or phosphate are competing reactions which are pH dependent. Alum is an offwhite crystal which when dissolved in water produces acidic conditions. As a solid, alum may be supplied in lumps, or in ground, rice or powdered form. Shipments may be in small bags (100 lb), in drums or in bulk quantities (over 40,000 lb). In liquid form, alum is commonly supplied as a 50 percent solution delivered in minimum loads of 4000 gal. The choice between liquid or dry alum use is dependent on factors such as availability of storage space, method of feeding and economics. In general, purchase of liquid alum is justified only when the supplier is close enough to make differences in transportation costs negligible. Dry alum is stored in mild steel or concrete bins with appropriate dust collection equipment. Since dry alum is slightly hydroscopic, provisions are made to avoid moisture which could cause caking and corrosive conditions. Before addition to wastewater, dry alum must be dissolved, forming a concentrated solution. Bulk stored or hopper filled alum is transported by either bucket elevator, screw conveyor or a pneumatic device to a feeder mechanism. Three basic types of feeders are in common use: volumetric, belt gravimetric and loss-in-weight gravimetric. The feeder supplies a controlled quantity of dry alum (accuracy ranges from about 1-7%) to a mixed dissolver vessel. The quantity supplied depends on the concentrate strength desired and the temperature, since alum solubility is temperature dependent. Because alum solution is corrosive, the dissolving chamber as well as following storage tanks, pumps, piping and surfaces that may come in contact with the solution or generated fumes must be constructed of resistant materials such as type 316 stainless steel, fiberglass reinforced plastic (FRP) or plastics. Rubber or saran lined pipes are commonly used. Liquid alum, which crystallizes at about $30^{\circ}F$ and freezes at about $18^{\circ}F$, is stored and shipped in insulated type 316 stainless steel or rubber-lined vessels. Feeding of liquid alum (purchased or made up on site) to wastewater treatment unit processes may be accomplished by gravity, via pumping or by using a roto dip-type feeder. Diaphragm pumps and valves are common.

Technology Status - Alum addition has been used for decades for coagulation and turbidity reduction in water treatment. Application to wastewater treatment is more recent and the technology well demonstrated.

Applications - Alum is used in wastewater treatment (sometimes in conjunction with polymers) for suspended solids and/or phosphorus removal. Alum coagulation may be incorporated into independent physical-chemical treatment, tertiary treatment schemes or as an add-on to existing treatment processes. In independent physical-chemical treatment (or tertiary treatment), alum is added directly to the wastewater, which is intensely mixed, flocculated and settled. Solids contact clarifiers may be used. In existing wastewater treatment process, alum may be added directly to primary clarifiers, secondary clarifiers or aeration vessels to improve performance. It should not be dosed directly to trickling filters because of possible deposition of chemical precipitates on the filter media. Alum has also been used as a filter aid in tertiary filtration processes and has been used to upgrade stabilization pond effluent quality.

Limitations - Alum solution is a corrosive material. Appropriate dosages are not stoichoimetric and must be reconfirmed frequently. Alkalinity is required for proper coagulation, and where inadequate, supplemental alkalinity must be provided (usually by lime addition). Alum sludge is voluminous and difficult to dewater.

Typical Equipment/No. Mfrs. (97-100) - Bins/over 50; Hoppers/over 40; Conveyors and Elevators/over 50; Liquid Storage tanks/over 50; Dry and Wet Feeders/over 50: pH instrumentation/over 50.

Performance - Typical performance for existing treatment plants using alum for upgrading are as follows:

Treatment System Type	Trickling Filter	Trickling Filter	Activated Sludge	Activated Sludge
Point of Addition	Final Clarifier	Primary Clarifier	Final Clarifier	Aeration Tank
Effluent BOD_5, mg/l	10-25	20-30	10-25	15-25
Effluent SS, mg/l	15-30	20-40	10-30	15-30
Effluent P, mg/l	0.5-2.0	1.0-3.0	0.2-1.5	0.5-1.5

Chemicals Required - The amount of alum required depends on multiple factors such as alkalinity and pH of wastewater, phosphate level and point of injection. Accurate dosages should be determined by jar tests and confirmed by field trials.

Residuals Generated - Alum sludges are substantially different in character from biological sludges in that volumes are greater and dewatering is more difficult. Alum sludge also has a tendency to induce undesirable stratification in anaerobic digesters.

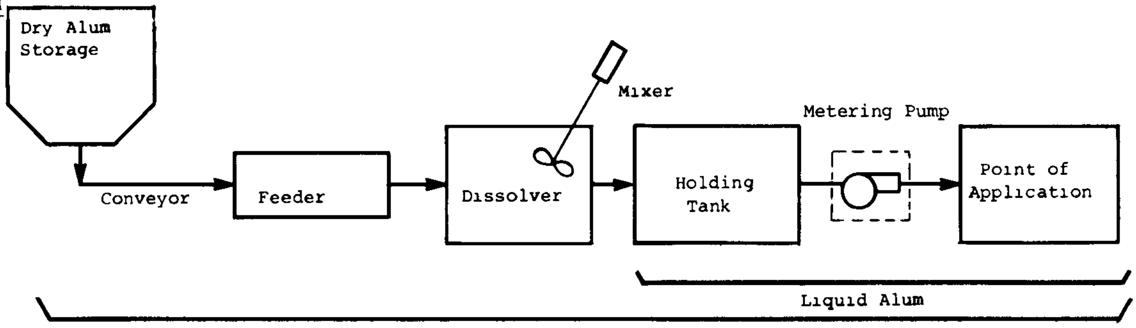
Design Criteria (99) - Dosage: Determined by jar testing, generally in the range of 5-20 mg/l as Al; Mixing: G = (approximately) 300/s, t is less than or equal to 30 s; Flocculation: GT = (approximately) 10^5 or GCT = (approximately) 100; Sedimentation: Overflow Rate = 500 to 600 gal/d/ft^2 (average), 800 to 900 ga/d/ft^2 (peak).

Unit Process Reliability - Reduces phosphate and suspended solids to low levels, although the effluent quality may vary unless filtration follows the clarification step.

Toxics Management - Alum is an effective chemical for precipitating and removing many heavy metals in wastewater. Among the metals reduced in concentration by more than 50 percent by alum coagulation are zinc, copper, barium, lead, chromium (III) and arsenic.

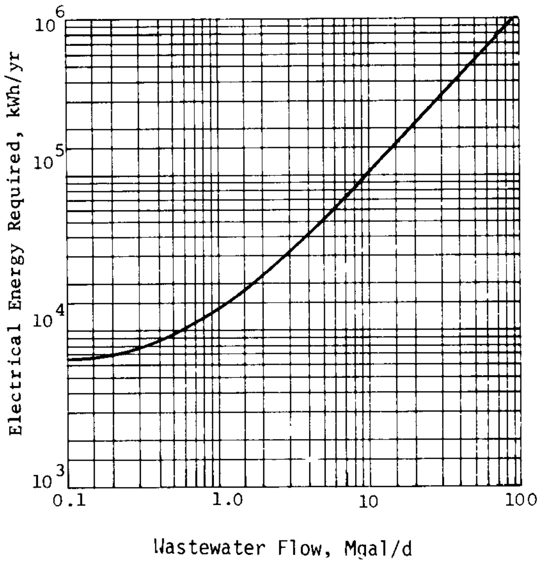
References - 29, 95, 97, 99, 100

FLOW DIAGRAM



ENERGY NOTES - Assumptions:

1. Power consumption based on the operation of pumps, mixers and feeders.
2. Alum dosage = 200 mg/l as $Al_2(SO_4)_3 \cdot 14\ H_2O$.
3. Type of energy: Electrical

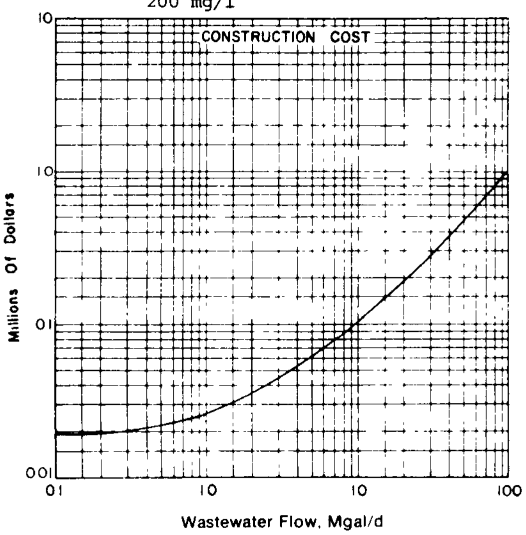


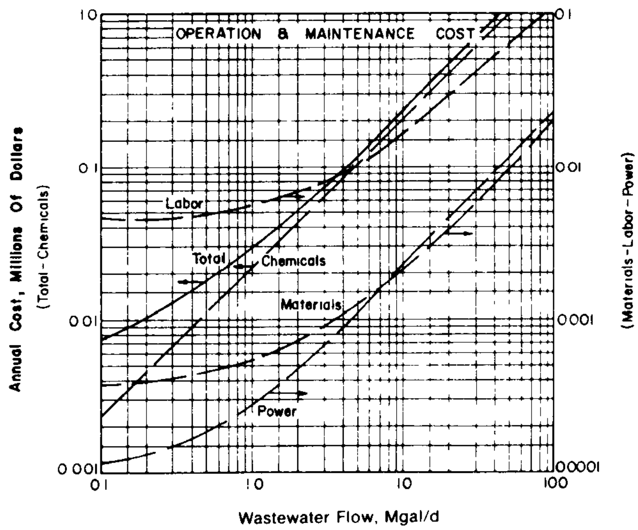
COSTS* - Assumptions:

1. Alum dosage = 200 mg/l as $Al_2(SO_4)_3 \cdot 14\ H_2O$. Phosphorus removal for other dosages, see adjustments below.
2. The rapid mix tank is constructed of concrete, and multiple basins are used for volumes greater than 1,500 ft^3.
3. Costs include liquid alum (8.3% Al_2O_3), chemical feed equipment sized for twice the average feed rate and storage of at least 15 days. Price of building is included except for plants with a capacity of less than 1 Mgal/d. Rapid mix tank includes stainless steel mixer.
4. Service life = 20 years.
5. ENR Index = 2475.

Adjustment factor: To adjust cost curves for other alum dosages, enter cost curve at effective flow (Q_E):

$$Q_E = Q_{DESIGN} \times \frac{\text{Alum Dose}}{200\ \text{mg/l}}$$





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

FERRIC CHLORIDE ADDITION FACT SHEET 5.1.2

Description and Common Modifications- Ferric chloride ($FeCl_3$) is a chemical coagulant which when added to wastewater reacts with alkalinity and phosphates, forming insoluble iron salts. The colloidal particle size of insoluble $FePO_4$ is small, requiring excess dosages of $FeCl_3$ to produce a well flocculated iron hydroxide precipitate which carries the phosphate precipitate. Large excesses of ferric chloride, and corresponding quantities of alkalinity, are required to assure phosphate removal. Exact ferric chloride dosages are usually best determined by jar tests and full scale evaluations. Ferric chloride is available in either dry (hydrated or anhydrous) or liquid form. Liquid ferric chloride is a dark brown oily-appearing solution supplied in concentrations ranging between 35 and 45 percent $FeCl_3$. Because higher concentrations of ferric chloride have higher freezing points, lower concentrations are supplied during winter. Liquid ferric chloride is shipped in 3,000 to 4,000 gallon bulk truckload lots, in 4,000 to 10,000 gallon carloads and in 5 to 13 gallon carboys. Ferric chloride solution stains surfaces it comes in contact with and is highly corrosive (a 1 percent solution has a pH of 2.0). Consequently, it must be stored and handled with care. Storage tanks are equipped with vents and vacuum relief valves. Tanks are constructed of fiberglass reinforced plastic, rubber lined steel and plastic lined steel. Because of freezing potential, ferric chloride solutions are either stored in heated areas or in heated and insulated vessels in northern climates. Ferric chloride solution should not be diluted because of possible unwanted hydrolysis. Consequently, feeding at the concentration of the delivered product is common. The stored solution is transferred to a day tank using graphite or rubber lined self-priming centrifugal pumps with corrosion resistant Teflon seals. From the day tank, controlled quantities are fed to the unit process using rotodip feeders or diaphragm metering pumps. Rotometers are not used for ferric chloride flow measurement because of its tendency to deposit on and stain the glass tubes. All pipes, valves or surfaces that come in contact with ferric chloride must be made of corrosion resistant materials such as rubber or Saran lining, Teflon or vinyl. Similar treatment results are obtainable by substituting ferrous chloride, ferric sulfate, ferrous sulfate or spent pickle liquor for ferric chloride. Details of storage feeding and control for these materials are similar to those for ferric chloride. Dry ferric chloride may also be dissolved on site before use in treatment.

Technology Status - Ferric chloride is commonly used in water treatment as a coagulant for turbidity reduction. Its use in wastewater treatment is more recent and well demonstrated.

Applications - Ferric chloride (sometimes with polymer addition) is used in wastewater treatment for suspended solids removal and/or phosphate removal. $FeCl_3$ coagulation may be incorporated into independent physical-chemical treatment and tertiary treatment schemes. In these applications, solids contact clarifiers or separate flocculation vessels are used for the treatment of either raw wastewater or secondary effluent. Ferric chloride coagulation may also be applied to existing treatment systems. Addition of ferric chloride before primary and secondary clarifiers has been practiced in both activated sludge and trickling filter plants.

Limitations - Ferric chloride is an extremely corrosive material which must be stored and transported in special corrosion resistant equipment. Dosages are not stoichiometric and must be rechecked frequently via jar tests. Ferric chloride coagulation requires a source of alkalinity, and in soft wastewaters, the pH of the clarified effluent might be decreased to a point requiring pH adjustment by addition of a supplemental base such as lime or caustic soda. Iron concentrations in plant effluents may become unacceptably high.

Typical Equipment/No. of Mfrs. (97, 100) - Liquid storage tanks/over 50; Dry and Wet feeders/over 50; pH instrumentation/over 50.

Performance (230) - Phosphorus removal studies at Baltimore, Maryland showed the following P (mg/l) levels:

Dosage	Primary Effluent Prior	Secondary Effluent (After Fe Addition)			
mg/l Fe	to Fe Addition	Activated Sludge	% Removal	Trickling Filter	% Removal
0	7.6	2.1	72	7.2	5
5	8.2	0.85	90	5.8	29
10	8.0	0.58	93	3.8	53
15	8.6	0.29	97	3.9	55
20	7.7	0.32	96	3.3	57

Chemicals Required - The amount of ferric chloride required depends on variable factors including pH and alkalinity of the wastewater, phosphate level, point of injection and mixing modes. Accurate doses should be determined by jar tests and confirmed by field evaluations. Base addition may be required when treating soft waste waters.

Residuals Generated - Used in standard biological processes, ferric chloride addition will increase the volume of sludge generated. Based on a full-scale study conducted in Baltimore, Maryland, the additional sludge generated by adding 15 mg/l Fe was 0.6 wet tons/Mgal. Iron coagulants produce sludges that are significantly different from biological sludges, especially in terms of dewatering characteristics.

Design Criteria (99) - Dosage: Determined by jar testing. Dosages of 20-100 mg/l $FeCl_3$ are common.
Mixing: G = (approximately) 300/s; t is less than or equal to 30/s.

Reliability - Reduces phosphate and suspended solids to low levels, although the effluent quality may vary unless filtration follows the clarification step.

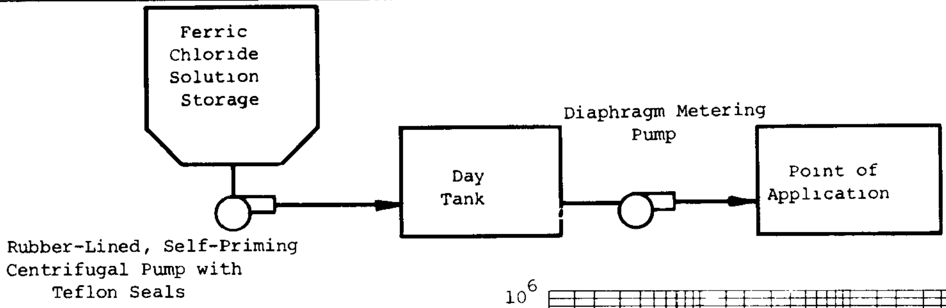
Toxics Management - Ferric chloride is an effective chemical for precipitating and removing many heavy metals in wastewaters. Among the metals reduced in concentration by more than 50 percent by ferric chloride coagulation are zinc, copper, barium, lead, chromium (III) and arsenic.

References - 29, 95, 97, 99, 100, 230

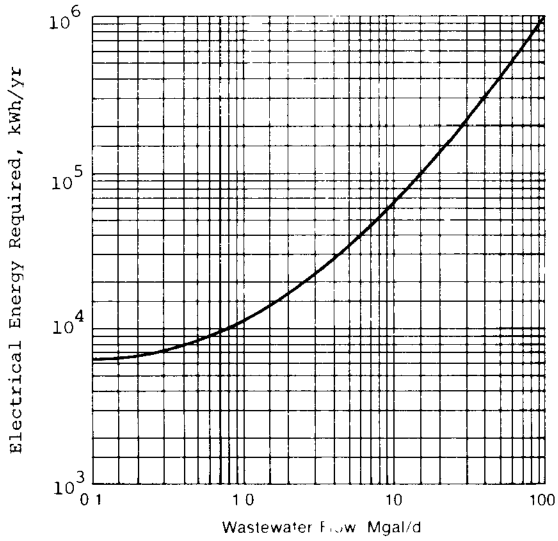
FERRIC CHLORIDE ADDITION

FACT SHEET 5.1.2

FLOW DIAGRAM -



ENERGY NOTES - Assumptions:
Power consumption based on the operation of pumps, mixers and feeders. $FeCl_3$ dosage = 100 mg/l. Type of energy: Electrical.

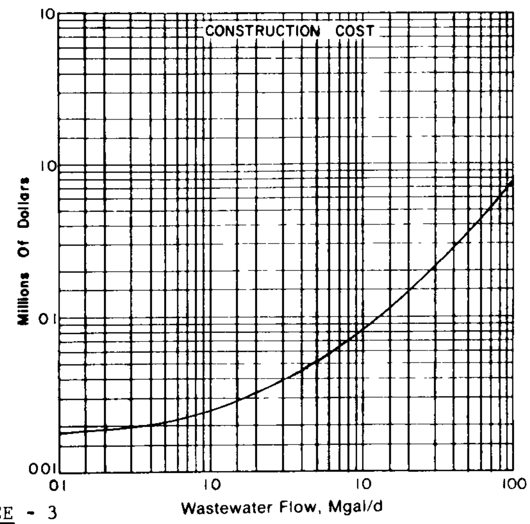


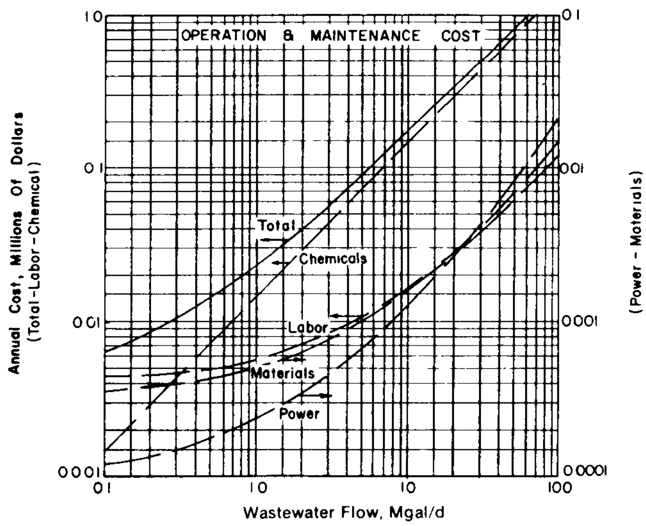
COSTS*- Assumptions:

1. $FeCl_3$ dosage = 100 mg/l.
2. The rapid mix tank is constructed of concrete, and multiple basins are used for volumes greater than 1,500 ft^3.
3. Costs include liquid ferric chloride, chemical feed equipment sized for twice the average feed rate, and storage of at least 15 days. Price of building is included except for plants with a capacity of less than 1 Mgal/d. Rapid mix tank includes stainless steel mixer.
4. Service life = 20 years.
5. ENR Index = 2475.

Adjustment factor: To adjust cost curves for other $FeCl_3$ dosages, enter cost curve at effective flow (Q_E):

$$Q_E = Q_{DESIGN} \times \frac{FeCl_3 \text{ Dose}}{100 \text{ mg/l}}$$





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

LIME CLARIFICATION OF RAW WASTEWATER — FACT SHEET 5.1.5

Description and Common Modifications - Lime clarification of raw wastewater removes suspended solids, while also removing phosphates. There are two basic processes, the low-lime system and the high-lime system. The low-lime process consists of the addition of lime to obtain a pH of approximately 9 to 10. Generally, a subsequent biological treatment system is capable of readjusting the pH through natural recarbonation. The high-lime process consists of the addition of lime to obtain a pH of approximately 11 or more. In this case, the pH generally requires readjusting with carbon dioxide or acid to be acceptable to the secondary treatment system.

Lime can be purchased in many forms, with quicklime (CaO) and hydrated lime ($Ca(OH)_2$) being the most prevalent forms. In either case, lime is usually purchased in the dry state, in bags or in bulk. Bulk lime can be (1) shipped by trucks that are generally equipped with pneumatic unloading equipment; or (2) shipped by rail cars, which consist of covered hoppers. The rail cars are emptied by opening a discharge gate which discharges to a screw conveyor. The bulk lime is then transferred by the screw conveyor to a bucket elevator which empties into the elevated storage tank. Bulk storage usually consists of steel or concrete bins. Storage vessels should be water and air tight to prevent the lime from "slaking."

Lime is generally made into a wet suspension or slurry before being introduced into the treatment system. The precise steps involved in converting from the dry to the wet stage will vary according to the size of operation and type and form of limes used. In the smallest plants, bagged hydrated lime is often charged manually into a batch mixing tank with the resulting "milk-of-lime" (or slurry) being fed via a so-called solution feeder to the process. Where bulk hydrate is used, some type of dry feeder charges the lime continuously to either a batch or continuous mixer, thence via solution feeder to point of application. With bulk quicklime, a dry feeder is also used which in turn feeds a slaking device, where the oxides are converted to hydroxides, producing a paste or slurry. The slurry is then further diluted to milk-of-lime before being piped by gravity or pumped to the process. Dry feeders can be of the volumetric or gravimetric type.

Technology Status - Established.

Typical Equipment (97, 100) - Bins/over 50; Hoppers/over 40; Conveyors and Elevators/over 50; Liquid Storage Tanks/ over 50; Dry and Wet Feeders/over 50; Lime Slakers/6; pH Instrumentation/over 50.

Applications - Lime addition to a primary clarifier is used for improved removal of suspended solids and the removal of phosphates. (The primary use of this process is for the removal of phosphates.) Will also remove toxic metals.

Limitations - Will generate additional amounts of sludge, over and above that generated by the normal primary clarification process (approximately twice the volume for low-lime and 5 to 6 times for high lime). Lime feed systems can require intensive operator attention. Even low-lime could present biological problems to fixed-growth systems with no pH adjustment. Increases operator safety needs.

Performance (29) - The following table presents data from one POTW:

	Lime Treatment to pH 11 mg/l		
	Influent	Effluent	% Removal
BOD_5	192	60	69
SS	195	47	76
Total Phosphorus	9.2	2.3	75

Chemicals Required - Lime (CaO or $Ca(OH)_2$); CO_2 or H_2SO_4 for high-lime.

Residuals Generated - Sludge, which will contain 1 to 1.5 pounds of dry solids per pound of lime added, plus the usual amount of solids produced in the primary settling process.

Design Criteria (29) - Lime requirements:

Feed Water Alkalinity (mg/l as $CaCO_3$)	Clarifier pH	Approximate Lime Dose (mg/l of CaO)
300	9.5	185
300	10.5	270
400	9.5	230
400	10.5	380

Unit Process Reliability - The process is highly reliable from a process standpoint, however increased operator attention and cleaning requirements are necessary to maintain mechanical reliability of the lime feed system.

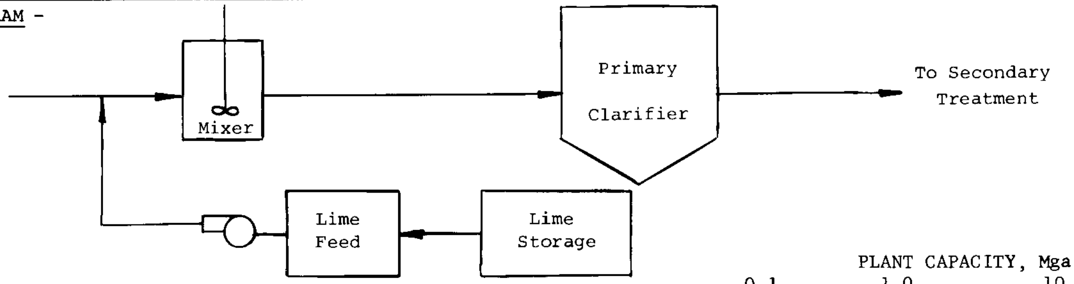
Environmental Impact - Will generate relatively large amounts of inorganic sludge that will need disposal.

References - 29, 97, 100, 102

LIME CLARIFICATION OF RAW WASTEWATER

FACT SHEET 5.1.5

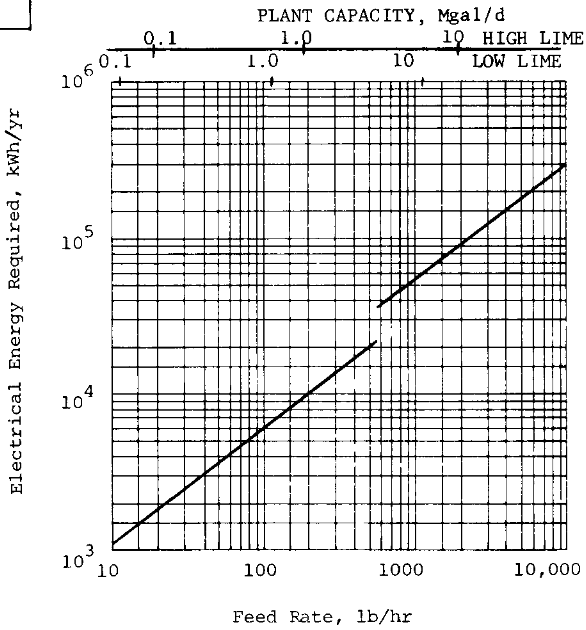
FLOW DIAGRAM -



ENERGY NOTES - Assumptions:

Design Assumptions:
1. Slaked lime used for 0.1 to 10 Mgal/d capacity plants
2. Quicklime used for 10 to 100 Mgal/d capacity plants

Operating Parameters:
1. 350 mg/l, low lime as $Ca(OH)_2$
2. 600 mg/l, high lime as $Ca(OH)_2$
3. Electrical energy at $.02/kWh

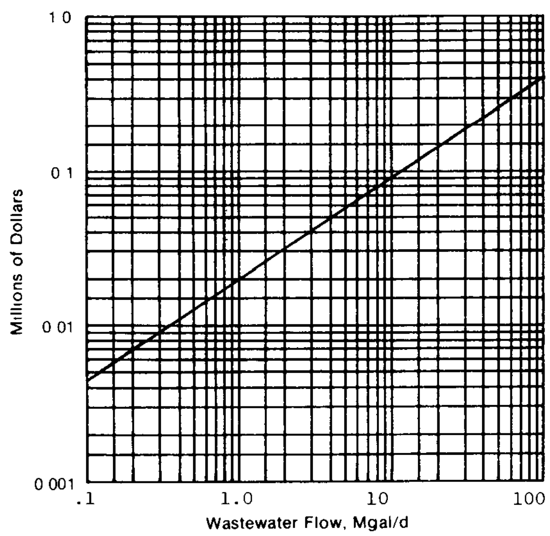


COSTS* - Assumptions: October 1973 dollars; ENR Index = 1933.

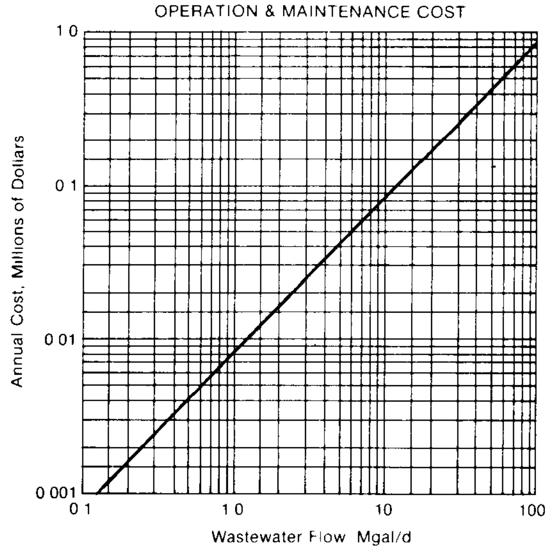
Construction costs include:
1. Chemical storage and feeding equipment
2. Hydrated lime for 0.1 to 10 Mgal/d plants
3. Pebble quicklime for 10 to 100 Mgal/d plants
4. Lime feed rates are based on a dosage of 150 mg/l and allow for peak rates of twice this capacity
5. Storage was provided for at least 15 days at the average rate.
6. Piping and buildings to house the feeding equipment are not included.

Operating costs include:
1. Lime cost, $27.50/ton
2. Operating costs include only the cost of lime. They do not include depreciation of equipment.

CONSTRUCTION COSTS



OPERATION & MAINTENANCE COST



REFERENCES - 3, 4, 29

*To convert construction cost to capital cost see Table A-2.

POLYMER ADDITION FACT SHEET 5.1.6

Description and Common Modifications - Polymers or polyelectrolytes are high molecular weight compounds (usually synthetic) which, when added to wastewater, can be used as coagulants, coagulant aids, filter aids, or sludge conditioners. In solution, polymers may carry either a positive, negative or neutral charge and, as such, they are characterized as cationic, anionic or nonionic. As a coagulant or coagulant aid, polymers act as bridges, reducing charge repulsion between colloidal and dispersed floc particles, increasing settling velocities. As a filter aid, polymers strengthen fragile floc particles controlling filter penetration and reducing particle breakthrough. Filterability and dewatering characteristics of sludges may similarly be improved through the use of polyelectrolytes. Polymers are available in predissolved liquid or dry form. Dry polymers are supplied in relatively small quantities (up to about 100 pound bags or barrels) and must be dissolved on site prior to use. A stock solution, usually about 0.2 to 2.0 percent concentration, is made up for subsequent feeding to the treatment process. Preparation involves automatic or batch wetting, mixing and aging. Stock polymer solutions may be very viscous. Surfaces coming in contact with the polymer stock solution should be constructed of resistant materials such as 316 stainless steel, fiberglass reinforced plastic or other plastic lining materials. Polymers may be supplied as a prepared stock solution ready for feeding to the treatment process. Many competing polymer formulations with differing characteristics are available, requiring somewhat differing handling procedures. Manufacturers should be consulted for optimum practices. Polymer stock solutions are generally fed to unit processes using equipment similar to that commonly in service for dissolved coagulant addition. (See Fact Sheets 5.1.1 and 5.1.2 on Alum and Ferric Chloride Addition.) Because of the high viscosity of stock solutions, special attention should be paid to the diameter and slopes of pipes, as well as the size of orifices used in the feed systems.

Technology Status - Polymer or polyelectrolyte usage in wastewater and water treatment has gained widespread acceptance. The technology for its use is well demonstrated and is common throughout the wastewater and water treatment fields.

Applications - Polymers are utilized in a variety of applications in wastewater treatment ranging from flocculation of suspended or colloidal materials either alone or in conjunction with other coagulants such as lime, alum or ferric chloride, to use as a filter aid or sludge conditioner. Polyelectrolytes may be added alone or with other coagulants to raw wastewater prior to primary treatment to effect or aid in suspended solids and BOD_5 removal. Similarly, polymers may be used to aid coagulation or as a primary coagulant in treatment of secondary effluent. As a filter aid, polyelectrolytes effectively strengthen fragile chemical flocs, facilitating more efficient filter operations.

Limitations - Frequent jar tests are necessary to assure proper dosages. Overdosages (1.0 to 2.0 mg/l) can sometimes work against the treatment process.

Typical Equipment - Bins/over 50; hoppers/over 40; liquid storage tanks/over 50; dry and wet feeders/over 50.

Performance - Generally, improvement in unit process performance has been achieved using polymer. But the performance varies depending upon its use as coagulant, coagulant aid or filter aid. Actual performance is best determined on a case by case basis.

Chemicals Required - Accurate dosages should be determined by bench scale evaluation.

Residuals Generated - Sludges generated in conjunction with polymer addition will be somewhat different from, but not necessarily more difficult to handle than biological sludges or chemical sludges generated without polymers.

Design Criteria - Dosage determined by jar testing. Materials contacting polymer solutions should be of the type 316 stainless steel, fiberglass reinforced plastic or plastic construction. Storage place must be cool and dry. Storage periods should be minimized. Viscosity considerations must be made in feeding system design.

Reliability - With proper control, capable of producing consistently high quality effluents.

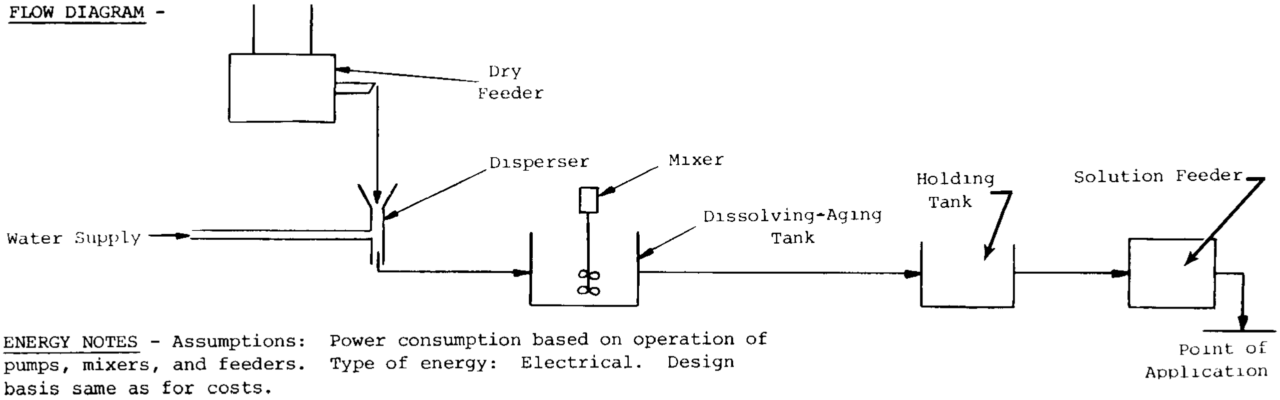
Environmental Impact - May improve sludge dewaterability; operator safety should be carefully considered.

References - 23, 29, 95, 99

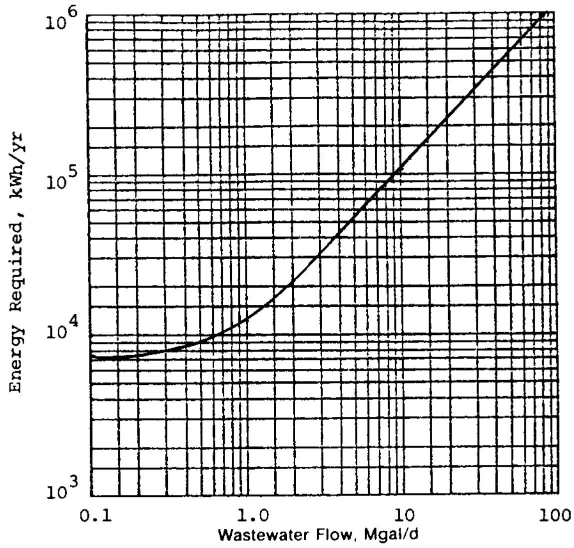
POLYMER ADDITION

FACT SHEET 5.1.6

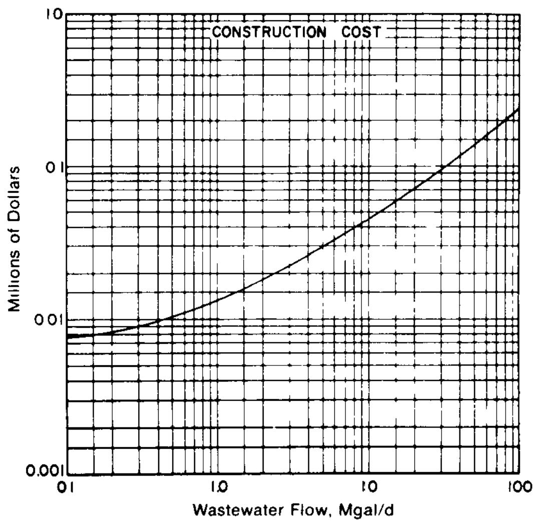
FLOW DIAGRAM -

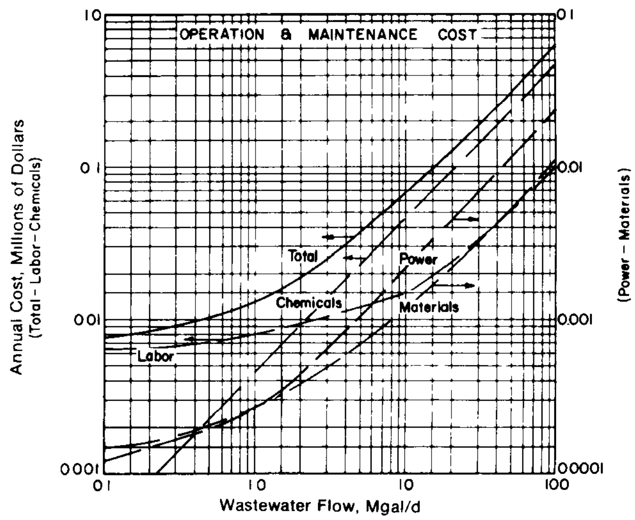


ENERGY NOTES - Assumptions: Power consumption based on operation of pumps, mixers, and feeders. Type of energy: Electrical. Design basis same as for costs.



COSTS* - Assumptions: ENR Index = 2475
1. System includes chemical storage, chemical feeding, rapid mix.
2. Polymer dosage at 1 mg/l (8.34 lb/Mgal); 0.25% solution.
3. Construction costs include: Piping and building to house the feeding equipment and bag storage. 1 Mgal/d plant size and smaller: use manual procedures. 2 systems of tanks and feeders are included. 10 Mgal/d plant size: cost includes feeders and mixing tanks, one day tank and 2 solution feeders. 100 Mgal/d plant size: cost includes 4 feeders and mixing tanks, 2 holding tanks and 10 solution feeders. The rapid mix tank is concrete, equipped with stainless steel mixer and handrails. 0.1 Mgal/d plant size: no separate building is required. Manual operation of feeder, mix tank, solution feeder and holding tank.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

POWDERED CARBON ADDITION FACT SHEET 5.1.7

Description - Powdered activated carbon is used in wastewater facilities to adsorb soluble organic materials and to aid in the clarification process. Powdered carbon is fed to a treatment system using chemical feed equipment similar to those used for other chemicals that are purchased in dry form. The spent carbon is removed with the sludge and can then be discarded or regenerated. Regeneration can be accomplished in a furnace or wet air oxidation system.

Powdered carbon can be fed to primary clarifiers directly, or to a separate sludge recirculation type clarifier which enhances the contact between the carbon and the wastewater. Powdered carbon can also be fed to tertiary clarifiers to remove additional amounts of soluble organics. Powdered carbon, when added to a sludge recirculation type clarifier, has been shown to be capable of achieving secondary removal efficiencies.

Powdered carbon can be fed in the dry state using volumetric or gravimetric feeders or can be fed in slurry form.

Modifications - A new technology has been developed over the past several years that consists of the addition of powdered activated carbon to the aeration basins of biological systems. This application is capable of the following: high BOD_5 and COD reduction, despite hydraulic and organic overloading; aiding solids settling in the clarifiers; a high degree of nitrification due to extended sludge age; a substantial reduction in phosphorus; adsorbing coloring materials such as dyes and toxic compounds; and adsorbing detergents and reducing foam (211, 212).

Technology Status - Two new municipal plants using powdered carbon addition to activated sludge are currently under construction. Several more are planned.

Typical Equipment (2, 3, 97, 100) - Powdered carbon - major producers/2; Volumetric and gravimetric feeders/over 50; Slurry feeders/over 50.

Applications - Has been used in the clarifiers and has the potential use in aeration basins to adsorb soluble organic materials, thus removing BOD_5 and COD, as well as some toxic materials.

Limitations - Will increase the amount of sludge generated. Regeneration will be necessary at higher dosages in order to maintain reasonable costs. Most powdered carbon systems will require post-filtration to capture any residual carbon particles. Some sort of flocculating agent such as an organic polyelectrolyte is usually required to maintain efficient solids capture in the clarifier.

Performance - Physical/chemical treatment (two contact type clarifiers in series) (106)

Average Process Treatment Results	Raw Wastewater	Chemical Effluent	Neutralized Chemical Effluent	Plant Effluent
Turbidity, JTU	33	4	4	3
Suspended Solids, mg/l	87	14	10	5
Total P, mg/l P	4.50	0.29	-	0.20
Soluble Total P, mg/l P	3.16	0.14	0.15	0.11
Total PO_4, mg/l P	2.82	0.10	0.06	0.11
Soluble, PO_4, mg/l P	2.25	0.04	0.05	0.08
COD, mg/l	136	-	55	14

Limited pilot and field scale data are available for powdered activated carbon addition to biological treatment units and its use in municipal treatment systems.

Chemicals Required - Powdered activated carbon, polyelectrolytes.

Residuals Generated - Sludge: 1 pound of dry sludge per pound of carbon added. If regeneration is practiced, carbon sludge is reactivated and reused with only a small portion removed to prevent buildup of inerts.

Design Criteria - The amount of powdered carbon fed to a system greatly depends on the characteristics of the wastewater and the desired effluent quality. However, powdered carbon will generally be fed at a rate between 50 and 300 mg/l.

Process Reliability - Powdered activated carbon systems are reasonably reliable from both a unit and process standpoint. In fact, powdered carbon systems can be used to improve process reliability of existing systems.

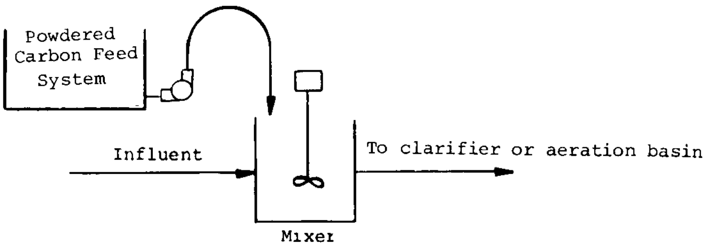
Environmental Impact - Land use requirements vary with application. Air pollution may result from regeneration. Spent carbon may be a land disposal problem unless regenerated.

References - 71, 106, 150

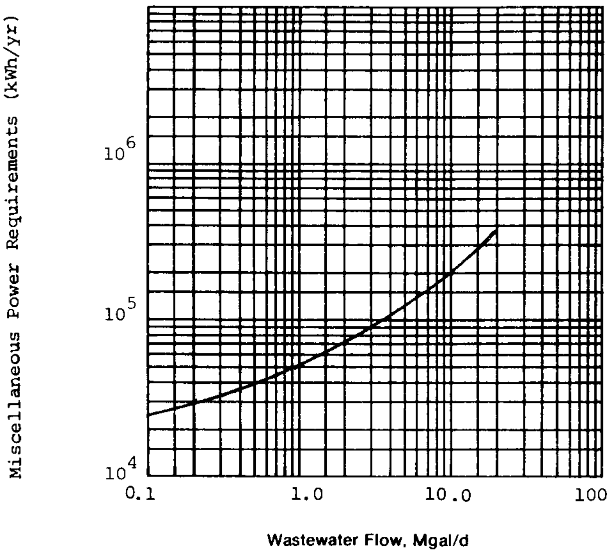
POWDERED CARBON ADDITION

FACT SHEET 5.1.7

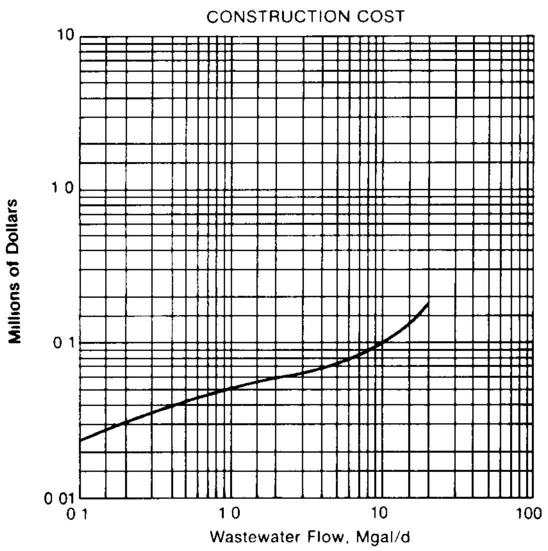
FLOW DIAGRAM -

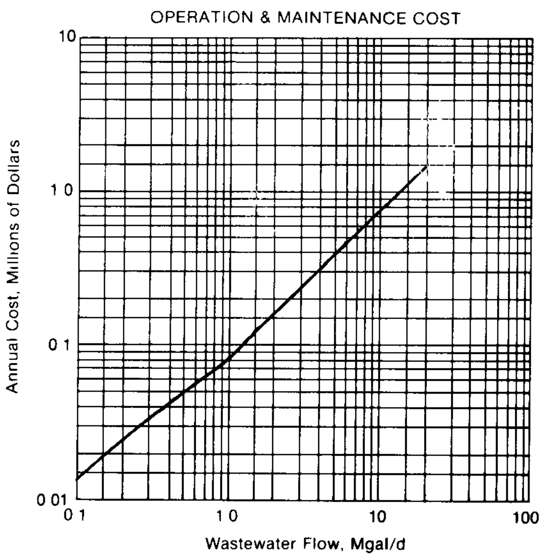


ENERGY NOTES - Includes energy for mixing and pumping chemicals.
Electricity = $.02/kWh



COSTS* - Assumptions: January 1977 dollars; ENR Index = 2494. Construction cost includes feeders, carbon slurry tanks, feed pumps and storage equipment. Operation and maintenance costs include labor, maintenance, power @ $0.02/kWh and materials.
Design basis: Carbon dosage, 80 mg/l @ $.30/lb; carbon feed concentration, 1 lb/gal slurry.





REFERENCE -84

*To convert construction cost to capital cost see Table A-2.

DEWATERED SLUDGE TRANSPORT (RAIL) FACT SHEET 6.1.1

Description - The movement by covered hopper cars, of dewatered sludge having a minimum solids content of 12 percent, from its point of origin, such as the treatment plant, to a distant designated site by common carrier railroad. The site has been selected for the particular sludge and is proximate to an existing railroad.

Modifications -

1. Open hopper cars (not recommended for other than well digested sludge).
2. Gondola cars (not recommended for other than well digested sludge).
3. Reduced costs are possible if cars are owned by shipper (justifiable for larger plants).

Technology Status (101) -

Not in widespread use even though railroad technology is highly developed for hauling freight in countless industries.

Limitations (8, 101) - The fixed position of a railroad limits disposal site locations. Generally, a minimum of 40 miles one way for each trip and a total load of 1000 ton/d is needed to compete with truck transportation. Scheduled deliveries of cars are difficult to predict if non-unit train operation is used.

Design Criteria (3, 101) -

Rail line should be near or next to the site to reduce length of spur or siding.
Sludge should have a density to achieve the approximate payload of the rail car.
Cars should be covered to avoid odor impact.
Cars should be gravity loaded from storage tank above car at POTW, and gravity unloaded into a hopper below car at site.
Movement of up to 74,000 yd^3 of sludge should be done with 50 yd^3 (approx. 50 ton) cars (unit train concept).
Movement of greater than 75,000 yd^3 of sludge should be done with 100 yd^3 (approx. 100 ton) cars (unit train concept).

Typical Equipment/No. Mfrs. (23) - Sludge handling and control/32; conveyors/4 (83); cars, dump/27; cars, hopper/16

Reliability (8, 101) - Delivery by unit train can provide a high level of reliability through good delivery schedules.

Environmental Impact - None for air and water. Only potential impact would result from use of open hopper or gondola cars. Moderate impact on land because of rail spur to site, and unloading equipment and storage area at site.

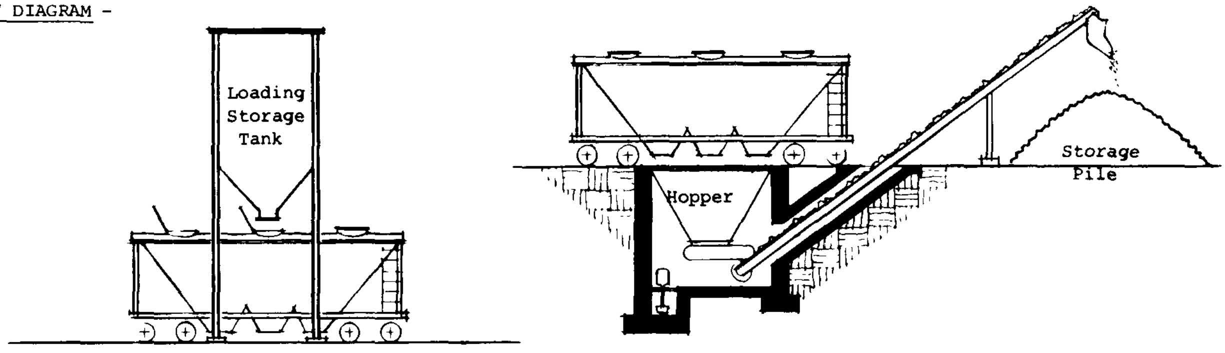
Comments (8, 101) - By virtue of its existing right of way, the railroad in many instances can provide the opportunity to use marginal or poor land of the type that can be reclaimed in some way by application of a non-specific sludge.

Transport to the site should be one element of an integrated design for the production and ultimate disposal of the sludge. Other important elements of this design are the methods and equipment to be used for unloading, storage, and distributing the sludge over the site.

References - 3, 8, 83, 101, 104, 142

DEWATERED SLUDGE TRANSPORT (RAIL) FACT SHEET 6.1.1

FLOW DIAGRAM -



Loading at Treatment Plant

Unloading at Site

Dewatered Sludge Loading and Unloading

ENERGY NOTES (161) - Rail transport can be considered to require approximately 25 percent of the energy in Btu/ton mile when compared to truck transport. See Fact Sheet 6.1.2 for truck energy requirements for large vehicles handling dewatered sludge.

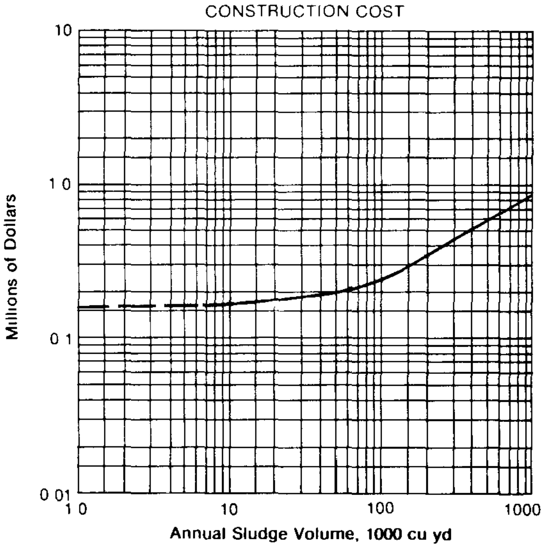
COSTS* - Assumptions: ENR Index = 2475

1. Construction cost includes: construction of loading facilities; loading storage tank sized for one carload (cars are gravity loaded).
2. Railroad provides hopper cars.
3. Construction cost does not include any construction work and equipment at site.
4. Operation and maintenance costs include: rail haul charges, labor, electric power, and supplies for the loading facilities; 50 yd^3 cars for 0 to 74,000 yd^3 of sludge; 100 yd^3 cars for greater than 75,000 yd^3 of sludge.
5. Rail haul charges based on travel distances of 40, 80, 160 mi one way in the central and north central areas of the country. Adjustments for other areas of the country:

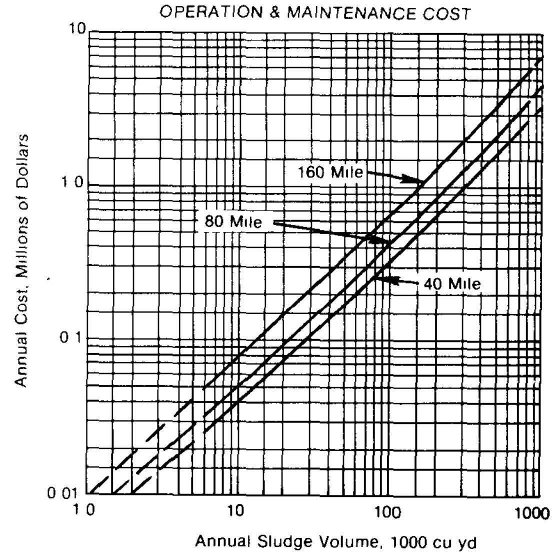
Area	Approximate RR Rate Variation, (adjust accordingly)
Northeast	25% higher than average
Southeast	25% lower than average
Southwest	10% lower than average
West Coast	10% higher than average

6. Costs based on eight hours operation per day.
7. Unloading costs not included.

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES - 3, 142, 161

*To convert construction cost to capital cost see Table A-2.

DEWATERED SLUDGE TRANSPORT (TRUCK) — FACT SHEET 6.1.2

Description - The movement over highways and roads by canvas covered, hydraulic lift, dump vehicles, of dewatered sludge having a minimum total solids content of 12 percent, from its point of origin, such as the treatment plant, to a distant designated site. The site has been selected for the particular sludge and is accessible to a road or highway.

Common Modifications (22, 96) -

1. Depending on state road laws, the type of vehicle would vary:
   - Two axle and three axle trucks.
   - Two axle tractor with one axle semi-trailer.
   - Two axle tractor with two-axle semi-trailer.
   - Three axle tractor with two axle semi-trailer.
   - Two or three axle truck with a two or three axle trailer.

2. Gasoline or diesel engine power. Diesel engine power preferred because of cheaper fuel and lower maintenance costs.

Technology Status - Highly developed and in widespread use.

Limitations (7, 8, 96) -

State road laws which limit load of vehicle. In Ohio, for example, the maximum payloads would be:

Vehicle	Payload, tons
3-axle tractor, 2 axle semi-trailer	22
3-axle truck	10
2-axle truck	7-1/2

Generally, highway and road loadings are in accordance with American Association of State Highway Officials Class Standards H10, H15, and H20.

Load limits may be restricted by practical on-site road conditions.

While truck transport generally has a lower initial investment cost, it will have higher operating cost relative to rail for most levels of design volume.

Vehicles carrying sludge should be able to reach the site without passing through heavily populated areas or business districts.

Design Criteria (3, 22, 73) -

Dewatered sludge should have a minimum of 12 percent total solids.

Vehicle should be loaded by gravity from a storage tank and gravity unloaded at site.

Loading equipment should be sized to fill vehicle in 20 minutes maximum.

Size of vehicle should be selected so that density and solid contents of sludge achieves approximate payload of the vehicle. For a 25 percent solid content, vehicle sizes of 10 yd^3 and 30 yd^3 are most cost-effective.

Loading tank should be sized to fill at least one vehicle.

Typical Equipment - Trucks and trailer equipment widely available.

Reliability - Very reliable, but dependent upon disposal site road conditions.

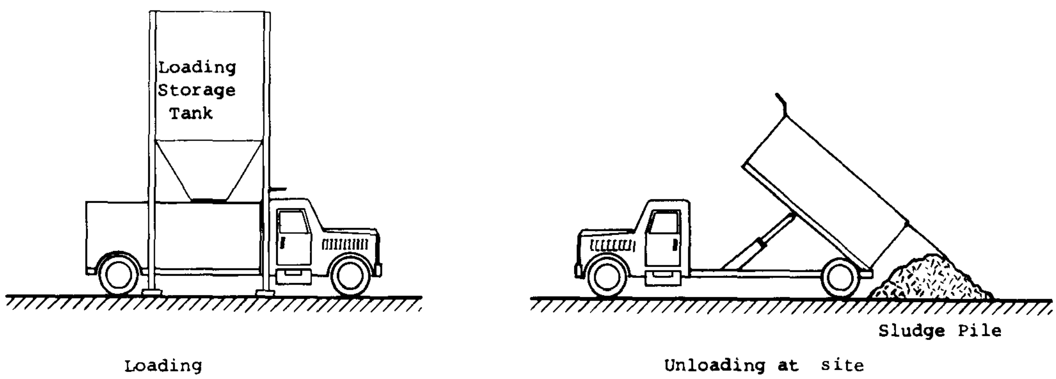
Environmental Impact - Small for land if temporary roads are built from highway to unloading area in site. Potential for air pollution due to traffic of heavy trucks, especially from large plants.

Comments - Highway vehicles offer flexibility of movement to various sites when compared to rail. Transport to the site should be one element of an integrated design for the production and ultimate disposal of the sludge. Other important elements of this design are the methods and equipment to be used for unloading, storage, and distributing the sludge over the site.

References - 3, 7, 8, 22, 73, 96, 142

DEWATERED SLUDGE TRANSPORT (TRUCK) FACT SHEET 6.1.2

FLOW DIAGRAM -

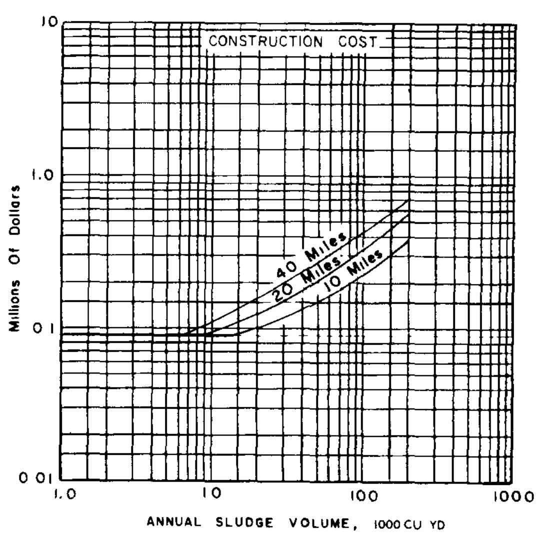


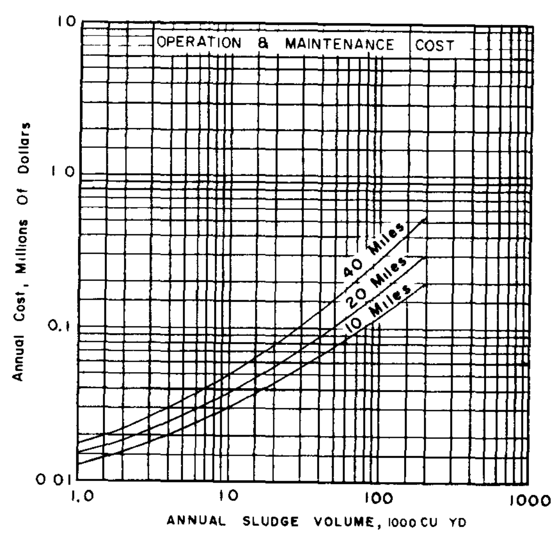
Dewatered Sludge Loading and Unloading

ENERGY NOTES (142) - Fuel requirement for hauling 10,000 yd^3/yr a one-way hauling distance of 1 mile is approximately 6.2 x 10^7 Btu and 2.8 x 10^7 Btu for 10 yd^3 and 30 yd^3 trucks, respectively.

COSTS*- Assumptions: ENR Index = 2475

1. Construction cost includes truck purchase and load/unload facilities. Truck sizes are 10 yd^3 and 30 yd^3, and are the most cost effective sizes for the volume of 25 percent total solids sludge transported. Storage at unloading site is not included.
2. Operation and maintenance cost includes truck maintenance, truck operation and fuel; labor for truck and loading facility operation; electric power and supplies for the loading facility.
3. Loading storage tank is sized to fill either a 10 yd^3 or 30 yd^3 truck in 20 minutes maximum.
4. Travel distances of 10, 20, or 40 miles one-way to site.
5. Eight hours operation per day for 360 days.





REFERENCES - 3, 142

*To convert construction cost to capital cost see Table A-2.

LAND APPLICATION OF SLUDGE FACT SHEET 6.1.3

Description - Techniques for applying liquid sludge, dried sludge and sludge cake to the land include tank truck, injection, ridge and furrow spreading, spray irrigation. Sludge can be incorporated into the soil by plowing, discing, or other similar methods. Ridge and furrow methods involve spreading sludge in the furrows and planting crops on the ridges. Utilization of this technique is generally best suited to relatively flat land and is well suited to certain row crops. Spray irrigation systems are more flexible, require less soil preparation and can be used with a wider variety of crops. High application rates are commonly used to reclaim strip mine spoils or other low quality land. Sludge spreading in forests has been limited, but offers opportunities for improved soil fertility and increased tree growth.

Applications - Is popular as a disposal method because it is simple. Also serves as a utilization measure since it is beneficial as a soil conditioner for agricultural, marginal, or drastically disturbed land. It contains considerable quantities of organic matter, all of the essential plant nutrients, and a capacity to produce water retaining humus.

Limitations - Constituents of sludge may limit the acceptable rate of application, the crop that can be grown, or the management or location of the site. Trace elements added to soil may accumulate in a concentration that is toxic to plants or is taken up and concentrated in edible portions of plants in a concentration that is harmful to animals or man. Trace elements problem can be prevented by limiting the amount of sludge to be applied, industrial pretreatment, selection of tolerant or non-accumulating crops, selection of crops not used in the human food chain, and adapting appropriate agronomic practices such as liming of the soil. Where population is concentrated, and agricultural land limited, sufficient land for sludge application may not be available. Terrain must be carefully selected; steep slopes and low lying fields are less suitable and require more careful management. Equipment with standard tires can cause ruts, compacted soil and crop damage or get stuck in muddy terrain.

Typical Equipment/No. Mfrs. (21) - Farm equipment or tank trucks with standard tires can be adapted for sludge application. However, specially designed sludge application equipment with high flotation tires and apparatus for applying liquid or dry sludge, or for subsurface injection is now available. This equipment has a 15 lb/in^2 compaction factor with an 8-ton payload and does minimize rutting, compaction or crop damage when sludge applications are made under proper soil moisture conditions.

Performance - Municipal sludge contains all of the essential plant nutrients. It can be applied at rates which will supply all the nitrogen and phosphorus needed by most crops. It may also increase the concentration in plants of certain elements which are at or near deficiency levels for animals. For instance, animal diets are often deficient in trace elements such as zinc, copper, nickel, chromium, and selenium. Thus sludge application may improve the quality of feeds and forages used for animal consumption. Sludge as fertilizer can provide the following agricultural needs:

Sludge	Nitrogen	Phosphate	Potash
1 ton dry sludge provides	60 lbs (50% avail)	40 lbs	5 lbs
Typical corn fertilizer provides (lb/acre)	180	50	60
If 6 tons dry sludge/acre were applied, would provide (lb/acre)	180 (avail)	240 (avail)	30 (avail)

Design Criteria -

Application rates depend on sludge composition, soil characteristics (usually 3%N; 2%P; 0.25%K), climate, vegetation, and cropping practices. Annual application rates have varied from 0.5 to more than 100 tons per acre.

Applying sludge at a rate to support the nitrogen needs of a crop of about 5 to 10 tons of digested solids in the liquid form, avoids problems associated with overloading the soil. Rates based on phosphorus needs are lower.

A pH of 6.5 or greater will minimize heavy metal uptake by most crops.

Unit Process Reliability - As a disposal process, very reliable; as a utilization process, careful control should be exercised.

Toxics Management - Soil has a variable capacity to filter, buffer, absorb, and chemically and biologically react with a sludge's constituents. Toxics may pass through the soil unchanged, be degraded by microorganisms, react with organic or inorganic compounds to form soluble or insoluble compounds, be adsorbed on soil colloids, or be volatilized from the soil. Factors influencing these pathways include the physical and chemical state of the material and of soil constituents, microbial population, solubility, pH, the cation exchange capacity, soil aeration, moisture and temperature. Generally, most heavy metals applied to the surface are bound in the soil.

Environmental Impact - Potential for toxics and pathogens to contaminate soil, water, air, vegetation, and animal life, and ultimately to be hazardous to humans. Accumulation of toxics in the soil may cause phytotoxic effects, the degree of which varies with the tolerance level of the particular plant specie and variety. Toxic substances such as cadmium that accumulate in plant tissues can subsequently enter the food chain, reaching human beings directly by ingestion or indirectly through animals. If available nitrogen exceeds plant requirements, it can be expected to reach groundwater in the nitrate form. Toxic materials and pathogens can contaminate groundwater supplies or can be transported by runoff or erosion to surface waters if improper loading occurs. Aerosols which contain pathogenic organisms may be present in the air over a landspreading site, particularly where spray irrigation is the means of sludge application. Some pathogens remain viable in the soil and on plants for periods of several months; some parasitic ova can survive for a number of years. Other potential impacts include public acceptance and odor.

References - 8, 11, 20, 21, 25, 33, 34, 66, 98

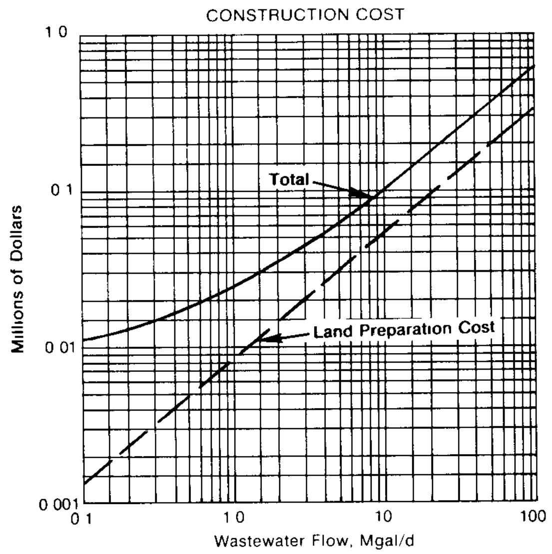
LAND APPLICATION OF SLUDGE | FACT SHEET 6.1.3

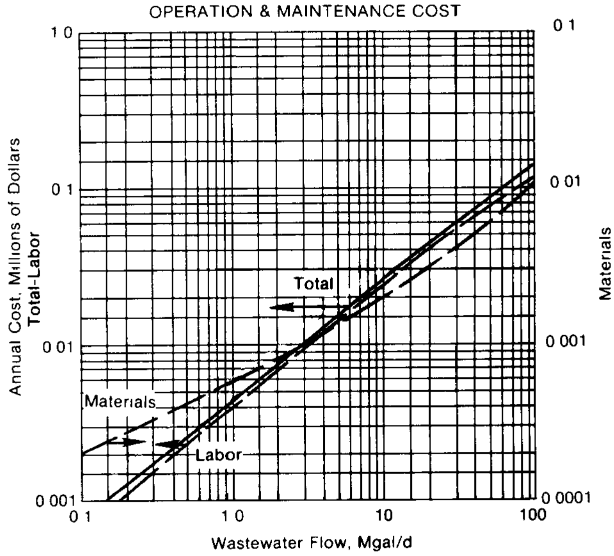
ENERGY NOTES (98) - Energy required to apply sludge to land is approximately 1.2 million Btu/dry ton sludge or 58,000 Btu/wet ton sludge @ 5 percent solids, excluding transport of sludge to the site.

COSTS* - (3) Assumptions:
Service Life 30 years; ENR = 2476

1. Construction costs include: storage lagoon (6 weeks); land preparation, monitoring wells (3 at 0.1 Mgal/d, 5 at 1 Mgal/d, 8 at 10 Mgal/d, 25 at 100 Mgal/d) and service roads.
2. Costs are for application of digested biological sludge - 900 lb/Mgal at 4 percent solids.
3. Transport of sludge to site is not included.
4. Sludge application rate - 10 ton (dry)/acre/yr.
5. Land costs are not included.
6. Sludge application is by subsurface injection - unit attached to haul truck.
7. Operation and maintenance costs include: labor costs for sludge operation, preventive maintenance, and minor repairs; material costs to include replacement of parts and repair performance by outside contractors.
8. If costs are desired for different application rates, enter curve at effective flow (Q_E).
   $$Q_E = Q_{DESIGN} \times \frac{10 \text{ ton (dry)/acre/yr}}{\text{New Design Application Rate}}$$

Note: Total costs have been derived from the material and labor costs given in reference 3.





An example of the costs for one project that utilizes high flotation equipment is provided (98).

Assumptions and Equipment Characterics

1. Equipment operates 50 wk/yr, 40 h/wk or 2000 hr/yr
2. Application rate 8000 gal/h, 5 percent dry solids = 400 gal dry solids/h X 8.34 lb/gal = 3336 lb/h = 3336 dry ton/yr.
3. Eight ton payload has 15 lb/in^2 compaction factor.
4. Haul distance from sludge source to spreading site = 1/4 mile
5. Fuel consumption: diesel - 6 gal/h; gas - 9 gal/h
6. Service life - 10 yr.
7. Prices as of November 1977. ENR Index = 2659

Operating Estimates of High Flotation Equipment

		$/yr	$/ton dry solids
Maintenance & Repair		2,000	.60
Fuel Cost			
Diesel @ 60¢/gal		7,200	2.16
Gas @ 65¢/gal		11,700	3.50
Depreciation		5,000	1.49
Labor		13,800	4.14
Total	Diesel	29,000	8.39
	Gas	32,500	9.73

REFERENCES - 3, 8, 98

*To convert construction cost to capital cost see Table A-2.

SLUDGE LANDFILLING - AREA FILL FACT SHEET 6.1.4

Description - A sludge disposal operation in which sludge is placed above the original earth cover and subsequently covered with soil. To achieve stability and soil bearing capacity, sludge is mixed with a bulking agent, usually soil. The soil absorbs excess moisture from the sludge and increases its workability. The large quantities of soil required may require hauling from elsewhere. Provisions must be made to keep the stockpiled soil dry. Installation of a liner is generally required for groundwater control and provisions made for surface drainage control, gas migration, dust, vectors and/or aesthetics. Area fills are more specifically categorized as follows:

Area Fill Mound - Sludge is mixed with a bulking agent, usually soil, and the mixture is hauled to the filling area, where it is stacked in mounds approximately 6 ft high. Cover material is then applied in a 3 ft thickness. This cover thickness may be increased to 5 ft if additional mounds are applied atop the first lift. The appropriate sludge/soil bulking ratio and soil cover thickness depend upon the solids content of the sludge as received, the need for mound stability and bearing capacity as dictated by the number of lifts and equipment weight. Lightweight equipment with swamp pad tracks is appropriate for area fill mound operations; heavier wheel equipment is appropriate in transporting bulking material to and from stockpiles. Construction of earthen containments is useful to minimize mound slumping; and for sloping sites.

Area Fill Layer - Sludge is mixed with soil on or off site and spread evenly in consecutive layers 0.5 to 3 ft thick. Interim cover between layers may be applied in 0.5 to 1 ft thick applications. Layering may continue to an indefinite height before final cover is applied. Lightweight equipment with swamp pad tracks is appropriate for area fill layer operations; heavier wheel equipment is appropriate for hauling soil. Slopes should be relatively flat to prevent sludge from flowing downhill. However, if sludge solids content is high and/or sufficient bulking soil is used, the effect can be prevented and layering performed on mildly sloping terrain.

Diked Containment - Dikes are constructed on level ground around all four sides of a containment area. Alternatively, the containment area may be placed at the toe of the hill so that the steep slope can be utilized as containment on one or two sides. Dikes would then be constructed around the remaining sides. Access is provided to the top of the dikes so that haul vehicles can dump sludge directly into the containment. A 1-3 ft interim cover may be applied at certain points during the filling; a 3-5 ft final cover should be applied when filling is discontinued. Cover material is applied either by a dragline based on solid ground atop the dikes or by track dozers directly on top of the sludge, depending upon sludge bearing capacity. Usually, operations are conducted without the addition of soil bulking agents, but occasionally soil bulking is added. Typical dimensions: 50-100 ft wide, 100-200 ft long, 10-30 ft deep.

Modifications - Codisposal: sludge/refuse

Technology Status - Relatively new, not in widespread use.

Applications - Suitable when subsurface placement is impossible due to shallow groundwater or bedrock.

Area Fill Mound - Suitable for stabilized sludge; good land utilization; higher manpower and equipment requirements due to the constant need to push and stack slumping mounds. Area Fill Layer - Suitable for stabilized sludge; poor land utilization; less manpower and equipment requirements. Diked Containment - Efficient land use; suitable for stabilized or unstabilized sludge; less soil requirement.

Limitations - Rainfall causes mounds to slump. Operating difficulties in wet and freezing weather.

Typical Equipment/No. of Mfrs. - Front-end loader/7; bulldozer/19; scraper/25; backhoe/45; dragline/13; grader/25.

Chemicals Required - Lime and masking agents to control odors.

Residuals Generated - None

Design Criteria -

	Area Fill Mound	Area Fill Layer	Diked Containment
Sludge solids content	Greater than 20%.	Greater than 15%.	20 to 28% for land-based equipment; more than 28% for sludge-based equipment.
Sludge characteristics	Stabilized.	Stabilized.	Stabilized or unstabilized.
Ground slopes	No limitation if suitably prepared.	Level ground preferred.	Level ground or steep terrain if suitably prepared.
Bulking required	Yes.	Yes.	Occasionally.
Bulking ratio soil: sludge	0.5 to 2 soil:1 sludge.	0.25 to 1 soil:1 sludge.	0 to 0.5 soil:1 sludge.
Sludge application rate	3000 to 14000 yd^3/acre.	2000 to 9000 yd^3/acre.	4800 to 15000 yd^3/acre.
Equipment	Track loader, backhoe with loader, track dozer.	Track dozer, grader, track loader.	Dragline, track dozer, scraper.

Process Reliability - Very reliable sludge disposal method.

Environmental Impact - Potential soil erosion, dust, vectors, noise and odor problems. Leachate and gas continue to be produced for many years after the fill is completed; leachate must be properly controlled to avoid groundwater and surface water contamination; gas is explosive and can migrate to nearby structures, or can stunt or kill vegetation if not properly controlled. Mud can be transferred to local roads by transport vehicles, can be alleviated by a wash pad located near the exit gate. Area fill layer relatively land intensive.

References - 148, 168

SLUDGE LANDFILLING - AREA FILL

FACT SHEET 6.1.4

FLOW DIAGRAM

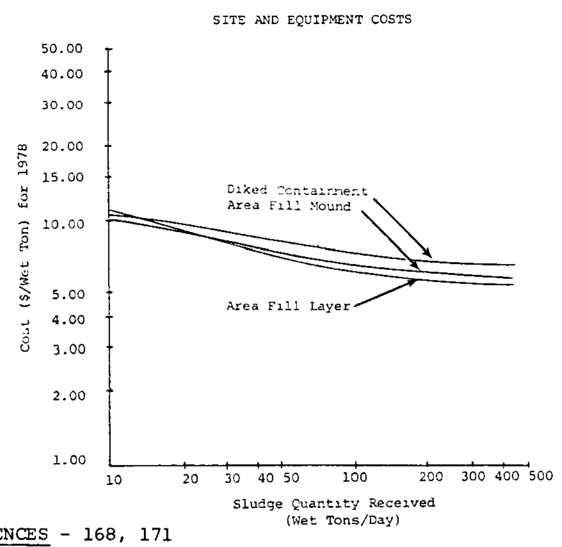
ENERGY NOTES (171) - Actual fuel consumption varies considerably with specific sludge, site and operating conditions. Fuel consumption rates for some typical construction equipment performing light to medium work is given below.

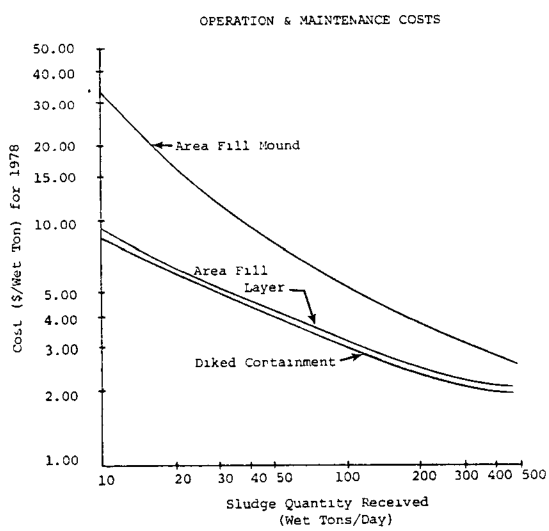
Equipment	Average Diesel Fuel, gal/hr	Equipment	Average Diesel Fuel, gal/hr
Caterpillar D-6	5.2	Grader - 25,000 lb	4.4
Caterpillar D-8	10.8	28,000 lb	4.8
Excavator - ½ yd^3	3.4	30,000 lb	5.2
1 yd^3	5.0	40,000 lb	6.0
1¼ to 1½ yd^3	8.8	54,000 lb	7.9
1½ to 2 yd^3	11.1	Track Loader - 1 yd^3	2.4
Wheel Loader 1½ yd^3	3.0	1½ yd^3	3.4
2 yd^3	3.7	2 yd^3	4.2
3 yd^3	4.6	2.5 yd^3	5.7
4 yd^3	6.2	3 yd^3	7.4
5 yd^3	9.0	4 yd^3	11.3
7 yd^3	13.2	Tractor-Scraper, small	4.9
		medium	11.4
		large	15.8

One case study that used a sludge landfill operation was estimated to consume 700,000 Btu/dry ton sludge (1 gal diesel fuel = 140,000 Btu).

COSTS* (168) - Assumptions: First quarter 1978 dollars; ENR Index = 2681.

1. Site and equipment costs include land ($2500/acre), site preparation (clearing, grubbing, surface water control ditches and ponds, monitoring wells, soil stockpiles, roads and facilities), equipment purchase, engineering (6%). Actual fill area consumes 50 percent of total site area.
2. Operating costs include labor ($8/hr, including fringe, overhead, administration), equipment fuel, maintenance and parts; utilities; laboratory analysis of water samples; supplies and materials.
3. Actual costs vary considerably with specific sludge and site conditions.





REFERENCES - 168, 171

*To convert construction cost to capital cost see Table A-2.

LIQUID SLUDGE TRANSPORT (PIPELINE) — FACT SHEET 6.1.5

Description (8, 22) - The movement of liquid sludge having a maximum total solids content of 5 percent, by centrifugal pumps through a pipeline of two miles, minimum length, from the point of origin, such as a wastewater treatment plant, to a designated site selected for the particular sludge. Depending on the terrain and length of the line, intermediate dry well pumping stations (factory packaged or field constructed) may be required to maintain the flow to the site.

Common Modifications (3, 8, 72, 105) -
Carbon steel pipe unlined and cement lined.
Cast iron pipe, unlined, and cement and glass lined. Ductile iron pipe, unlined and cement lined.
Cement-asbestos.
Fiberglass-reinforced epoxy pipe. Plastic pipe.
Depending on the length and pressure drop of the line, intermediate lift stations are provided.
Depending on the sludge utilization procedure to be followed at the site, dewatering at the site may be necessary.

Technology Status - Highly developed and in relatively widespread use.

Limitations (26, 73) - Relatively high capital cost; long construction period; site must be available for a long period of time; flushing or "pigging" of entire line may become necessary requiring shut-down of line.

Design Criteria (22, 105) - Sludges are thixotropic. The most economical sludge pumping occurs at the critical velocity where turbulent flow begins, and where the mixing and agitation reduce the viscosity (and head loss). Some critical velocities at 4 percent solids for various pipe diameters are:

	Critical Velocity (ft/s)	
Dia.	Lower	Upper
8	3.58	4.52
10	3.55	4.42
14	3.45	4.31
20	3.40	4.23

Maintaining the operating velocity in the lower portion of the turbulent flow zone results in maximum economy. Critical velocity is a function of solids content as well as pipe size.

Increasing the velocity is one method for causing turbulence, viscosity reduction, and self-cleaning. However velocities much above the critical will involve an excessive head loss because of friction. Head losses attributable to the sludge characteristics increase when: the solids concentration increases; size of the coarse sludge particles increase; the volatile content increases; the temperature decreases; the velocities are too high or too low. Effective grit removal is necessary for economical pumping. Grit increases viscosity and settles out during periods of little or no flow causing a temporary increase in pipe roughness and head loss. Pumping anaerobically digested sludge results in lower head loss as a result of friction than pumping raw primary sludge of the same solids content (dry basis) and flow condition. Turbulent flow tends to prevent deposition of grease. Pipeline materials and linings influence head losses as a result of differing friction flow factors. Mechanical and chemical aids such as macerators, in-line mixers, and polymers are sometimes used to reduce viscosity and head loss. Operating controls usually are float control, density gauges, flow meters, pressure switches and pressure gauges. The literature indicates that the hydraulic characteristics of wastewater sludges have not been well defined because of their indefinite nature and that finite predictions of head losses are impossible to make. The approach has been to provide an adequate safety factor when designing sludge pump and piping systems.

Brief characteristics of Pipeline and Pumping Stations (105) -

Description	Material	Application	Advantages	Disadvantages
Pipe	Cast or ductile iron, unlined	General use; high pressures	Less expensive than most	Undergoes corrosion grease build-up
Pipe	Cast or ductile iron, cement-lined	General use; high pressures	No corrosion, slow grease build-up	More expensive than unlined
Pipe	C.I. glass lined	Not in general use.	No corrosion, slow grease build-up	Most expensive
Pipe	Steel, unlined	General use; high pressures	Less expensive than most	Undergoes corrosion
Pipe	Steel, cement-lined	General use; high pressures	No corrosion, slow grease build-up	More expensive than unlined steel
Pipe	Cement-asbestos	General use; moderate pressures	No corrosion, slow grease build-up	Relatively brittle
Pipe	Fiberglass-reinforced epoxy pipe	Not in general use; moderate pressures	No corrosion, slow grease build-up	As expensive as glass-lined pipe
Pipe	Plastic	Not in general use; lower pressures	No corrosion, slow grease build-up	Expensive
Pumping Station Packaged	Various	In general use	Less costly than field constructed	10,000 gal/min max. 200 ft head max.
Pumping Station Field Const.	Various	In general use	High capacity, high heads	Field constructed more expensive

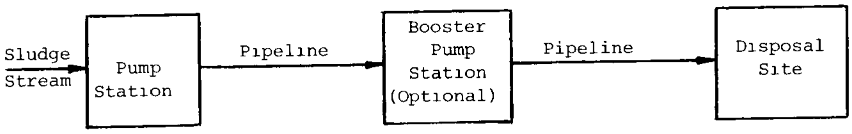
Reliability - Very reliable if properly installed.

Environmental Impact - None for air and water; considerable impact on land during installation. Potential for ground water pollution if leak develops.

References - 3, 8, 22, 26, 72, 105

LIQUID SLUDGE TRANSPORT (PIPELINE) FACT SHEET 6.1.5

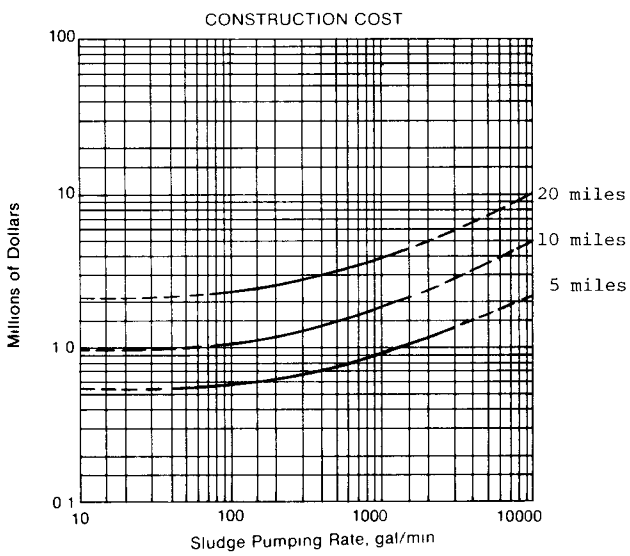
FLOW DIAGRAM -

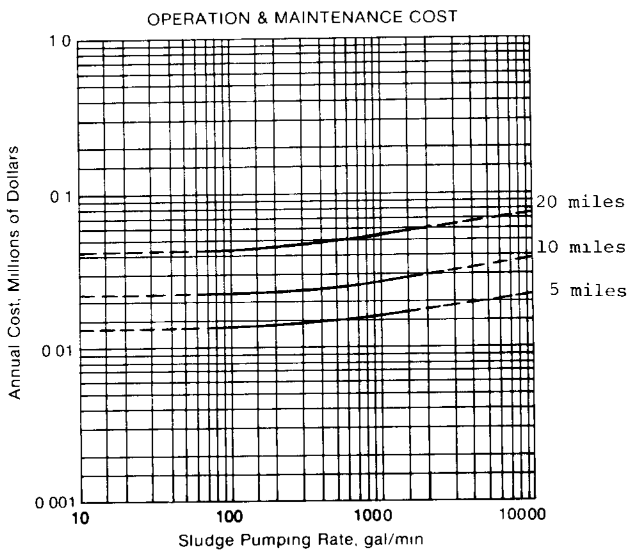


ENERGY NOTES - Each pipeline is highly site specific due to static head and the dynamic head requirements dictated by the pipe material and size and the characteristics of the sludge being pumped. Approximate energy requirements for a pipeline can be computed from the equation kWh/yr = 1900 (Mgal/d/yr X ft of total head) after actual conditions have been determined, when assuming a wire to water efficiency of 60 percent for the pump station.

COSTS* (3) - Assumptions: ENR Index = 2475

1. Construction cost includes: pipeline and pumping stations, one major highway crossing per mile, one single rail crossing per 5 miles, nominal number of driveways and minor road crossings.
2. Pipeline is buried 3 to 6 ft. (add 15 percent for 6 to 10 ft.), no elevation change in pipeline.
3. Pipeline is cement-lined cast or ductile iron, 4 inch minimum pipe size.
4. Pumps are dry-pit, horizontal or vertical, non-clog centrifugal (1780 r/min).
5. Construction cost does not include: rock excavation or major unusual problems (add 70 percent to cost for hard rock).
6. Operation cost includes: labor, supplies, and electrical power for pump stations; 12 hours pumping per day; flow velocity of 4 ft/s.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

LIQUID SLUDGE TRANSPORT (RAIL) FACT SHEET 6.1.6

Description - Liquid sludge having a maximum total solids content of six percent may be transported by railroad tank cars from point of origin, such as a wastewater treatment plant or pipeline terminus, to a designated site. The site may be adjacent to the railroad or joined by pipeline to the unloading site. The cars used may be owned or rented by the operator depending upon the economics of the location.

By virtue of its existing right-of-way, the railroad in many instances can provide the opportunity for use of selected land for sludge disposal. Transport to the site from the railroad terminus may be a major element in the development of an integrated disposal system. Other important considerations include the methods and equipment to be used for unloading, storage, and distributing the sludge at the site.

Technology Status - Not in widespread use even though railroad technology is highly developed.

Limitations - Fixed position of railroad limits site selection. Relative transportation costs ($/ton dry solids basis) indicate that railroad tank cars are the most expensive method of transporting sludge for distances up to approximately 150 miles when compared to a tank truck and up to approximately 200 miles when compared to a pipeline. For greater distances, rail tank car transportation is least expensive. May not be applicable for small operation.

Design Criteria - Rail line should be near or next to the site to reduce length of spur, siding, or pipeline. Sludge storage at wastewater treatment plant should equal one day's production.

Cars should be 20,000 gallon capacity, and pumping station filling rate should be 1.5, 2, 3, and 15 hours, respectively, for 1, 10, 20, and 100 car groups.

Cars should be gravity unloaded at the terminus for pumping to storage and/or disposal.

Typical Equipment/ No. of Mfrs. (23) - Sludge handling and control/32; cars, dump/14.

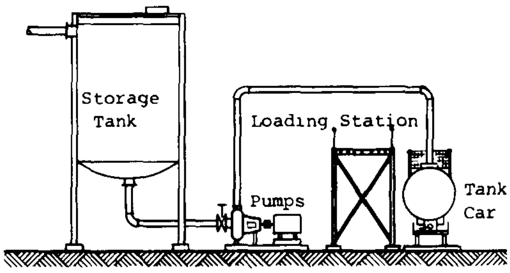
Reliability - With respect to scheduled deliveries to the site: very reliable for unit train; not reliable for single or few cars, since railroads would tend to preferentially select equipment for use in heavy tonnage hauls of other commodities.

Environmental Impact - None for air and water unless leak in car.

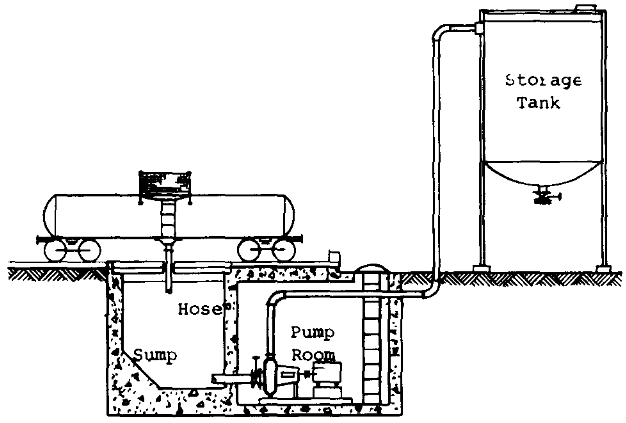
References - 3, 7, 8, 23, 72, 83, 101, 104, 142

LIQUID SLUDGE TRANSPORT (RAIL) FACT SHEET 6.1.6

FLOW DIAGRAM -



Treatment Plant



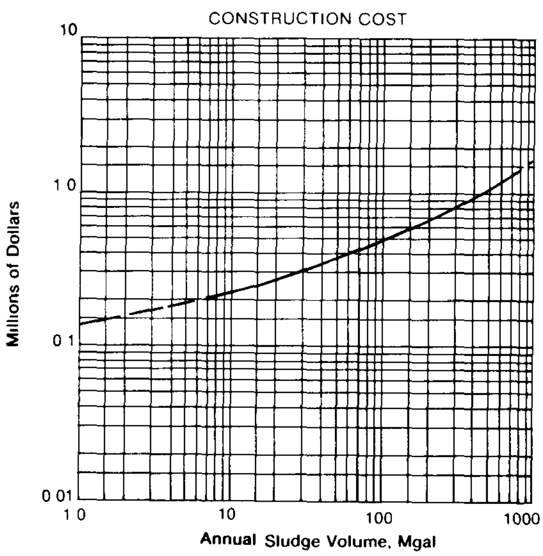
Site

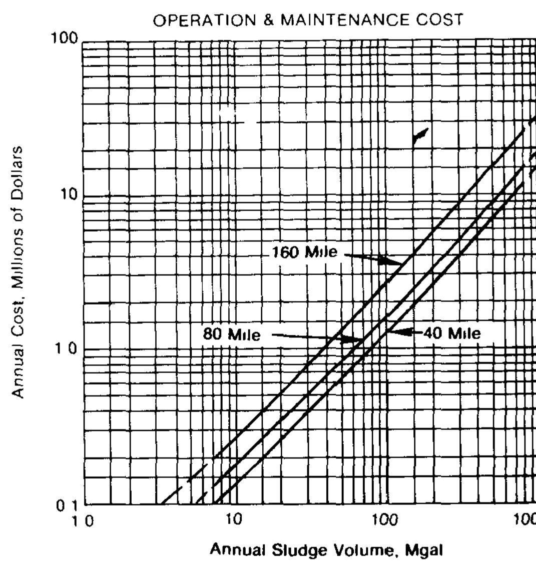
ENERGY NOTES (161) - Rail transport can be considered to require approximately 25 percent of the energy in Btu/ton mile when compared to truck transport. See Fact Sheet 6.1.7 for truck energy requirements for large vehicles. Pumping energy for loading is insignificant compared to the transport energy.

COSTS*- Construction cost includes loading facilities: storage for one day's production; pump and piping system sized to fill 1, 10, 20 and 100 tank cars each with 20,000 gal capacity to be filled in 1.5, 2, 3, and 15 h, respectively. Solids content at 4 percent. Construction cost does not include storage at unloading area. Operation cost includes 8 h/d operation; car lease, labor, electrical energy, supplies maintenance (Full car maintenance annual lease rate is assumed at $525/car); travel distances of 40, 80 and 160 miles one way; rail haul charges based on the following:

Area	Approximate R.R. Rate Variation (adjust Accordingly)
North Central and Central	Average Rate - Approximately $0.06/ton mile
Northeast	25 percent higher than average
Southeast	25 percent lower than average
Southwest	10 percent lower than average
West Coast	10 percent higher than average

ENR Index = 2475.





REFERENCES - 3, 161, 142

*To convert construction cost to capital cost see Table A-2.

LIQUID SLUDGE TRANSPORT (TRUCK) — FACT SHEET 6.1.7

Description - The movement over highways and roads by tank trucks, of liquid sludge having a maximum total solids content of 6 percent, from its point of origin, such as a wastewater treatment plant, to a distant designated site selected for the particular sludge. The site is next to a road or highway.

Common Modifications (96) -

Depending upon state road laws, the type of vehicle would vary between the following:

- Two axle and three axle tank trucks.
- Two axle tractor with one axle semi-tank trailer.
- Two axle tractor with two axle semi-tank trailer.
- Three axle tractor with two axle semi-tank trailer.
- Two or three axle tank truck with a two or three axle tank trailer.

Gasoline or diesel engine power. Diesel engine power preferred because of cheaper fuel and lower maintenance costs.

Technology Status - Highly developed and in widespread use.

Limitations (7, 8, 21, 73, 96) -
State road laws which limit load of vehicle. In Ohio, for example, the maximum payloads would be:

Vehicle	Payload, Gal	(Tons)
2 axle tank truck (Note a.)	1200	(5)
3 axle tank truck (Note b.)	2500	(10)
5 axle tractor semi-trailer tank (Note c.)	5800	(24)

Note a. Most commonly used vehicle for hauling and, if the site surface is suitable, for spreading as well. Normally, special off-road tank vehicles are used for spreading.

Note b. Some wastewater treatment plants use vehicles of this type, with only a fraction of the legal loads, to provide better flotation over soft ground.

Note c. Montgomery County, Ohio uses this vehicle with about a 5000 gal (21 ton) capacity to haul and spread.

Generally, highway and road loadings are in accordance with American Association of State Highway Officials Class Standards H10, H15, H20, HS15, and HS20.

Transportation of sludge by pipeline is generally more economical and more convenient than tank truck handling, although it does have higher capital costs and is inflexible. Relative transportation costs ($/ton dry solids basis) indicate that tank trucks are the most expensive method for transporting sludge for distances of approximately 150 miles and over when compared to pipeline and railroad tank car. For less than 150 miles it is less expensive than railroad tank car, assuming that both require unloading at the disposal site.

Truck transport generally has a lower initial investment cost but will have higher operating costs relative to rail or pipeline transport for most levels of design volume. Trucks are very flexible.

Design Criteria (3) -

Liquid sludge should have a maximum solids content of 6 percent.

Vehicle should be loaded by gravity from a storage tank and gravity unloaded at the site.

Loading equipment should be sized to fill vehicle in 20 minutes maximum.

Typical Equipment/No. of Mfrs.- See Society of Automotive Engineers (SAE) roster of truck and trailer manufacturers.

Reliability - Very reliable.

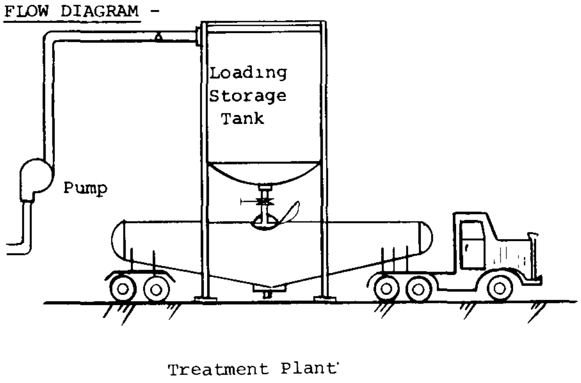
Environmental Impact - None for air and water unless a leak develops in the tank. Small for land if temporary roads are built from highway to unloading area within disposal site. Noise and general disruption due to truck traffic may constitute a nuisance.

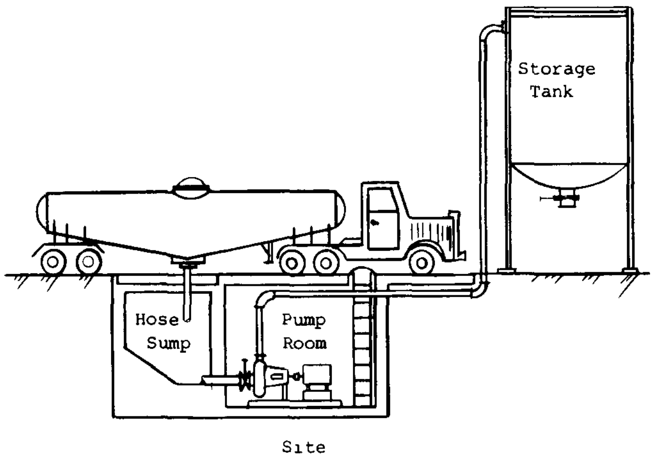
Comments (8) - Highway vehicles offer some flexibility of movement to various sites when compared to rail. Transport to the site should be one element of an integrated design for the production and ultimate disposal of the sludge. Other important elements of this design are the methods and equipment to be used for unloading, storage, and distributing the sludge at the site.

References - 3, 7, 8, 21, 73, 96

LIQUID SLUDGE TRANSPORT (TRUCK) FACT SHEET 6.1.7

FLOW DIAGRAM -

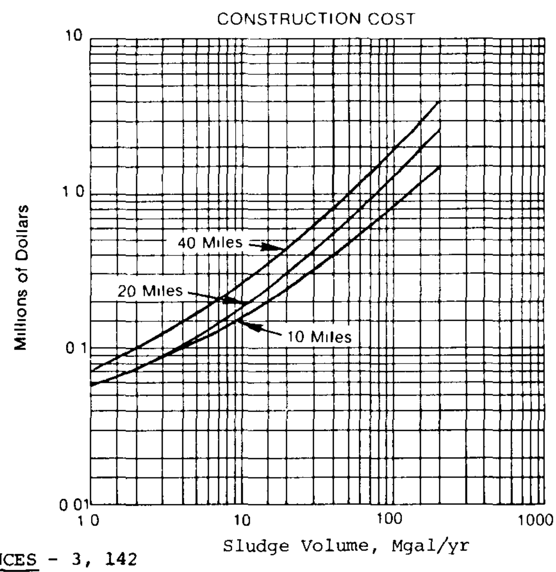


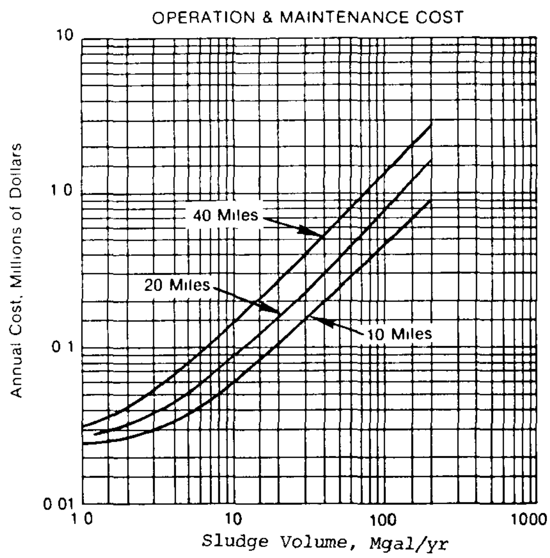


ENERGY NOTES (142) - Approximate average annual Btu used per Mgal sludge per one-way tripmile for 1,200, 2,500, and 5,500 gal trucks are, respectively, 51×10^6; 22×10^6; 14×10^6 Btu. Electrical energy required for pumping is insignificant with respect to transportation energy needs.

COSTS* - Assumptions: ENR Index = 2475

1. Construction cost includes load/unload facilities and purchase of the most cost effective size trucks per volume of sludge transported; i.e., 1200 gal, 2500 gal, and 5500 gal. Does not include storage at unloading site.
2. Equipment is sized to fill truck in 20 min. maximum.
3. Sludge = 4 percent solids.
4. Operation and maintenance costs include truck maintenance and operation and supplies for the loading facility.
5. Fuel cost (Gasoline) = $0.60/gal; electrical power @ $.02/kWh.
6. Labor @ $7.50/h.
7. Most cost effective size trucks per volume of sludge transported; i.e., 1200 gal, 2500 gal, 5500 gal.
8. 8 h/d operation; 360 d/yr.
9. Travel distances of 10, 20, or 40 miles one way to disposal site.





REFERENCES - 3, 142

*To convert construction cost to capital cost see Table A-2.

SLUDGE PUMPING FACT SHEET 6.1.8

Description (22) - Sludges, scum, screenings, and sludge cakes have different viscosities and solids content at different locations. Pumps are employed to move these materials where gravity flow is not possible or where the receiving location requires a specific flow and pressure of the pumped fluid. Capacities up to 80,000 gal/min and 210 ft head with fluids having up to 20 percent solids content are required.

Common Modifications (22) - Electric motor or internal combustion engine power. Variable speed belt, chain, and fluid drives. Materials of pump internal parts construction vary according to the properties of the fluids pumped.

Technology Status - Highly developed.

Applications (22, 52) - Stormwater treatment facilities where gravity return of residuals to the dry weather sewer is not possible. Wastewater treatment plants to convey residuals from process to process. Wastewater treatment plants to convey sludge from plant to disposal site by pipeline.

Typical Equipment/No. of Mfrs. (23) - Pump units/34.

Design Criteria (7, 22, 52) - Sludge pumping equipment is selected on the basis of sludge concentration and the operation intended:

Pump Type	Max.Solids Handled, %	Max.Suction Lift, ft	Capacity gal/min	Max.Head ft	Typ.Eff. %	Typical Applications
Centrifugal, 2 port, non-clog	2	15	50-20,000	200	60-85	Raw wastewater, primary and secondary settled sludges, land application, chem. treated sludge, incinerator slurries.
Centrifugal, vortex flow	6	15	20-5,000	210	55-65	Sludge recirculation, effluents with stringy material.
Mixed flow	2	15	1000-80,000	60	80-88	Sludge recirculation, land application.
Air lift	6	NA	30-150	60	low	Raw wastewater, return sludge, scum.
Screw lift	6	0	100-70,000	40	70-80	Raw wastewater, return sludge.
Positive Displ. progressing cavity, plunger, and diaphragm	20	28	30-700	500+	30-80	Primary settled, thickened, digested, incinerated, heat conditioned, and chemically treated sludges, scum.

Viscosity limit for efficiently operated centrifugal type pumps is 3000 to 3500 sSu

Non-clog, low r/min, low head centrifugal pumps are used for pumping return activated sludge because the sludge is dilute, contains only fine solids, and the sludge's flocculent solids would not be significantly sheared by the pump.

Plunger and progressing-cavity pumps are best for concentrated sludges to overcome high friction-head losses in discharge lines. However solids should be reduced to small size (max. 1.5" for progressing cavity).

Screw lift pumps are good for variable capacity operation because the rate of discharge is controlled by the fluid level at the inlet to the screw. Variable speed drive not required.

In general, the centrifugal and screw lift pumps are used to handle larger sludge flows with lower solids content and where precise control of flow is not required.

Air lift pumps, though of simple design and construction and not susceptible to clogging, are difficult to throttle and control and require large amounts of air.

Flow conditions can be improved by adding certain types of polymers to reduce viscosity of the fluid.

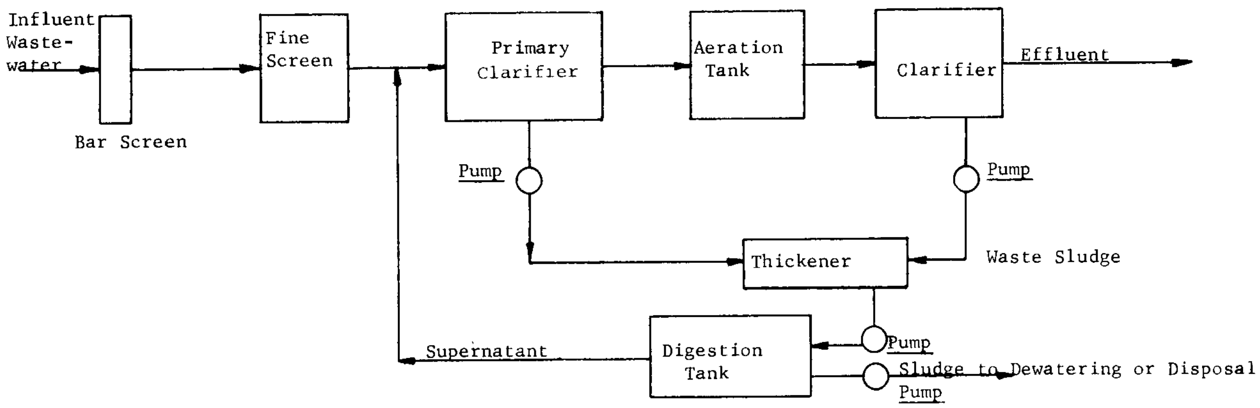
Reliability - Ten to 20 year expectancy provided manufacturer's maintenance procedures are followed. Reliability highly dependent on power source.

Environmental Impact - Low impact on air and water. Small impact on land for pumps which are in process lines. Potential for pollution under failure conditions.

References - 7, 22, 52

SLUDGE PUMPING FACT SHEET 6.1.8

FLOW DIAGRAM - Possible locations for major sludge pumps in a wastewater treatment plant:



ENERGY NOTES - Each pump application is highly site specific due to static head and the dynamic head requirements dictated by the piping configuration and the characteristics of the sludge being pumped. Approximate energy requirements for a pump installation can be computed by the following equation:

$$\text{kWh/yr} = \frac{1140\ (\text{Mgal/d X ft of total head})}{\text{Wire to Water Pump Efficiency}}$$

Wire to water efficiencies may vary from 75 percent to less than 40 percent, depending upon the type pump used and its size. Use of variable speed drives at speeds other than 100 percent speed generally lowers the wire to water efficiency.

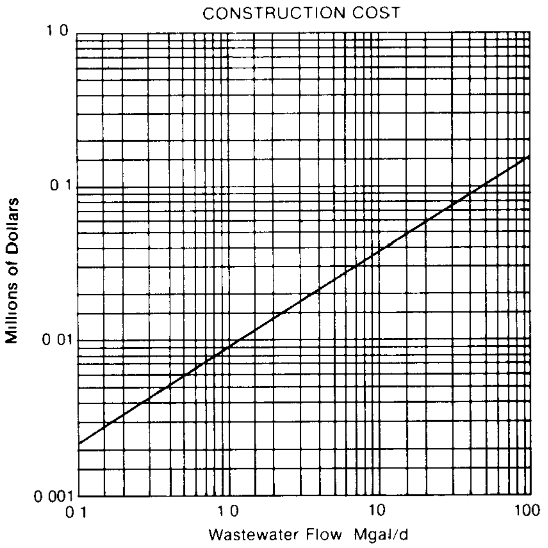
COSTS - ENR INDEX = 2475 *

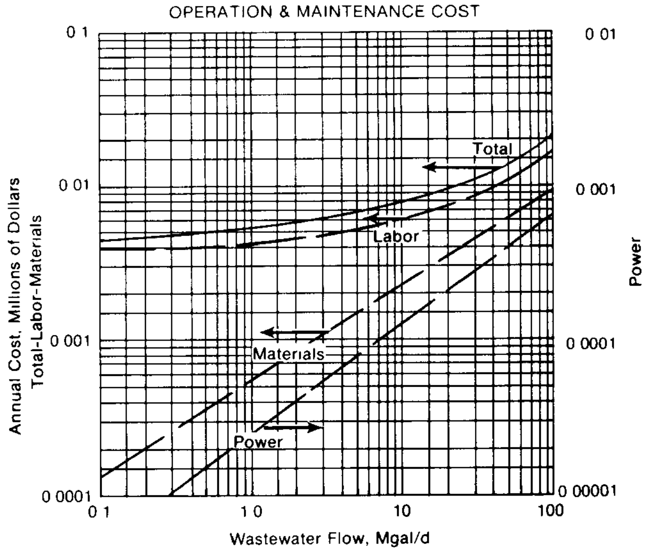
1. Costs are based on a sludge loading of 1900 lb/Mgal at 4% solids, i.e., 5700 gal of sludge/Mgal for combined primary and secondary sludge after thickening.
2. Non-clog centrifugal pumps. Service life: 10 years.
3. To adjust costs for alternative sludge quantities and characteristics, enter curves at effective flow (Q_E):

$$Q_E = Q_{DESIGN} \times \frac{\text{NEW DESIGN SLUDGE MASS, LB/MGAL}}{1{,}900\ \text{lb/Mgal}} \times \frac{4\%}{\text{NEW DESIGN CONCENTRATION (\%)}}$$

Note: New Design concentration should not exceed 5%.

4. Power at 2¢/kWh.





REFERENCES - 3, 22

*To convert construction cost to capital cost see Table A-2.

SLUDGE STORAGE

FACT SHEET 6.1.9

Description (7,8) - For the purposes of this fact sheet, sludge storage is the retention and blending of thickened primary and secondary sludges in an open tank. The purposes of sludge storage are to reduce the pathogen population by aeration and mixing, to further stabilize the sludge, to equalize short-term peak loads, and to either prepare the sludge for further processing or provide the means for loading the sludge into a disposal system. (The detention afforded by sludge storage can be used to further thicken the sludge.)

Common Modifications (22) - Rectangular or cylindrical tanks can be used, and agitators can be used for mixing. Sludge can also be mixed by the use of recycle. Air or pure oxygen can be used for aeration and mixing.

Sludge storage can also be used for chemical, tertiary, as well as other sludges. Sludge scraper mechanisms with picket arms would then be required.

Technology Status - In widespread use.

Typical Equipment/No. of Mfrs. (23) -

Agitators/10; air compressors/8; blowers/7; mixers/26.

Applications - Can be applicable where separate thickening processes for primary and activated sludges are used. It is also used between multiple sludge treatment processes so that each unit can be batch operated.

Limitations - Potential for odor problems.

Chemicals Required - None.

Residuals Generated - None.

Design Criteria (8,22) - Tank floor slope is generally 1:12. This increased depth near the center of the tank can serve to compact the sludge. Sludge concentration increases as a function of the depth of the sludge blanket. Effluent line should draw compressed solids out of the bottom of the tank. Mixing by air diffusion requires at least 25 $ft^3/min/1000\ ft^3$. Mixing by agitators (mixers) requires approximately 1.0 $hp/1000\ ft^3$.

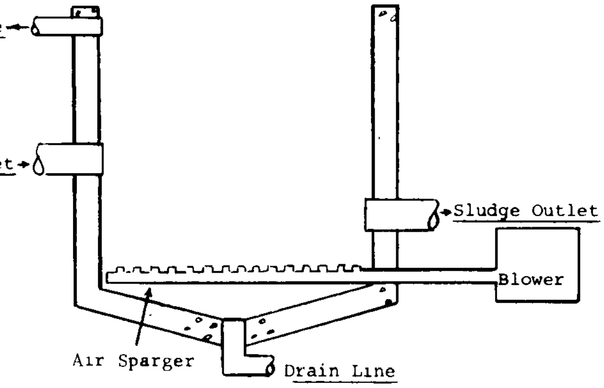
Process and Mechanical Reliability - High degree of reliability provided regular maintenance procedures for the air and mixing equipment are followed.

Environmental Impact - Can create odor problems if breakdown of air system occurs. Land: Moderate--depends on size of tank. No residuals are generated.

References - 7, 8, 22, 23

SLUDGE STORAGE | FACT SHEET 6.1.9

FLOW DIAGRAM



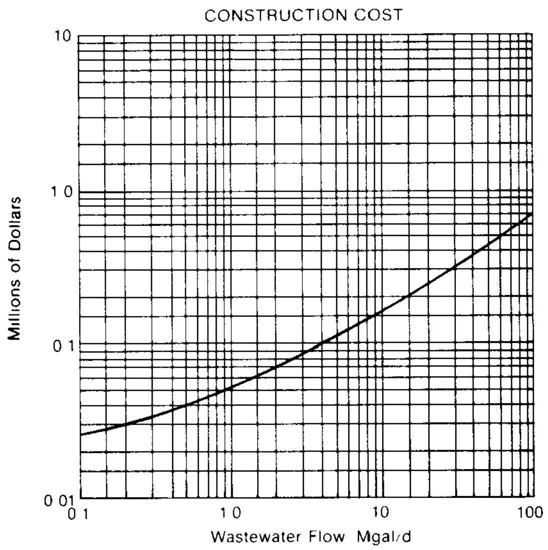
Sludge Storage Tank

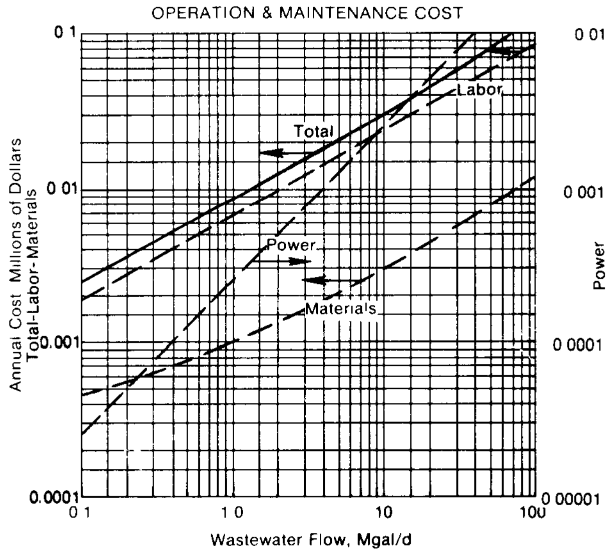
ENERGY NOTES - Based upon the "Cost" assumptions shown below, kWh/yr = 4242 x million gallons per day of plant throughput assuming that all conventional activated sludge plant sludges pass through the storage tank.

COSTS*- Assumptions: ENR Index = 2475

1. Construction cost includes storage tank and air-supply system.
2. Operation cost includes storage of thickened primary and secondary sludge (1900 lb/Mgal; at 4% solids); mixing by diffused air (25 CFM/1000 ft^3 or approximately 130 hp/Mgal of sludge.
3. To adjust costs for other sludge quantities and concentrations, enter the curves at effective flow (Q_E).

$$Q_E = Q_{DESIGN} \times \frac{\text{New Design Sludge Mass}}{1900\ \text{lb/Mgal}} \times \frac{4\%}{\text{New Design Sludge Concentrations}}$$





REFERENCES - 3, 4, 22

*To convert construction cost to capital cost see Table A-2.

SLUDGE LANDFILLING - SLUDGE TRENCHING FACT SHEET 6.1.10

Description - Stabilized or unstabilized sludge is placed within a subsurface excavation and covered with soil. Trench operations are more specifically categorized as follows: narrow trench and wide trench. Narrow trenches are defined as having widths less than 10 ft; wide trenches are defined as having widths greater than 10 ft. The width of the trench is determined by the solids content of the receiving sludge and its capability of supporting cover material and equipment. Distances between trenches should be large enough to provide sidewall stability, as well as space for soil stockpiles, operating equipment and haul vehicles. Design considerations should include provisions to control leachate and gas migration, dust, vectors, and/or aesthetics. Leachate control measures include the maintenance of 2 to 5 ft of soil thickness between trench bottom and highest groundwater level or bedrock (2 ft for clay to 5 ft for sand), or membrane liners and leachate collection and treatment system. Installation of gas control facilities may be necessary if inhabited structures are nearby.

Narrow trench - Sludge is disposed in a single application and a single layer of cover soil is applied atop this sludge. Trenches are usually excavated by equipment based on solid ground adjacent to the trench, and equipment does not enter the excavation. Backhoes, excavators and trenching machines are particularly useful. Excavated material is usually immediately applied as cover over an adjacent sludge-filled trench. Sludge is placed in trenches either directly from haul vehicles, through a chute extension, or by pumping. The main advantage of a 2 to 3 ft narrow trench is its ability to handle sludge with a relatively low solids content (15 to 20 percent). Instead of sinking to the bottom of the sludge, the cover soil bridges over the trench and receives support from undisturbed soils along each side of the trench. A 3 to 10 ft width is more appropriate for sludge with solids content of 20 to 28 percent, which is high enough to support cover soil.

Wide trench - Usually excavated by equipment operating inside the trench. Track loaders, draglines, scrapers and track dozers are suitable. Excavated material is stockpiled on solid ground adjacent to the trench for subsequent application as cover material. If sludge is incapable of supporting equipment, cover is applied by equipment based on solid undisturbed ground adjacent to the trench. A front-end loader is suitable for trenches up to 10 ft wide; a dragline is suitable for trench widths up to 50 ft. If sludge can support equipment, a track dozer applies cover from within the trench. Sludge is placed in trenches by one of the following methods: from haul vehicles directly entering the trench and haul vehicles dumping from the top of the trench. Dikes can be used to confine sludge to a specific area in a continuous trench.

After maximum settlement has occurred in approximately one year, the area should be regraded to ensure proper drainage.

Common Modifications - Codisposal: Sludge/refuse

Technology Status - Fully demonstrated.

Applications - A relatively simple sludge disposal method suitable for stabilized or unstabilized sludge. Does not require special expertise beyond the skills necessary to operate the above-mentioned equipment, plus administrative skills. Narrow trench system particularly well suited for smaller communities.

Limitations - Frozen soil conditions and precipitation cause operating difficulties.

Typical Equipment/No. of Mfrs. (83) - Front-end loader/7; bulldozer/19; scraper/25; backhoe/45; dragline/13; trencher/4; grader/25.

Chemicals Required - Lime and masking agents to control odors.

Residuals Generated - None

Design Criteria -

	Narrow Trench (less than 10 ft)	Wide Trench (more than 10 ft)
Sludge Solids Content	15 to 20 percent for 2 to 3 ft widths; 20 to 28 percent for 3 to 10 ft widths.	20 to 28 percent for land-based equipment; more than 28 percent for sludge based equipment.
Ground Slopes	Less than 20 percent.	Less than 10 percent.
Cover Soil Thickness	2 to 3 ft for 2 to 3 ft widths; 3 to 4 ft for 3 to 10 ft widths.	3 to 4 ft for land based equipment; 4 to 5 ft for sludge based equipment.
Sludge Application Rate	1,200 to 5,600 yd^3/acre.	3,200 to 14,500 yd^3/acre.
Equipment	Backhoe with loader, excavator, trenching machine.	Track loader, dragline, scraper, track dozer.

Process Reliability - Very reliable sludge disposal method.

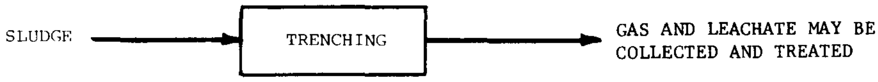
Environmental Impact - Potential soil erosion and odor problems. Leachate and gas continue to be produced for many years after the fill is completed; leachate must be properly controlled to avoid groundwater and surface water contamination; gas is explosive or can stunt or kill vegetation if not properly controlled. The narrow trench method is relatively more land intensive.

References - 148, 168

SLUDGE LANDFILLING - SLUDGE TRENCHING

FACT SHEET 6.1.10

FLOW DIAGRAM

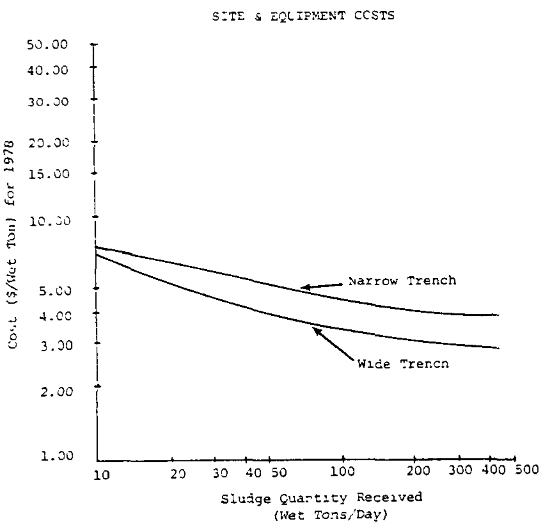


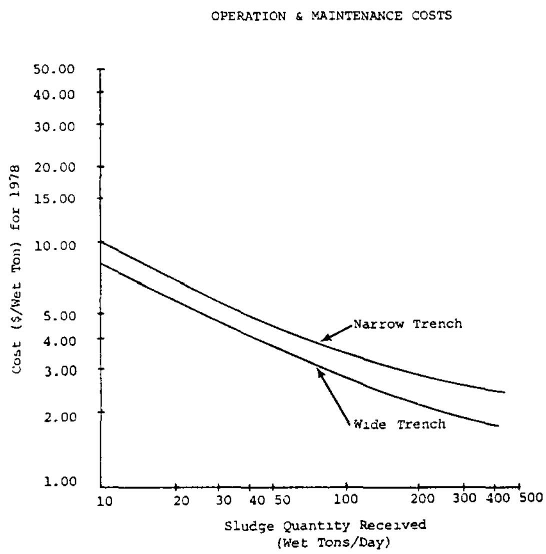
ENERGY NOTES (171) - Actual fuel consumption varies considerably with specific sludge, site and operating conditions. Fuel consumption rates for some typical construction equipment performing light to medium work is given below.

Equipment	Average Diesel Fuel, gal/hr	Equipment	Average Diesel Fuel, gal/hr
Caterpillar D-6	5.2	Grader - 25,000 lb	4.4
Caterpillar D-8	10.8	28,000 lb	4.8
Excavator - ½ yd^3	3.4	30,000 lb	5.2
1 yd^3	5.0	40,000 lb	6.0
1-1/4 to 1-1/2 yd^3	8.8	54,000 lb	7.9
1-1/2 to 2 yd^3	11.1	Track Loader - 1 yd^3	2.4
Wheel Loader 1-1/2 yd^3	3.0	1-1/2 yd^3	3.4
2 yd^3	3.7	2 yd^3	4.2
3 yd^3	4.6	2.5 yd^3	5.7
4 yd^3	6.2	3 yd^3	7.4
5 yd^3	9.0	4 yd^3	11.3
7 yd^3	13.2	Tractor-Scraper, small	4.9
		medium	11.4
		large	15.8

COSTS*, 1978 dollars (168) - ENR Index = 2776

1. Site and equipment costs include land ($2500/acre), site preparation (clearing, grubbing, surface water control ditches and ponds, monitoring wells, soil stockpiles, roads and facilities), equipment purchase, engineering (6%). Actual fill area consumes 50 percent of total site area.
2. Operating costs include labor ($8/hr, including fringe, overhead, administration), equipment fuel, maintenance and parts; utilities; laboratory analysis of water samples; supplies and materials.
3. Actual costs vary considerably with specific sludge and site conditions.





REFERENCES - 168, 171

*To convert construction cost to capital cost see Table A-2.

SLUDGE LAGOONS — FACT SHEET 6.1.11

Process Description (8, 56) - Digested sludge has often been applied to sludge lagoons adjacent to or in the proximity of treatment facilities. These sludge lagoons are primarily designed to accomplish long-term drying of the digested sludge through the physical processes of percolation and evaporation, primarily the latter. This method of sludge processing has been extremely popular in the U.S. due to its relatively low cost (when inexpensive land is plentiful) and minimal O&M requirements, especially at smaller wastewater treatment facilities. The process is relatively simple, requiring periodic decanting of supernatant back to the head of the plant and occasional mechanical excavation of dewatered or dried sludge for transportation to its ultimate disposal location. Lagoons can be a very useful process step. Supernatant is far better (low SS) than supernatant from a secondary digester or even a thickener. Ultimate disposal of the product solids often is as a soil conditioner or for landfilling.

Sludge lagoons may also be used as contingency units at treatment plants to store and/or process sludges when normal processing units are either overloaded or out of service.

The drying time to 30 percent solids is generally quite lengthy and may require years. Climatic conditions and pre-lagoon sludge processing greatly influence lagoon performance. In warmer, drier climates well-digested sludges are economically and satisfactorily treated by sludge-drying lagoons because of their inherent simplicity of operation and flexibility. Complete freezing causes sludge to agglomerate so when it thaws supernatant decants or drains away easily. Well-digested sludges minimize potential odor problems which are inherent in this type of system. Multiple-cells are required for efficient operation.

Common Modifications (56) - Methods and patterns of loading, supernatant recycling techniques and mechanical cleaning techniques vary with location, climate, and type of sludge to be processed.

Technology Status - This technology is widely used for industrial and municipal sludge processing throughout the world.

Limitations - There is a high potential for odors and nuisance insect breeding if feed sludges are not well-digested. Odor and nuisance control chemicals are not entirely satisfactory. Also, definitive data on performance and design parameters are lacking despite the popularity of this approach.

Typical Equipment/No. Mfrs (23) - Front-end loaders/7; bulldozers/19; dragline/13.

Applications - A simple sludge drying method for digested sludge in smaller communities by virtue of the fact that large inexpensive land areas are required.

Chemicals Required - Lime or other odor control chemicals may be required if digestion is incomplete.

Residuals Generated - Generally, the residuals resulting from a well-operated lagoon will be in the range of 30 percent solids and are suitable for use as a soil conditioner or for landfilling.

Design Criteria (8, 56) -

Dikes:	Slopes of 1:2 exterior and 1:3 interior to permit maintenance and mowing and to prevent erosion; width sufficient to allow vehicle transport during cleaning.
Depth:	1.5 to 4.0 feet of sludge depth (depending upon climate)
Bottom:	Separation from groundwater is dependent upon application depths and soil characteristics, but should not be less than 4 feet to prevent groundwater contamination.
Cells:	A minimum of two cells is required.
Loading Rates:	2.2 to 2.4 lb solids/yr/ft^3 of capacity. 1.7 to 3.3 lb solids/ft^2 of surface/30 days of bed use. 1 to 4 ft^2/capita (depending on climate).
Decant:	Single or multiple level decant for periodic returning supernatant to head of plant.
Sludge Removal:	Approximately 1.5 to 3 yr intervals.

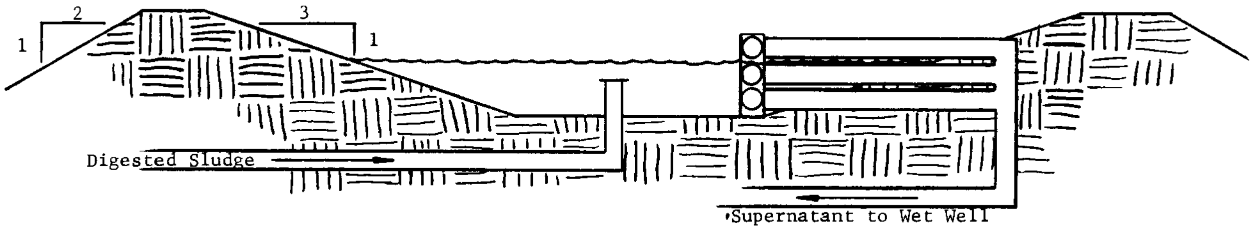
Process Reliability - Where properly designed, process reliability is function of reliability of upstream processing (digestion).

Environmental Impact - Odor and vector potential high unless properly designed and operated; land-use requirement high; groundwater pollution potential high unless proper site characterization incorporated into design.

References - 8, 56, 83

SLUDGE LAGOONS FACT SHEET 6.1.11

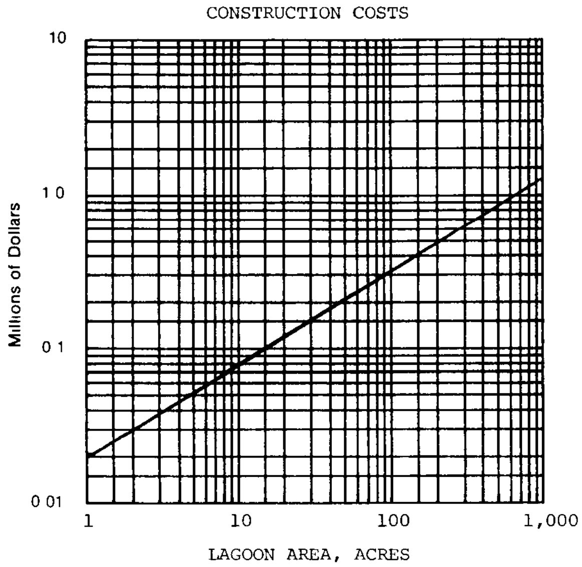
FLOW DIAGRAM -

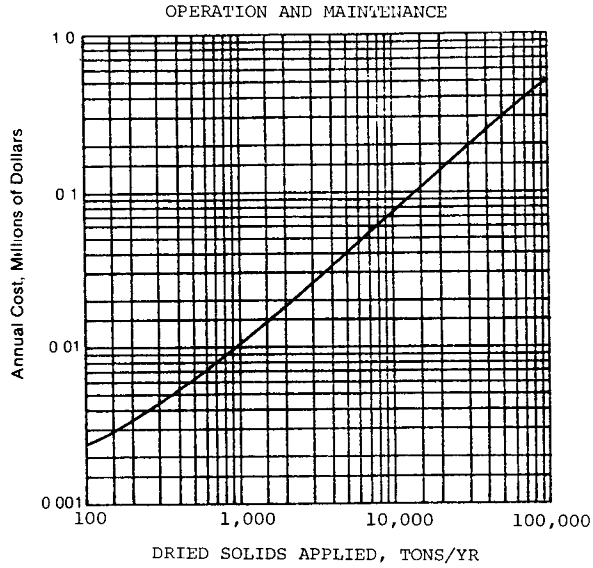


ENERGY NOTES - No external energy required other than possible sludge pumping from digester (see Fact Sheet 6.1.8) and supernatant pumping (see Fact Sheet 3.1.13).

COSTS*-

1. Costs = 2nd quarter, 1977 dollars· ENR Index = 2515
2. Construction costs includes process piping, equipment, concrete, steel and excavation.
3. Sizing = 4 acres/Mgal/d, 1.5 ft depth of sludge
4. Operation and maintenance includes materials, supplies, maintenance, operation and residuals removal.
5. Labor = $7.50/h





REFERENCES - 5, 56, 201

*To convert construction cost to capital cost see Table A-2.

CO-INCINERATION OF SLUDGE - SLUDGE INCINERATOR FACT SHEET 6.2.1

Description - Co-incineration is incineration using a combination of wastewater sludge and a combustible material, other than natural gas or fuel oil, in a single furnace. By combining sludge with other materials, a combined furnace feed can be formed which has both a low water content and a heating value high enough to eliminate the need for supplemental furnace fuel. Some (of the combustible) materials are: municipal solid waste, coal, wood wastes, textile wastes, bagasse, and farm wastes, such as corn stalks, rice husks, etc.

Co-incineration was first demonstrated in this country in Franklin, Ohio, utilizing a fluidized bed furnace. The fuel consisted of the rejected organic waste stream from the solid waste fiber recovery operation and wastewater sludge. Organic residue from the fiber recovery system, a 20 percent solids slurry, is mixed with 5 percent solids sludge, dewatered to 45 percent solids in a cone press, and combusted in the fluidized bed incinerator. The incinerator requires about 3000 Btu per pound of as-received material to sustain combustion and as the combination of solid waste and sludge contain about 3600 Btu per pound, autogenous conditions are maintained. However, with only 600 Btu per pound available as excess energy, the potential for energy recovery is low.

Co-incineration using a multiple hearth sludge incinerator has been tested both in the United States and in Europe. Early testing in Europe using raw solid waste proved less than successful. However, converting the organic portion of solid waste into a fluff to fuel the multiple hearth proved technically viable. This technique was demonstrated at a wastewater treatment plant in Concord (central Contra Costa County), California, in an EPA-supported demonstration. In the demonstration, an existing multiple hearth sludge incinerator (16 ft dia., 6 hearth) was modified to accept refuse-derived fuel (RDF) as a fuel. (The RDF mixed with the sludge having a solids content of 16 percent was introduced into the top hearth, or fed directly into the third hearth. The latter method proved more efficient. Approximately 70 to 100 percent excess air was used. The system was operated eight hours per day for two months with a combined wet feed rate of up to 10 ton/hr. Autogenous combustion could be maintained with an RDF/sludge ratio of 1:2 using a sludge solids content of 16 percent. The unit operated either in the incineration mode (all excess air added to furnace proper) or the starved air combustion mode (oxygen deficient in the furnace, excess air added at afterburner). The latter mode was preferred.

In a bench-scale study recently completed, the addition of pulverized coal to liquid sludge showed that the coal improves filtration efficiency slightly and results in a higher solids content in the filter cake than if the coal is added directly to the sludge cake. Addition of the coal to the liquid sludge prior to filtration results in a furnace feed which has a higher solids content and heat value than pure sludge. This reduces or eliminates the supplemental fuel demand. This approach solves the problem of solids content versus fuel value in one step. Coal, of course, is not a waste material of little value. However, it substitutes a fossil fuel of great abundance for scarce fuel oil and gas.

Technology Status - Technical feasibility of co-incineration in sludge incinerators with solid waste has been demonstrated; however, there were only three municipal plants in operation in United States as of December, 1976 (91).

Applications - To provide a new low cost fuel source for existing sludge disposal facilities; derivation of wastewater treatment plant power from a new energy source; use of same device to dispose of two waste products thereby realizing capital and operating cost benefits, as well as reduced land requirement for disposal.

Limitations - Shredders are required to produce a nominal 1 inch refuse size. More excess air is required with co-incineration versus separate sludge incineration. In addition, institutional constraints may have to be resolved such as: existing long term refuse disposal contracts, jurisdictional disputes between currently separate wastewater treatment and solid waste disposal government agencies.

Typical Equipment/No. of Mfrs. (10, 25, 77) -
Multiple Hearth Furnace System - Multiple Hearth Furnaces/10, Sludge Dewatering Devices/15, Flapgate Valves/6, Cooling and Combustion Air Fans/42, Sludge Conveyors/7, Gas Scrubbers/3, Ash Handling System/1, Fluid Bed Furnace System - Screw Feeders (Sludge)/7, Combustion Air Fans/42, Recuperative Air Heaters/29, Exhaust Gas Scrubbers/3, Ash Handling System/1, Combustible Material Preparation and Feed Systems.

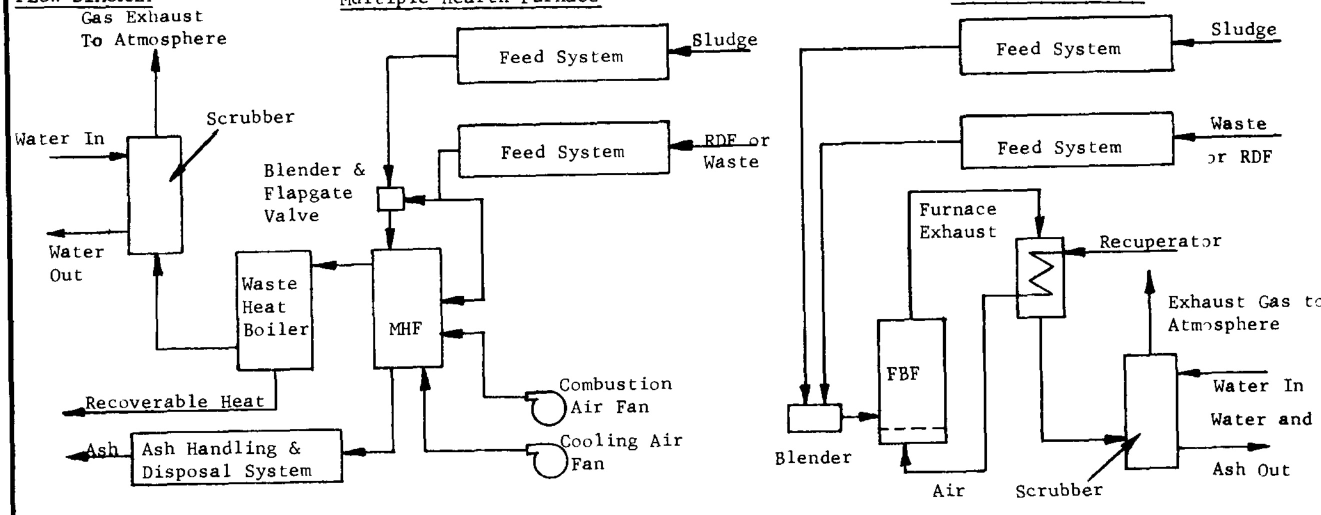
Environmental Impact - The impact is a strong function of feed material and sludge composition. The probable uncontrolled particulate emissions from a co-incineration MHF furnace are about 10 percent greater than those from sludge incineration alone. Available data indicate that toxic organics can be destroyed during incineration and that the bulk of metals, except Hg, can be removed by particulate collectors (91). Hg emissions appear to be acceptable but must be compared to allowable ambient concentrations at time of design.

References - 8, 25, 43, 65, 10, 77, 91

FACT SHEET 6.2.1

CO-INCINERATION OF SLUDGE - SLUDGE INCINERATOR

FLOW DIAGRAM - Multiple Hearth Furnace; Fluid Bed Furnace



Co-incineration in Multiple Hearth Furnace (MHF) Co-incineration in Fluid Bed Furnace (FBF)

ENERGY NOTES (91) - Using the power and fuel cost/ton cited below, the electrical energy usage is 100 kWh/ton, and the auxiliary fuel requirement is approximately 59,000 Btu/ton.

COSTS (91) - Co-incineration/Multiple Hearth Furnace (Capacity 600 ton/d refuse; 224 ton/d sludge at 20 percent solids). Costs, Mid 1975. Assumptions for the cost estimate: Capital costs include equipment, labor and materials for installation, construction overhead and contingency (15 percent of equipment modules only). Manpower includes four shifts/d, seven d/wk operation with supervision and maintenance. Salary/overhead ranges from $10,000 to $20,000/yr ($17,000 for operators and senior maintenance people). Twenty percent is added to total manpower cost for overtime, vacations, holidays, etc. Power costs = $.027/kWh. Fuels costs = $2.73/($10^6$) Btu. Water and sewer costs = $0.37/1,000 gal. Residue disposal cost = $4.00/ton. ENR Index = 2205

CAPITAL COST

Item	Cost
Shredder:	
Two Primary Shredders	$ 562,000
Two Screen & Mag. Separators	746,000
Two Secondary Shredders	628,000
Conveyors	930,000
Subtotal	$ 2,866,000
Pneumatic Conveying System	366,000
Storage Silo (166,000 ft^3)	1,541,000
Four Feed Conveyors (Storage to Furnace)	648,000
Four Multiple-Hearth Furnaces (22 ft diameter X 11 ft hearth)	13,800,000
Building	4,314,000
Direct Construction Cost (DCC)	$23,535,000
Design, Construction Management, Start-Up (15% DCC)	3,530,000
Land ($50,000/acre)	350,000
Legal Fees (3% DCC)	706,000
Bond Discount (3% Total Cost)	844,000
Total Facility Cost	$28,965,000
Facility Cost Per ton/d (Design Cap.)	$ 35,200

OPERATING COST

Item	Cost per Ton*	Total Ann. Cost
Manpower (45 employees)	$ 3.40	$ 699,000
Power (2885 kWh/h)	2.72	561,200
Water/Sewer (1310 gal/min)	1.02	209,400
Auxiliary Fuel (85,300 gal/yr)	0.16	32,300
Maintenance (2.5% Incinerator DCC) (5% Shredder DCC)	3.20	660,000
Overhead (1% DCC)	1.14	235,400
Residue (161 ton/d)	0.94	193,200
Total Operating Cost	$12.58	$2,591,100

*Costs based on 824 ton/d facility with a ratio of refuse:sludge at approximately 3:2.

REFERENCE - 91

CO-INCINERATION OF SLUDGE - SOLID WASTE INCINERATOR — FACT SHEET 6.2.2

Description - Co-incineration is incineration using a combination of wastewater sludge and another combustible material, other than natural gas or oil, in a single furnace. Some other combustible materials include: municipal solid waste, coal, wood wastes, textile wastes, and farm wastes.

One approach to co-disposal, that of using a solid waste incinerator as the volume reduction unit, was tried many times. In the past 50 years, many municipal incinerators were used for rudimentary co-disposal. The problems of material handling, feeding, and firing were never successfully addressed, and as a result the concept was generally abandoned. As the technology of municipal solid waste incineration matured into efficient, sophisticated devices, co-incineration was again considered and great strides were made. A number of incinerators and waterwall combustion units have been tested as co-incineration devices, and some plants are operating on a day-to-day basis. These plants use the heat released from the solid waste combustion to dewater or dry the sludge to its autogenous point. The form of the heat is either hot flue gas, steam from the waterwall combustion unit or waste heat boiler, or heat from the fire itself. Mechanical dewatering devices in the co-disposal plants can be driven by steam or electricity generated within the plant itself. The drying can take place in the furnace or in a separate vessel.

Two plants in this country use flue gas to dry the sludge and then burn the sludge solids in the furnace. Ansonia, Connecticut has a 200 ton/d (design) refractory incinerator. About 55 ton/d of refuse are disposed of in an eight-hour shift. Sludge from the integrated wastewater treatment plant at about four percent solids is dried in a high speed disk co-current spray dryer. Hot flue gases from the secondary combustion chamber at 1200^{o}F are introduced into the spray dryer. Vapors and dry solids are blown into the furnace above the second grate where the solids burn in suspension. However, the dried sludge is presently not burned but used for fertilizer by local residents.

Another small refractory incinerator, 50 ton/d average throughput, in Holyoke, Massachusetts, uses the same general technique but the sludge, after mechanical dewatering to 28 percent solids, is dried in a rotary dryer. Hot flue gas from the incinerator is used to directly heat the sludge in the dryer. The dried solids are then burned in suspension above the refuse grates. No exportable energy is recovered in either of these plants.

A different technique was tested in Norwalk, Connecticut. The tests proved the viability of the idea and it is being replicated in Glen Cove, New York. In this approach, the heat of the burning solid waste directly dries the sludge and the dried solids burn along with the waste. This is accomplished by spraying the sludge at about five percent solids into the charging chute forming a layer of sludge on the solid waste. As the solid waste flows into the furnace from the charging chute, the sludge layer remains on top of the solid waste. In the furnace, the heat from the burning solid waste first drives off the moisture from the sludge, and then the dry sludge solids burn along with the solid waste on the grates. The plant at Glen Cove will have waste heat boilers installed and the steam will be used to generate electricity.

Two co-incineration plants are currently operating in Europe. One is at Dieppe, France, the other at Krefeld, West Germany. Both utilize a waterwall combustion unit to burn the solid waste and wastewater sludge.

Technology Status - At least five co-incineration plants are operating worldwide (three in the United States) utilizing solid waste incinerators. Thus, the technical viability of this approach has been demonstrated on a full scale basis, but, it is not widely used.

Applications - Use of a single device to dispose of both sludge and another solid waste material, thus reducing capital and operating costs; derivation of wastewater treatment plant power and fuel requirements from a more economical waste energy source; reduction of land requirements for disposal.

Limitations - A number of institutional constraints have to be resolved such as the existence of contracts with private firms which define ownership of the solid refuse. Also, wastewater treatment and solid waste disposal are often controlled by different government agencies. The co-incineration plant site must be within pumping distance of the wastewater treatment plant. The minimum excess air rate for co-incineration in refuse incinerators is 150 percent (91). The minimum flue gas temperature suitable for odor destruction is 1400^{o}F.

Typical Equipment/No. of Mfrs. (10, 77) -

Incinerator/10, Stokers/5, Air Supply Fans/40, Exhaust Gas Scrubbers/3, Ash Handling System/1, Refuse Handling and Feed System/9.

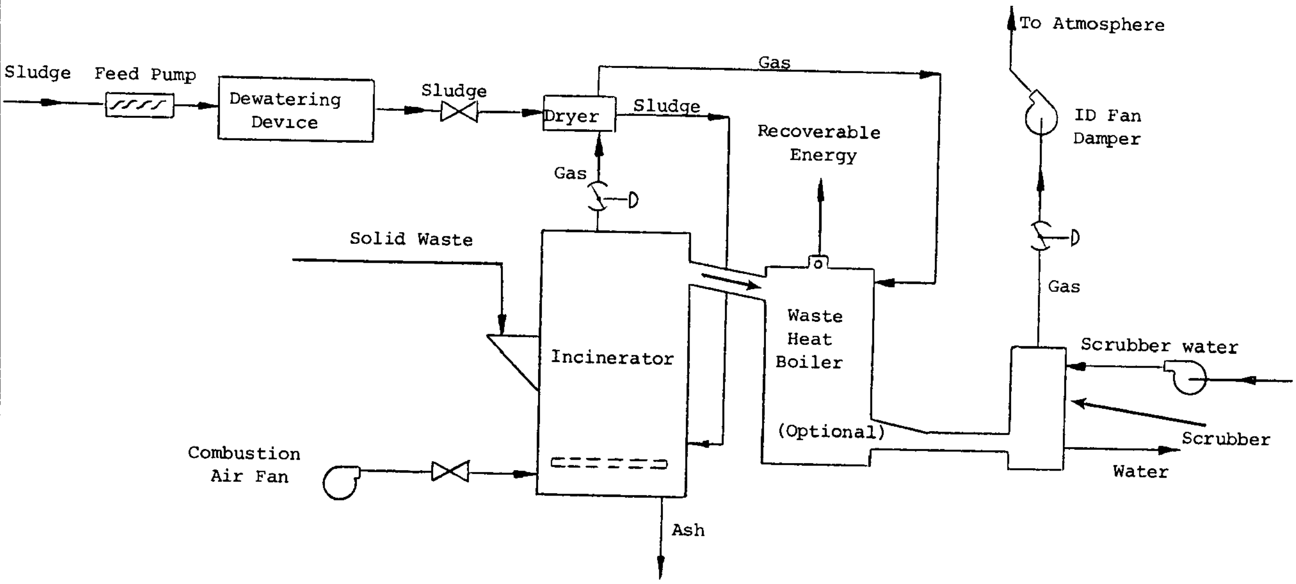
Performance - Volume and weight reductions for co-incineration will be about the same as for separate incineration of both materials.

Environmental Impact - Data is required to establish impact with various feed combinations; however, uncontrolled particulate emission from a refuse incinerator would roughly double with co-incineration. Emission of SO_x, NO_x, HCl and CO is usually insignificant but must be evaluated in terms of the feed composition and the emission inventory of the region (91). Available data indicate that toxic organics (PCB's, pesticides, etc.) will either be destroyed by the thermal condition or will be retained in the particulate collection equipment and ash (91). Volatile Hg emissions are usually low, but must be evaluated in relation to the ambient concentrations at the time of design.

References - 8, 43, 65, 10, 77, 91

CO-INCINERATION OF SLUDGE - SOLID WASTE INCINERATOR | FACT SHEET 6.2.2

FLOW DIAGRAM -



ENERGY NOTES (91) - Using the power and fuel cost/ton cited below, the electrical energy usage is 44 kWh/ton, and the auxiliary fuel requirement is approximately 73,000 Btu/ton.

COSTS (91) - Based on mid-1975 costs for an incinerator with design capacity of 600 ton/d refuse, 224 tons/d sludge. ENR Index = 2205

1. Capital costs include equipment, labor and material for installation, construction overhead and contingency (15 percent on equipment modules only).
2. Manpower includes four shifts, seven d/wk operation with supervision and maintenance. Salary/overhead ranges from \$10,000 to \$20,000/yr (\$17,000 for operators and senior maintenance people). Twenty percent is added to total manpower cost for overtime, vacations, holidays, etc.
3. Power costs: \$.027/kWh. Fuel costs: \$2.73/(10^6 Btu). Water and Sewer costs: \$0.37/1000 gal. Residue disposal cost: \$4.00/ton.

CAPITAL COST

Item	Cost
Incinerator DCC	$15,291,000
Drier Circuit:	
Rotary Drier, Fan, Cyclone	$ 1,477,000
Ductwork	138,000
Conveyors & Pug Mill	278,000
Subtotal	1,893,000
Additional Building	1,370,000
Direct Construction Cost	$18,554,000
Design, Construction Management, Start-up (15% of DCC)	2,783,000
Land (50,000 per acre)	500,000
Legal Fees (3% DCC)	557,000
Bond Discount (3% Total Cost)	672,000
Total Facility Cost	$23,066,000
Facility Cost per ton/d (Design Capacity)	$28,000

OPERATING COST

Item	Cost Per* Ton	Total Annual Cost
Manpower (46 employees)	$3.61	$ 744,000
Power (1265 kWh/h)	1.20	247,700
Water/Sewer (435 gal/min)	0.29	59,700
Auxiliary Fuel & Heating (128,800 gal/yr)	0.20	41,200
Maintenance (2.5% DCC)	2.25	463,800
Overhead (1% DCC)	0.90	185,500
Residue Disposal (161 ton/d)	0.94	193,200
Total Operating Cost	$9.39	$1,935,100

*Based on 824 tons of combined refuse/sludge feed in a ratio of approximately 3:2.

REFERENCE - 91

COMPOSTING SLUDGE, STATIC PILE FACT SHEET 6.2.3

Description - Wastewater sludge is converted to compost in approximately eight weeks in a four-step process:

Preparation - Sludge is mixed with a bulking material such as wood chips or leaves, in order to facilitate handling, to provide the necessary structure and porosity for aeration, and to lower the moisture content of the biomass to 60 percent or less. Following mixing, the aerated pile is constructed and positioned over porous pipe through which air is drawn. The pile is covered for insulation.

Digestion - The aerated pile undergoes decomposition by thermophilic organisms, whose activity generates a concomitant elevation in temperature to 60°C (140°F) or more. Aerobic composting conditions are maintained by drawing air through the pile at a predetermined rate. The effluent air stream is conducted into a small pile of screened, cured compost where odorous gases are effectively absorbed. After about 21 days the composting rates and temperatures decline, and the pile is taken down, the plastic pipe is discarded, and the compost is either dried or cured depending upon weather conditions.

Drying and Screening - Drying to 40 to 45 percent moisture facilitates clean separation of compost from wood chips. The unscreened compost is spread out with a front end loader to a depth of 12 inches. Periodically a tractor-drawn harrow is employed to facilitate drying. Screening is performed with a rotary screen. The chips are recycled.

Curing - The compost is stored in piles for about 30 days to assure no offensive odors remain and to complete stabilization. The compost is then ready for utilization as a low grade fertilizer, a soil amendment, or for land reclamation.

Modifications - 1. Extended high pile - pile height is extended to 18 ft using a crane (still experimental). Can result in savings of space and materials. 2. Aerated Extended Pile - each day's pile is constructed against the shoulder of the previous day's pile, forming a continuous or extended pile. Can result in savings of space and materials.

Technology Status - Successfully demonstrated at four locations and projected to be capable of serving large cities. Experiments are ongoing on various operating parameters.

Applications - Suitable for converting digested and undigested sludge cake to an end product of some economic value. Insulation of the pile and a controlled aeration rate enable better odor and quality control than the windrow process from which it evolved.

Limitations - The drying process is weather-dependent and requires at least two rainless days. The use of compost on land is limited by the extent to which sludge is contaminated by heavy metals and industrial chemicals. Industrial pretreatment of wastewater treatment plant influent should increase the availability of good quality sludges for composting.

Typical Equipment/No. of Mfrs. (83) - Front-end loader/16 or crane/more than 100; four inch perforated plastic pipe/more than 100; blower/more than 100; timer/more than 100; tractor-drawn/23; harrow/42; rotary screen/55.

Performance - Sludge is generally stabilized after 21 days at elevated temperatures. Maximum temperatures of between 60° to 80°C are produced during the first three to five days, during which time odors, pathogens and weed seeds are destroyed. Temperatures above 55°C (131°F) for sufficient periods can effectively destroy most human pathogens. The finished compost is a humus-like material, free of malodors, and useful as a soil conditioner containing low levels of essential plant macronutrients such as nitrogen and phosphorus and often adequate levels of micronutrients such as copper and zinc.

Chemicals Required - None

Residuals Generated - Final product is compost.

Design Criteria (79) - Construction of the pile for a 10 dry ton/d (43 wet tons) operation: 1. A 6-in. layer of unscreened compost for base. 2. A 94 ft loop of 4-in. dia. perforated plastic pipe is placed on top (hole dia. 0.25 in.). 3. Pipe is covered with 6-in. layer of unscreened compost or wood chips. 4. Loop is connected to a 1/3 hp blower by 14 ft of solid pipe fitted with water trap to collect condensate. 5. Timer is set for cycle of 4 minutes on and 16 minutes off. 6. Blower is connected to conical scrubber pile (2yd^3 wood chips covered with 10yd^3 screened compost) by 16 ft of solid pipe. 7. Sludge (wet) - wood chip mixture in a volumetric ratio of 1:2.5 is placed on prepared base. 8. A 12-in. layer of screened compost is placed on top for insulation.
Air Flow: 100 ft^3/h/ton of sludge; land area requirement for 10 dry tons processed daily: 3.5 acres, including runoff collection pond, bituminous surface for roads, mixing, composting, drying, storage, and administration area. Pile dimension: 53 ft X 12 ft X 8 ft high. Population equivalent, 100,000.

Process Reliability - High degree of process reliability through simplicity of operation. Thoroughness (percent stabilization) is a function of recycle scheme, porosity distribution in pile, and manifold design.

Toxics Management - Heavy metals entering the process remain in the final product. The degree of removal of organic toxic substances is not defined.

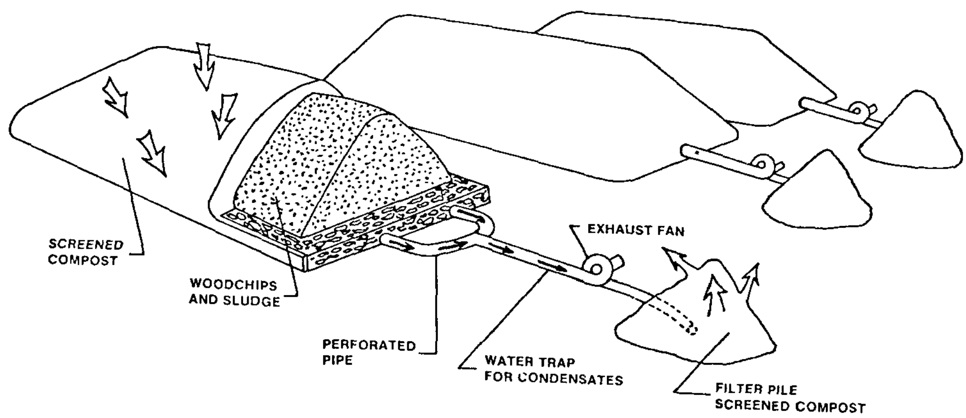
Environmental Impact - Potential odor problems can occur for a brief period between the time a malodorous sludge arrives at site, is mixed and is covered by the insulating layer. Human pathogen generation and aerosol distribution potential dictates careful attention to downwind land use.

References - 78, 79, 80, 81, 82

COMPOSTING SLUDGE, STATIC PILE

FACT SHEET 6.2.3

FLOW DIAGRAM



ENERGY NOTES -
1. Electricity consumed for a 10 dry ton/d operation = 75,000 kWh/yr or 7500 kWh/yr/dry ton sludge.
2. Fuel consumed for a 10 dry ton/d operation = 2.29 billion kWh/yr or 229 MkWh/yr/dry ton sludge.

COSTS** (1976 dollars) ENR Index = 2401
1. Quantity processed, 10 dry tons/d; compost distribution will realize no net revenues or costs to the municipality.
2. Blower is 1/3 hp; front-end loader is equipped with 3.5 yd^3 bucket.
3. Sewer line installation - 400 ft of 8 inch sewer line @ $35/ft.
4. Asphalt composting pad costs include grading, 12 inch crushed stone, 4 inches of asphalt.
5. Site is operated 8 h/d, 7 d/wk; staff includes 1 Superintendent, 4 equipment operators; labor costs include: 5 wks off for paid sick leave, vacations, holidays; $400/person for health insurance; 6% FICA; 0.3 man yr of overtime. Superintendent receives $7.50/h; operators receive $6/h.
6. Equipment maintenance 6 percent purchase price; insurance estimated 1 percent purchase price.
7. Gasoline 57¢/gal, 1.1 gal/dry ton loading; diesel 41¢/gal, 3.5 gal/dry ton loading; electricity 2¢/kWh, 17.3 kWh/dry ton loading; woodchips, $3.50/$yd^3$.

CONSTRUCTION COST

Item	Dollars
Site development:	
Asphalt pad (1.5 acre)	83,800
Roads, administration	13,000
Electrical work	20,000
Sewer	14,000
Pond, drainage	28,000
Equipment:	
Office trailer	5,000
Storage	1,500
Front end loaders (2 pieces)	106,000
Screen	16,300
Tractor	4,700
Pickup	4,700
Blowers (33 pieces)	2,500
Construction Cost	$299,500

OPERATION AND MAINTENANCE COST

	$/yr	$/dry ton
Operating Costs:		
Woodchips	35,000	9.60
Plastic pipe	12,200	3.34
Gasoline	2,300	.63
Diesel	5,300	1.45
Electricity	1,500	.41
Equipment maintenance	8,400	2.30
Equipment insurance	1,400	.44
Pad, road maintenance	1,200	.33
Water/sewer	500	.14
Labor	77,500	21.23
Miscellaneous supplies	4,400	1.20
Total	149,700	41.01*

* O&M costs for a 50 dry ton/d operation have been estimated to amount to $28/dry ton.

REFERENCES - 79, 82

**To convert construction cost to capital cost see Table A-2.

COMPOSTING SLUDGE, WINDROW

FACT SHEET 6.2.4

Description - Composting is the microbial degradation of sludge and other putrescible organic solid material by aerobic metabolism in piles or windrows on a surfaced outdoor area. The piles are turned periodically to provide oxygen for the microorganisms to carry out the stabilization and to carry off the excess heat that is generated by the process. When masses of solids are assembled, and conditions of moisture, aeration and nutrition are favorable for microbial activity and growth, the temperature rises spontaneously. As a result of biological self-heating, composting masses easily reach 60°C (140°F) and commonly exceed 70°C (150°F). Peak composting temperatures approaching 90°C (194°F) have been recorded. Temperatures of 140 to 160°F serve to kill pathogens, insect larvae and weed seeds. Nuisances such as odors, insect breeding and vermin harborage are controlled through rapid destruction of putrescible materials. Sequential steps involved in composting are preparation, composting, curing and finishing.

Preparation - To be compostable, a waste must have at least a minimally porous structure and a moisture content of 45 to 65 percent. Therefore, sludge cake, which is usually about 20 percent solids, cannot be composted by itself but must be combined with a bulking agent, such as soil, sawdust, wood chips, refuse, or previously manufactured compost. Sludge and refuse make an ideal process combination. Refuse brings porosity to the mix, while sludge provides needed moisture and nitrogen, and both are converted synergistically to an end product amenable to resource recovery. The sludge is suitably prepared and placed in piles or windrows.

Composting - The composting period is characterized by rapid decomposition. Air is supplied by periodic turnings. The reaction is exothermic, and wastes reach temperatures of 140°F to 160°F or higher. Pathogen kill and the inactivation of insect larvae and weed seeds are possible at these temperatures. The period of digestion is normally about six weeks.

Curing - This is characterized by a slowing of the decomposition rate. The temperature drops back to ambient, and the process is brought to completion. The period takes about two more windrow weeks.

Finishing - If municipal solid waste fractions containing non-digestible debris have been included, or if the bulking agent such as wood chips is to be separated and recycled, some sort of screening or other removal procedure is necessary. The compost may be pulverized with a shredder, if desired.

Common Modifications - Composting by the static pile method is discussed in Fact Sheet 6.2.3. Composting within a vessel is an emerging technology.

Technology Status - Successfully demonstrated.

Applications - A sludge treatment method that successfully kills pathogens, larvae and weed seeds. Is suitable for converting undigested primary and/or secondary sludge to an end product amenable to resource recovery with a minimum capital investment and relatively small operating commitment.

Limitations - A small porous windrow may permit such rapid air movement that temperatures remain too low for effective composting. The outside of the pile may not reach temperatures sufficiently high for pathogen destruction. Pathogens may survive and regrow. Sale of product may be difficult.

Typical Equipment/No. of Mfrs. (83) - Commonly available equipment can be used, including front-end loaders/16; tractor-drawn/23; harrow/42; rotary screen/55. Equipment is currently being developed specifically for sludge composting.

Performance - Sludge is converted to a relatively stable organic residue, reduced in volume by 20 to 50 percent. The residue loses its original identity with respect to appearance, odor and structure. The end product is humified, has earthy characteristics; pathogens, weed seeds and insect larvae are destroyed.

Chemical Requirements - None

Residuals Generated - None

Design Criteria - Approximate land requirement: 1/3 acre/dry ton sludge daily production, which is roughly equivalent to a population of 10,000 with primary and secondary treatment. Windrows can be 4 to 8 ft high, 12 to 25 ft wide at the base, and variable length. Sludge cannot be composted by itself but must be combined with a bulking agent to provide the biomass with the necessary porosity and moisture content. Biomass criteria: moisture content, 45 to 65 percent; C/N ratio between 30 to 35:1; C/P, 75 to 150:1; air flow 10 to 30 ft^3 air/d/lb VS. Detention time, six weeks to 1 year.

Process Reliability - Highly reliable. Ambient temperatures and moderate rainfall do not affect the process.

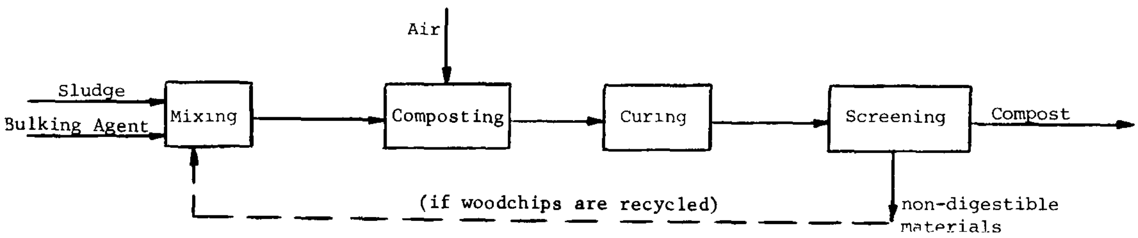
Environmental Impact - Is relatively land intensive; potential for odors; may be aesthetically unacceptable. The compost product represents an environmental benefit when used as a soil amendment. Other uses include wallboard production, livestock feed, litter for the chicken industry, and adsorbent for oil spill cleanup. Human pathogen generation and aerosol distribution potential dictates careful attention to downwind land use.

References - 8, 20, 33, 202, 203, 205

COMPOSTING SLUDGE, WINDROW

FACT SHEET 6.2.4

FLOW DIAGRAM -



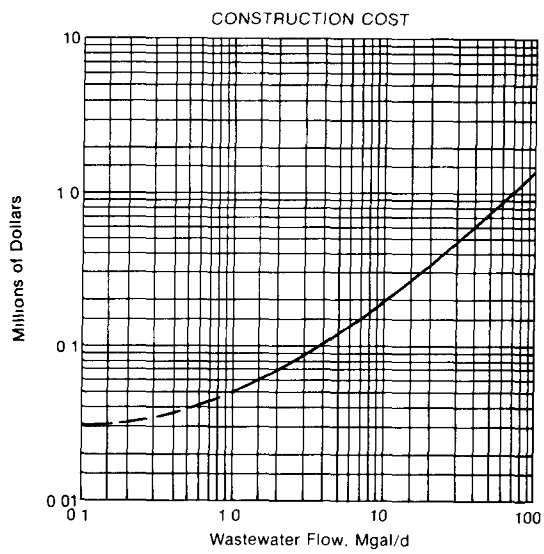
ENERGY NOTES - Actual fuel consumption varies with specific site and operating conditions. Fuel consumption for some typical construction equipment that can be utilized for sludge composting is presented in Fact Sheet 6.1.10 A mixer-separator has been developed that mixes sludge and bulking agent and also separates compost from the bulking agent. The 125 yd^3/h mixer-separator consumes approximately 3 gal/h of diesel fuel.

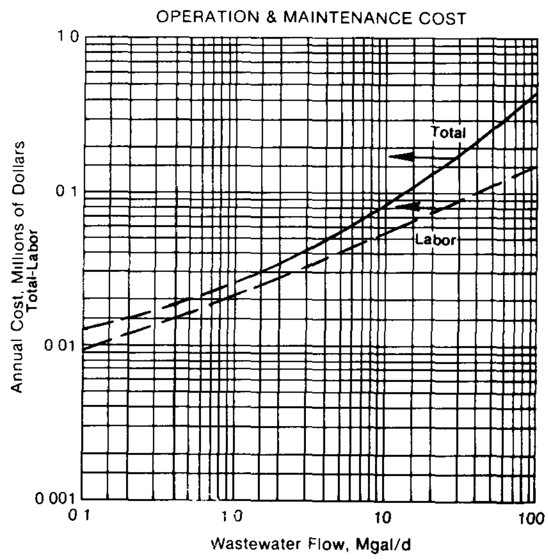
COSTS* - Assumptions: ENR Index = 2475

1. Service life, 17 years
2. Construction costs include asphalt pads, roads, sewer, drainage pond, electrical work, engineering.
3. Sludge production rate = 900 lb/Mgal (dry solids), digested.
4. Land requirement, 0.35 acres/(ton/day). Assumed land cost = $10,500/acre.
5. Costs apply to composting of digested or raw biological sludge.
6. Adjustment factor: To adjust for sludge composting rates different from 900 lb/Mgal, enter cost curves at effective flow (Q_E).

$$Q_{(E)} = Q_{DESIGN} \times \frac{\text{New Design Sludge Mass}}{900 \text{ lb/Mgal}}$$

Note: Costs other than labor are not given in Reference 3 but are assumed to include materials, fuel, etc.





REFERENCES - 3, 205

*To convert construction cost to capital cost see Table A-2.

Description - Sludge incineration is a two-step process involving drying and combustion after preliminary dewatering. A typical sludge contains 75 percent water and 75 percent volatiles in dry solids. Self-sustained combustion without supplementary fuel is often possible with dewatered raw sludges having a solids concentration greater than 30 percent.

The FBF is a vertically oriented, cylindrically shaped, refractory lined, steel shell which contains a sand bed and fluidizing air distributor. The FBF is normally available in diameters of 9 to 25 feet and heights of 20 to 60 feet. There is one industrial unit operating with a diameter of 53 feet. The sand bed is approximately 2.5 feet thick and rests on a refractory lined air distribution grid containing tuyeres through which air is injected at a pressure of 3 to 5 lb/in^2 to fluidize the bed. Bed expansion is approximately 80 to 100 percent. Temperature of the bed is controlled between 1400^{o} F and 1500^{o} F by auxiliary burners and/or a water spray or heat removal system above the bed. Ash is carried out the top of the furnace and is removed by air pollution control devices, usually wet venturi scrubbers. Sand is lost by attrition at an approximate rate of five percent of the bed volume every 300 hours of operation. Furnace feed can be introduced either above or directly into the bed depending on the type of feed. Generally, sludge is fed directly into the bed.

Excess air requirements for the FBF vary from 20 to 40 percent. It requires less supplementary fuel than a multiple hearth furnace. An oxygen analyzer in the stack controls the air flow into the reactor and the auxiliary fuel feed rate is controlled by a bed temperature controller.

Start-up fuel requirements are very low, and no fuel is required for start-up following an overnight shutdown. The FBF is very attractive for intermittent operation. Afterburners are not required to comply with air pollution regulations.

Common Modifications - An air preheater is used in conjunction with a fluidized bed to reduce fuel costs. Also, cooling tubes may be submerged in the bed for purposes of energy recovery.

Technology Status - The first fluidized bed wastewater sludge incinerator was installed in 1962. There are now many units operating in the United States with capacities of 200 to 1000 lb/h of dry solids.

Applications - Reduction of sludge volume, thereby reducing land requirements for disposal. Energy recovery potential. Most suitable where hauling distances to disposal sites are long, or where regulations concerning alternative methods are prohibitive.

Limitations - Since a minimum amount of air is always required for bed fluidization, fan energy savings during load turndown (i.e. sludge feed reduction) are minor. Generally not cost effective for small plants.

Typical Equipment/No. of Mfrs. - FBF/6, Screw Pumps/4, Air Fans/42, Gas Scrubbers/3, Ash Handling Systems/1

Performance - The mass of dry solids is reduced to 25 to 35 percent of the amount entering the unit.

Design Criteria - Bed loading rate = 50 to 60 lb wet solids/ft^2/hr. Superficial bed velocity = 0.4 to 0.6 ft/s. Sand effective size = 0.2 to 0.3 mm (uniformity coeff = 1.8), Operating temperature = 1400 to 1500^{o}F (normal) - 2200^{o}F+ (maximum), bed expansion = 80 to 100 percent, sand loss = 5 percent of bed volume per 300 hours of operation.

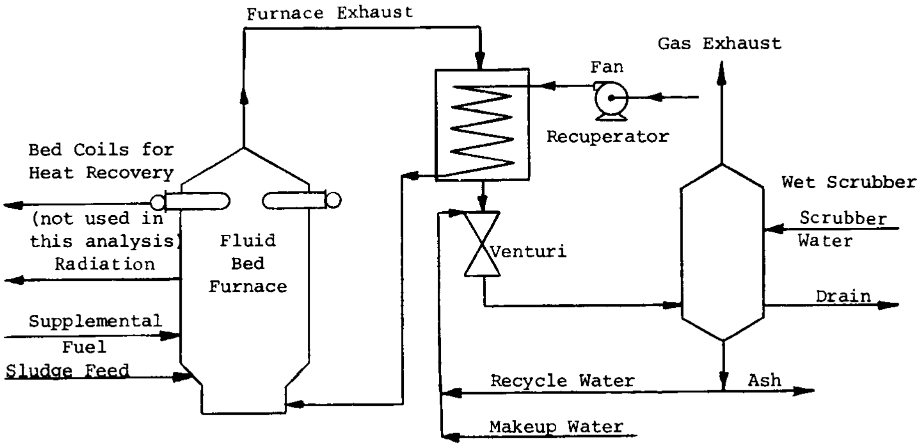
Unit Process Reliability - Some extensive maintenance problems have occurred with air preheaters. Scaling of the venturi scrubbers has also been a problem. Screw feeds and screw pump feeds are both subject to jamming because of either overdrying of the sludge feed at the incinerator or because of silt carried into the feed system with the sludge. Another frequent problem has been the burnout of spray nozzles or thermocouples in the bed.

Environmental Impact - Particulate collection efficiencies of 96 to 97 percent are required to meet current emission standards. There are very few data on the amount of toxic metals which are volatilized and discharged. Limited test data (8) indicate that 4 to 35 percent of the mercury entering an incinerator with emission controls will volatilize and be emitted to the atmosphere (excluding particulate forms). Gaseous emissions of CO, HCl, SO_2 and NO_2 may be appreciable; additional air pollution control measures may be necessary. Pesticides and PCB's are found in the sludge, but tests indicate that they can be destroyed during incineration and should not be a problem.

References: - 3, 8, 10, 25, 43, 56, 77

INCINERATION OF SLUDGE, FLUIDIZED BED FURNACE (FBF) — FACT SHEET 6.2.5

FLOW DIAGRAM -



ENERGY NOTES - Using the design basis below, electrical energy requirements are approximately 90,000 kWh/yr/dry ton/d or 85,000 kWh/yr/Mgal/d plant flow; fuel requirements are approximately 90 gal/dry ton of sludge or 13 x 10^6 Btu/dry ton. Fuel requirements are very sensitive to the moisture content of the sludge and other factors. As a result, adjustments should only be made after detailed study for each case.

COSTS* - Assumptions: ENR Index = 2475

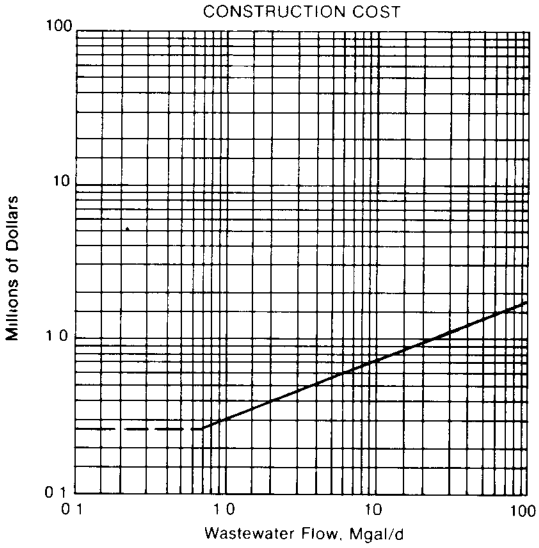
Design Basis:

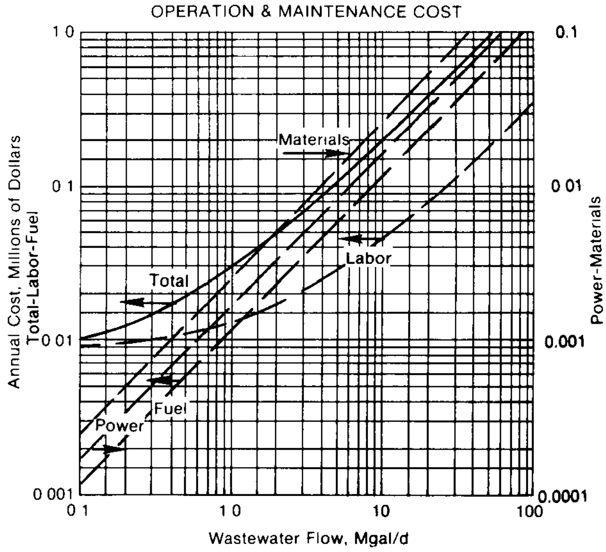
Construction costs include reactor, air blowers, and accessories, preheaters, scrubbers, fuel pumps, and building. Costs are for undigested dewatered primary and secondary sludge (1,900 lb/Mgal at 20 percent solids; 75 percent volatile).

Operations:

Plant flow, Mgal/d	Operating, d/wk	Operating, h/d
0.1	1	20
1.0	7	20
10.0	7	20
100.0	7	20

Fuel cost = $2.66/MBtu. Power cost = $0.02/kWh.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

INCINERATION OF SLUDGE, MULTIPLE HEARTH FURNACE (MHF) — FACT SHEET 6.2.6

Description - Sludge incineration is a two-step process involving drying and combustion after preliminary dewatering. A typical sludge is 80 percent water and has a dry solids volatility of 75 percent. Self-sustained combustion without supplementary fuel is often possible with dewatered raw primary sludges which can frequently be dewatered to 30 percent solids.

The MHF is a vertically oriented, cylindrically shaped, refractory lined, steel shell (diameter = 4 to 25 ft) containing 4 to 13 horizontal hearths positioned one above the other. The hearths are constructed of high heat duty fire brick and special fire brick shapes. Sludge is raked radially across the hearths by rabble arms which are supported by a central rotating shaft that runs the height of the furnace. The cast iron shaft is motor driven with provision for speed adjustment from 1/2 to 1-1/2 r/min. Sludge is fed to the top hearth and proceeds downward through the furnace from hearth to hearth. Inflow hearths have a central port through which sludge passes to the next lower hearth. Outflow hearths have ports on their periphery. These ports tend to regulate gas velocities also. The central shaft contains internal concentric flow passages through which air is routed to cool the shaft and rabble arms. The flow of combustion air is countercurrent to that of the sludge. Gas or oil burners are provided on some hearths for start-up and/or supplemental use as required.

The rabble arms provide mixing action as well as movement to the sludge so that a maximum sludge surface is exposed to the hot furnace gases. Because of the irregular surface left by the rabbling action, the surface area of sludge exposed to the hot gases is as much as 130 percent of the hearth area. While there is significant solids-gas contact time on the hearths, the overall contact time is actually still greater, due to the fall of the sludge from hearth to hearth through the countercurrent flow of hot gases.

The various phases of the incineration process occur in three zones of the MHF. The drying zone consists of the upper hearths, the combustion zone consists of the central hearths, and the lower hearths comprise the cooling zone. Temperatures in each zone are:

- Drying zone - sludge about $100^{\circ}F$; air about $800^{\circ}F$
- Burning zone - sludge and air about $1500^{\circ}F$
- Cooling zone - sludge about $400^{\circ}F$, air about $350^{\circ}F$.

Common Modifications - An after burner fired with oil or gas is provided where required by local air pollution regulations to eliminate unburned hydrocarbons and other combustibles.

Technology Status - The MHF is the most widely used wastewater sludge incinerator in the United States today. As of 1970, 120 units have been installed.

Applications - Reduction of sludge volume thereby reducing land requirements for disposal. Energy recovery potential. Used in plants that have long hauling distances to land or ocean disposal sites or where regulations prohibit these alternate disposal methods.

Limitations - Capacities of MHF's vary from 200 to 8,000 lb/h of dry sludge. Maximum operating temperatures are limited to $1700^{\circ}F$. With high energy feeds there may be operational problems. The MHF requires 24 - 30 hours for furnace warm-up or cool-down to avoid refractory problems. Failure of rabble arms and hearths have also been encountered. Nuisance shutdowns have also occurred due to ultraviolet flame scanner malfunctions. Thickening and dewatering pretreatment is required.

Typical Equipment/No. of Mfrs. (10, 77) - MHF/6; flapgate valves/6; cooling and combustion air fans/42; sludge conveyors/7; gas scrubber/3.

Performance - Dry solids are reduced to 20 to 25 percent of the mass entering the unit. The recoverable heat ranges from 18 percent of the total heat input (sludge and supplementary fuel) at 20 percent solids concentration to 45 percent of the total heat input at 40 percent solids concentration.

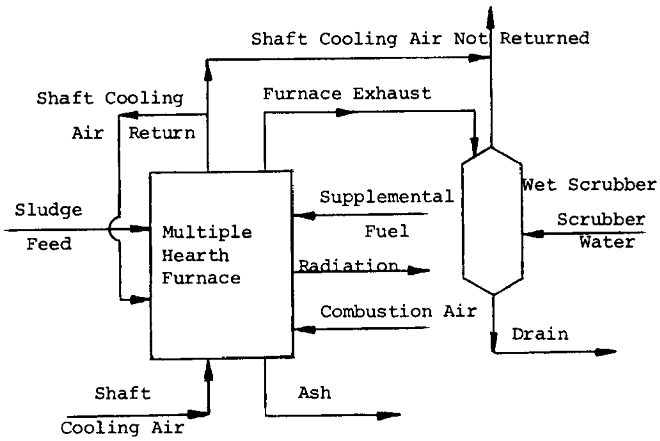
Design Criteria - Maximum operating temperature = $1700^{\circ}F$. Hearth Loading Rate = 6 to 10 lb wet solids/ft^2/h with a dry solids concentration of 20 to 40 percent. Combustion air flow = 12 to 13 lb/lb dry solids. Shaft cooling air flow = 1/3 to 1/2 of combustion air flow. Excess Air = 75 percent to 100 percent (43).

Environmental Impact - Particulate collection efficiencies of 96 to 97 percent are required to meet current emission standard. There are very few data on the amount of toxic metals which are volatilized and discharged. Limited test data (8) indicate that 4 to 35 percent of the mercury entering an incinerator with emission controls will volatilize and be emitted to the atmosphere (excluding particulate forms). Gaseous emissions of CO, HCl, SO_2 and NO_2 are expected to be acceptable. Pesticides and PCB's are found in the sludge, but tests indicate that they can be destroyed during incineration and should not be a problem.

References - 3, 8, 10, 25, 43, 77

INCINERATION OF SLUDGE, MULTIPLE HEARTH FURNACE (MHF) FACT SHEET 6.2.6

FLOW DIAGRAM -



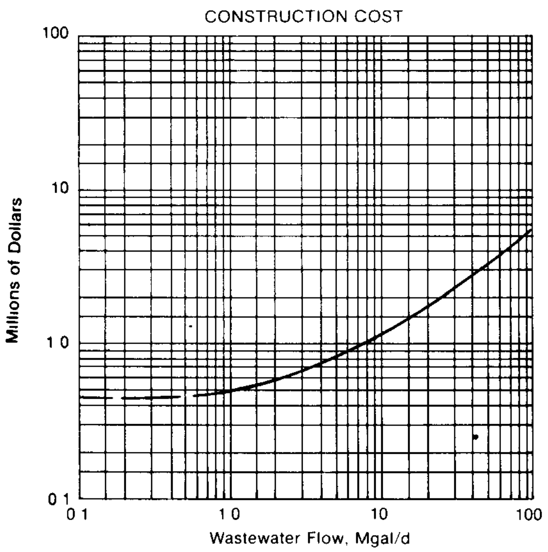
ENERGY NOTES - Using the design assumptions below, electrical energy requirements are approximately 31,000, 135,000 and 1,250,000 kWh/yr for 1, 10 and 100 Mgal/d plant flow. Fuel requirements for startup and incineration amount to approximately $4,500 \times 10^6$ Btu/yr/Mgal/d. Fuel requirements are very sensitive to the moisture content of the sludge and other factors. As a result, adjustments should only be made after detailed study of the case.

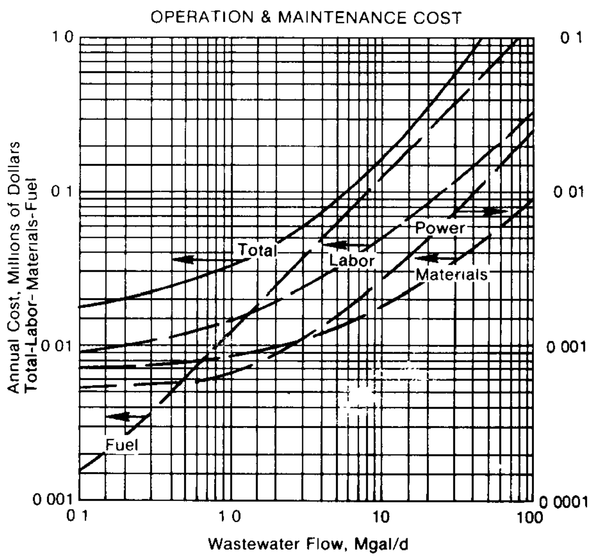
COSTS* - Assumptions: ENR Index = 2475
Design Basis:
Construction costs include incinerator, building, sludge conveyor, ash handling equipment, gas scrubbers. Costs are for undigested dewatered primary and secondary sludge (1,900 lb/Mgal at 20 percent solids; 75 percent volatile).

Operations:

Plant flow, Mgal/d	Operating, d/wk	Operating, h/d
0.1	1	20
1.0	7	20
10.0	7	20
100.0	7	20

Fuel requirements for warm-up and incineration are $4,500 \times 10^6$ Btu/yr/Mgal/d.
Fuel cost = $2.66/MBtu. Power cost = $0.02/kWh.





REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

CO-DISPOSAL BY STARVED AIR COMBUSTION — FACT SHEET 6.2.7

Description - Co-disposal of sludge by starved air combustion (SAC) is an extension of the process described in Fact Sheet 6.2.8 using waste materials such as municipal solid waste, wood wastes, farm wastes, etc. as fuel additives to allow operation of the unit without auxiliary fossil fuel in the case of high moisture content sludge or sludges with low solids heating value.

At a test run at the Central Contra Costa Sanitary District operated wastewater treatment plant in Concord, California, a 16-ft diameter, 6-hearth, multiple hearth furnace (MHF) processed a combination of sludge and refuse derived fuel (RDF). Mixed municipal refuse was shredded, classified, and screened prior to addition to the MHF where the RDF was the light fraction from the air classifier. The sludge had a solids content of 16 percent, a volatile solids content of 75 percent, and a heating value of 9,000 Btu/lb dry solids, whereas the RDF had a solids content of 75 percent, very few inerts, and a heating value of 7,500 Btu/lb of dry solids. The furnace feed rate was varied from pure sludge to pure RDF. A combustible gas was produced with a heating value of 130 Btu/sdft^3. This combustible gas could be fired in a waste heat boiler for steam production, used as the fuel for a lime recalcination furnace, or used for space heating.

During the test, the RDF could be fed to hearths 3 or 1. Sludge was always fed to hearth 1. Temperatures were maintained by controlling the amount of air fed to the furnace. The off-gases from the furnace were allowed to burn in an afterburner with the introduction of combustion air. Afterburner temperatures were approximately 2200°F, although the gas could be combusted to produce a temperature as high as 2500°F with no supplemental fuel addition.

The major shaft furnace systems available, the Purox (oxygen enrichment) and Torrax (regenerative heat recovery) units by Union Carbide Co. and The Carborundum Co., respectively, have similar basic operating principles. Refuse is charged at the top of the refractory lined shaft, providing a seal, and, as it descends through the furnace, hot pyrolytic gases from the slagging and combustion zones move in a countercurrent direction, thus providing pre-ignition and drying of the sludge and refuse. Preheated air or oxygen-enriched air is injected into the combustion zone at the base of the shaft furnace, where combustion of the pyrolyzed char occurs.

Preheating and oxygen enrichment serve essentially the same purpose: maintaining a furnace temperature high enough (2500-3000°F) to form a slag and to produce a pyrolysis gas with as high a heating value as possible. The slag formed is virtually free of combustibles. The cooled gases (low heating value), after preliminary cleaning, can be burned in a secondary combustion chamber with energy recovery in the form of a waste-heat boiler.

Technology Status - Technical feasibility has been demonstrated, however, there are no plants in commercial use.

Applications - Reduction in volume of two solid waste streams and energy conservation; use a single device to dispose of two waste products, thereby realizing capital and operating cost benefits.

Limitations - Institutional constraints may hamper implementation; for instance, in many localities, wastewater treatment and solid waste disposal are controlled by different governmental agencies. Many communities have long-term (15 to 20 years) contracts with private firms for refuse handling and disposal which define ownership of the refuse. See Fact Sheets on Multiple Hearth Furnaces and Fluid Bed Furnaces for other limitations. In shaft furnaces, proper temperatures in the slag tap area must be maintained to prevent slag freezing. The Purox system and the MHF require a shredded refuse feed.

Typical Equipment/No. of Mfrs. (10, 77, 97) - SAC reactors/10; scrubbers/3; ash disposal system/1; fans/42; waste heat boiler/27; sludge dewatering device/15; sludge conveyors/7; combustible material preparation and feed system/25.

Performance - Quantity of dry solids (combined sludge and RDF) is reduced to 19 to 26 percent of amount entering reactor (43).

Design Parameters - For Multiple Hearth Furnaces (43):

Hearth Sludge Loading Rate = 11 to 13 lb wet solids/(h)(ft^2)

Unit Process Reliability - No data available. MHF units have experienced failures of rabble arms and hearths along with nuisance trips due to flame scanner malfunction. Fluid bed units have experienced scaling of scrubbers with bed media and plugging of sludge feed systems. Freezing of slag bed and contamination of slag bed with refuse have been experienced on shaft furnace systems.

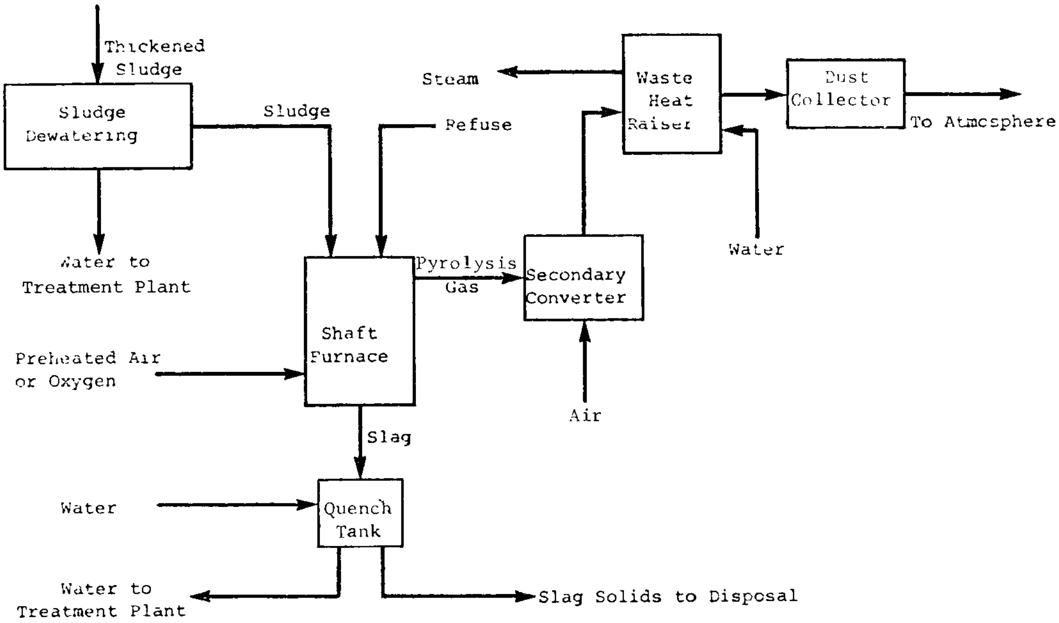
Environmental Impact - Data required to evaluate is not available for this process. However, the impact will depend on compositions of feed material and operating conditions. Hydrocarbons and CO emissions are not of concern since product fuel gas is sought. SO_2 and NO_x emission from reactor may be reduced relative to co-incineration due to deficiency of oxygen; however, higher temperatures in the afterburner could cause a NO_x problem.

References - 43, 10, 77, 91, 97, 148, 221, 222, 223, 224, 226

CO-DISPOSAL BY STARVED AIR COMBUSTION

FACT SHEET 6.2.7

FLOW DIAGRAM



ENERGY NOTES - From the estimate below, electrical power requirements are 51 kWh/t of refuse and sludge. Auxiliary fuel requirements are 6.2 gal of fuel oil or 780,000 btu/t of refuse and sludge.

COSTS - Mid-1975 dollars; ENR Index = 2212, Co-incineration/SAC (sludge and refuse). Design capacity 600 ton/d refuse; 224 ton/d sludge, annual capacity 206,000 tons.

Capital Costs Include: Equipment, labor and materials for installation, construction overhead and contingency at 15 percent of each equipment module.

Manpower Costs Include: Four shifts, seven days per week operation; supervision and maintenance. Salary and overhead ranged from $10,000 to $20,000 ((operators and senior maintenance people at $17,000 per year). Twenty percent is added for overtime, vacations, holidays, etc.

Power Costs: $0.027/kWh Water and Sewer Costs: $0.37/1000 gal Fuel Costs: $2.73/10^6 Btu

Residue Disposal Cost: $4/ton

Capital Cost

Item	Cost
Two Shaft Furnaces	$18,125,000
Additional Building	1,541,000
Direct Construction Cost	$19,666,000
Design, Construction Management Start-Up (15% DCC)	2,950,000
Land ($50,000/acre)	250,000
Legal Fees (3% DCC)	590,000
Bond Discount (3% Total Cost)	704,000
Total Facility Cost	$24,160,000
Facility Cost Per ton/d (Design Cap.)	$29,300

Operating Cost

Item	Cost Per Ton*	Total Annual Cost
Manpower (42 employees)	$ 3.15	$648,000
Power (1450 kWh/h)	1.37	282,000
Water/Sewer (300 gal/min)	0.23	48,000
Auxiliary Fuel & Heating (1,057, 400 gal/yr)	2.14	440,700
Maintenance (2.5% DCC)	2.37	491,600
Overhead (1% DCC)	.95	196,700
Residue (488 ton/d	0.71	146,500
Total Operating Cost	$10.92	$2,253,600

* Based on Annual Throughput.

REFERENCE - 91

STARVED AIR COMBUSTION OF SLUDGE FACT SHEET 6.2.8

Description - The process utilizes equipment and process flows similar to incineration except that less than the theoretical amount of air for complete combustion is supplied. Autogenous starved air combustion (SAC) can be achieved with a sludge solids concentration greater than 25 percent. For lower concentrations, an auxiliary fuel may be required, depending on the percent volatiles in the solids. High temperatures decompose or vaporize the solid components of this sludge. The gas phase reactions are pyrolytic or oxidative, depending on the concentration of oxygen remaining in the stream. Under proper control, the gas leaving the vessel is a low Btu fuel gas that can be burned in an afterburner to produce power and/or thermal energy. Some processes utilize pure oxygen instead of air and thus produce a higher Btu fuel gas. The solid residue is a char with more or less residual carbon, depending on how much combustion air had to be supplied to reach the proper operating temperatures. Since the process is neither purely pyrolytic nor purely oxidative, it is called starved-air combustion or thermal gasification, rather than pyrolysis. Other processes still in the development stage use indirect heating, rather than the partial combustion. These are true pyrolysis processes. SAC reduces the sludge volumes and sterilizes the end product. Unlike incineration, it offers the potential advantages of producing useful by-products and of reducing the volume of sludge without large amounts of supplementary fuels. The gas which is produced has a heat value up to 130 Btu/standard dry cubic foot using air for combustion and is suitable for use in local applications, such as combustion in an afterburner or boiler or for fuel in another furnace. SAC has a higher thermal efficiency than incineration due to the lower quantity of air required for the process. In addition, capital economies can be realized due to the smaller gas handling requirements.

Furnaces may be operated in one of three modes resulting in substantially different heat generation and residue characteristics. The Low Temperature Char (LTC) mode only pyrolyzes the volatile material thereby producing a charcoal-like residue with a high ash content, the High Temperature Char (HTC) mode produces a charcoal-like material converted to fixed carbon and ash, and the Char Burned (CB) mode reacts away all carbon and produces ash as a residue. Heat recovered is maximum for the CB mode, less for the HTC mode, and substantially less for the LTC mode of operation.

SAC operation has shown the following advantages in addition to those discussed above: easier to control than a standard incinerator; more stable operation with little response to changes in feed; more feed capacity as compared to an equal area for incineration; all equipment used is currently being manufactured; less air pollutants and easier air pollution control management; lower sludge solids content required for autogenous operation.

Technology Status - Autogenous SAC of sludge has been demonstrated at a full scale Multiple Hearth Furnaces (MHF) project at the Central Contra Costa Sanitary District in California. One SAC unit for disposal of sludge from a 40 Mgal/d industrial wastewater treatment plant is reported to have gone on stream in 1978 and other units are out for bid.

Applications - Reduction of sludge volume and production of fuel gas for a nearby combustor or furnace. Most existing MHF's can easily be retrofitted to operate in the SAC mode.

Limitations - There are significant disadvantages, such as:
- Need for afterburner may limit use in existing installations due to space problems.
- Relatively large amount of instrumentation is required.
- Must be very careful of bypass stack exhaust since furnace exhaust is high in hydrocarbons and may be combustible in air. This may result in bypassing only after afterburning with appropriate emergency controls in some areas.
- Corrosivity of furnace exhaust gases.
- Combustibles in ash may create ultimate disposal problems.
- Sludge volume reduction lower than with incineration.
- Requires recovery of the energy in the product gas to fully realize the improved efficiency.

Typical Equipment/No. of Mfrs. (10, 77, 97) - SAC Reactor/10, Waste Heat Boiler/27, Exhaust Gas Scrubbers/3, Sludge Dewatering Devices/15, Afterburner/10.

Performance - Unit can operate without auxiliary fuel, including afterburner, with sludge dewatered to the range of 29 to 39 percent solids. Based on a limited number of pilot scale tests, the off-gas from an MHF unit operating in the SAC mode, with sludge alone, ranges from 18 to 73 Btu/std ft^3.

Design Criteria - MHF systems - Hearth loadings of 9 to 15 lb wet (22 percent) solids/ft^2/h; for autogenous combustion, sludge solids content 25 to 39 percent depending upon volatility. Off-gas heating value dependent upon operating mode.

Unit Process Reliability - Mechanical function of MHF units under the SAC mode is expected to be similar to the conventional operating modes. Increased operating stability is expected to result in higher process reliability.

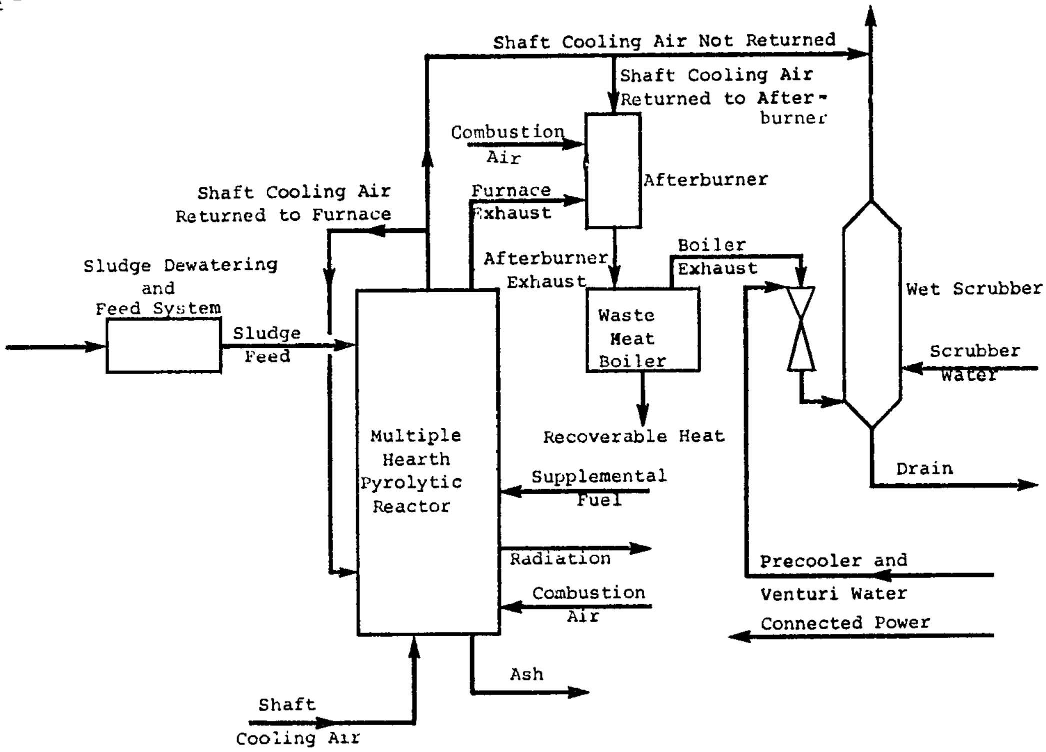
Environmental Impact - Air pollution can be expected to be less of a problem due to the lower air flows and the potential for particulate carryover. Data to date indicate conventional equipment can achieve acceptable controls. Depending upon the mode of operation, heavy metals in the sludge can be retained in the residue.

References - 8, 43, 10, 77, 97, 148, 220, 221, 222, 223, 224.

STARVED AIR COMBUSTION OF SLUDGE

FACT SHEET 6.2.8

FLOW DIAGRAM -



ENERGY NOTES - Using assumptions below, the electrical energy requirements are 23 kWh/ton, and the auxiliary or startup fuel requirements are 3.1 gal fuel oil or 0.43 X 10^6 Btu/ton of sludge.

COSTS - Third quarter 1978 dollars. ENR Index = 2829

1. 324 ton/d design capacity at 40 percent dry solids. Annual throughput 80,000 tons.
2. Direct construction cost includes Multiple Hearth Furnace installed, with drives, fans, motor controls, gas scrubber, external afterburner, ash handling system, auxiliary fuel system, instrumentation, piping, painting, initial operation and test.
3. Manpower costs = $17,500/yr average; power cost = $0.02/kWh; fuel cost = $2.73/$10^6$ Btu; water and sewer costs = $0.37/1,000 gal; residue disposal = $5/ton.

Capital Cost	
Direct Construction Cost (DCC)	$2,325,000
Design, Construction Management (20% DCC)	465,000
Land ($50,000/acre)	250,000
Legal fee (3% DCC)	69,750
Bond discount (3% Total Cost)	99,000
Total Cost	$3,325,000

Operating Cost

	Cost/ton*	Annual Cost
Manpower, 20 employees	$4.37	$350,000
Power, 210 kWh/h	.46	36,800
Water/sewer @ 385 gal/min)	.89	70,800
Auxiliary fuel (250,000 gal/yr)	1.19	95,500
Maintenance (2.5% DCC)	1.03	83,100
Overhead (1% DCC)	.42	33,250
Residual disposal	.94	75,000
Total Cost	$9.30	$744,450

*Based on 80,000 ton/yr throughput

REFERENCES - 91, 225

SLUDGE DRYING

FACT SHEET 6.2.9

Description - In this process the moisture in the sludge is reduced by evaporation to 8 to 10 percent by the application of hot air, without combusting the solid materials. For economic reasons, the moisture content of the sludge must be reduced as much as possible through mechanical means prior to heat drying. The five available heat treating techniques are flash, rotary, toroidal, multiple hearth and atomizing spray.

Flash drying is the instantaneous vaporization of moisture from solids by introducing the sludge into a hot gas stream. The system is based on several distinct cycles which can be adjusted for different drying arrangements. The wet sludge cake is first blended with some previously dried sludge in a mixer to improve pneumatic conveyance. The blended sludge and hot gases from the furnace at about 1200°F to 1400°F (650 to 760°C) are mixed and fed into a cage mill in which the mixture is agitated and the water vapor flashed. The residence time in the cage mill is only a matter of seconds. The dry sludge with eight to ten percent moisture is separated from the spent drying gases in a cyclone, with part of it being recycled with incoming wet sludge cake and another part being screened and sent to storage.

A rotary dryer consists of a cylinder which is slightly inclined from the horizontal and revolves at about five to eight r/min. The inside of the dryer usually is equipped with flights or baffles throughout its length to break up the sludge. Wet cake is mixed with previously heat dried sludge in a pug mill. The system may include cyclones for sludge and gas separation, dust collection scrubbers, and a gas incineration step.

The toroidal dryer uses the jet mill principle, which has no moving parts, dries and classifies sludge solids simultaneously. Dewatered sludge is pumped into a mixer where it is blended with previously dried sludge. The blended material is fed into a doughnut-shaped dryer, where it comes into contact with heated air at a temperature of 800°F to 1100°F. The particles are dried and broken up into fine pieces and are carried out of the dryer by the air stream. The dried, powdered sludge is supplemented with nitrogen and phosphorus and formed into briquettes which are crushed and screened to produce final products.

The multiple hearth furnace is adapted for heat drying of sludge by incorporating fuel burners at the top and bottom hearths, plus down draft of the gases. The dewatered sludge cake is mixed in a pug mill with previously dried sludges before entering the furnace. At the point of exit from the furnace, the solids temperature is about 100°F, and the gas temperature is about 325°F.

Atomizing drying involves spraying liquid sludge in a vertical tower through which hot gases pass downward. Dust carried with hot gases is removed by a wet scrubber or dry dust collector. A high-speed centrifugal bowl can also be used to atomize the liquid sludge into fine particles and to spray them into the top of the drying chamber where moisture is transferred to the hot gases.

Technology Status - Heat drying of sludge was developed more than 50 years ago; however, it is not widely used.

Application - It is an effective way for ultimate sludge disposal and resource conservation when the end products are applied on land for agricultural and horticultural uses. Although it is an expensive process, it can become a viable alternative, if the product can be successfully marketed.

Limitations - Cost and high operator skill.

Typical Equipment/No. of Mfrs. - Complete heat drying systems are generally proprietory. The major equipment includes mixers, furnaces, cyclones, screens, dryers, wet scrubbers, dust collectors, air blowers, heaters, spraying devices, sludge feed pumps and handling equipment.

Performance - Heat drying destroys most of the bacteria in the sludge. However, undigested heat dried sludge is susceptible to putrefaction if it is allowed to get wet in thick layers on the ground. Heat drying does not cause any significant decrease of the heavy metals concentration in the sludge. In general, heat dried sludge contains nutrients which are only about one-fifth of those contained in chemical fertilizers. Heat dried sludge is therefore useful only as a fertilizer supplement and a soil conditioner.

Physical, Chemical and Biological Aids - Heat; nitrogen and phosphorus may be added to increase nutrient values of the dried sludge.

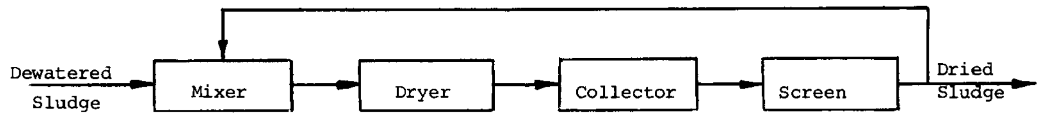
Residuals generated - All the solids captured in the wet scrubbers and dry solids collectors are recycled and incorporated in the end products.

Design Criteria - Approximately 1,400 Btu are needed to vaporize one pound of water, based on a thermal efficiency of 72 percent. Less fuel would be required with additional heat recovery. Chemical scrubbers are used, or chemicals are added prior to heat drying. Excessive drying tends to produce a sludge that is dusty or contains many fine particles, which is less acceptable for marketing, and should be avoided. Wet scrubbers and/or solids collectors are needed. Standby heat drying equipment is needed for continuous operation.

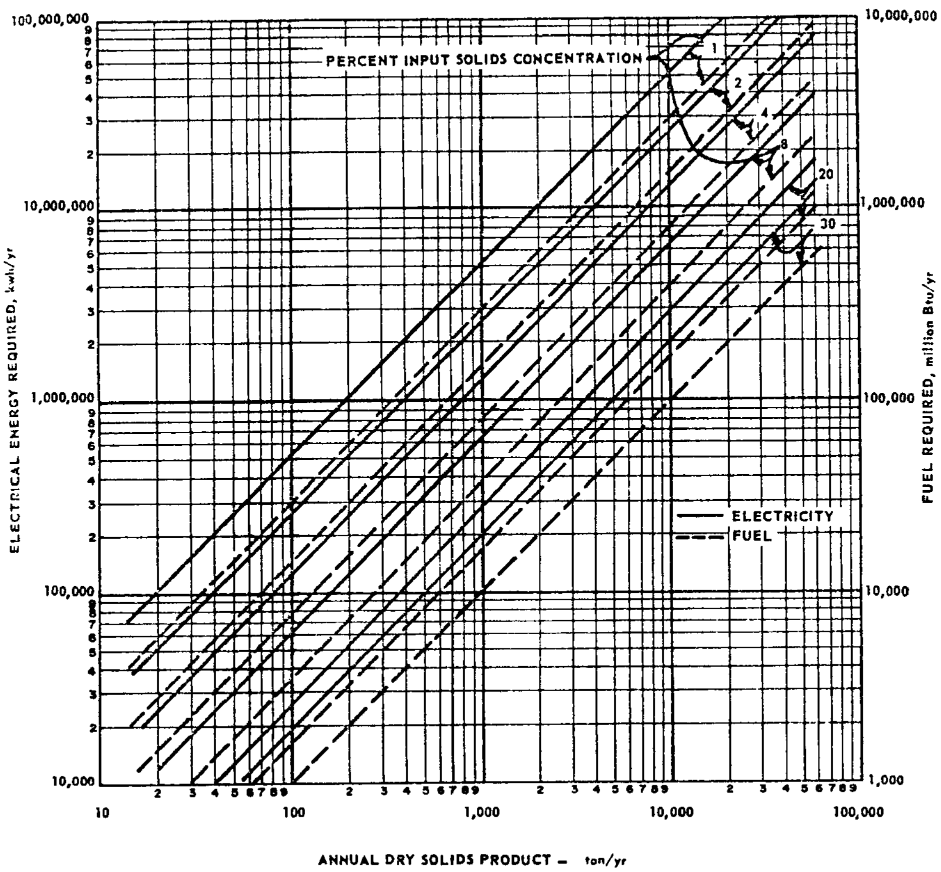
Environmental Impact - Potential for explosion and air pollution if the system is not properly operated and maintained.

Reference - 213

FLOW DIAGRAM -



ENERGY NOTES (4) - Assumptions: Dryer efficiency = 72 percent; product moisture content = 10 percent; power includes blowers, fans, conveyors; continuous operation.



COSTS -

1. City of Houston, production cost unknown, $21/dry ton revenue (1972 F.O.B. Houston).
2. City of Milwaukee, $90/dry ton production, $54/dry ton revenue, $36/dry ton net cost (1975).
3. City of Chicago, $60/dry ton production, $15/dry ton revenue, $45/dry ton net cost (1968).

REFERENCES - 3, 4, 7, 22, 23, 30, 201

CENTRIFUGAL DEWATERING FACT SHEET 6.3.1

Description (8) - Centrifuges are used to dewater municipal sludges. They use centrifugal force to increase the sedimentation rate of sludge solids. The three most common types of units are the solid bowl type, the disc type, and the basket type.

The solid bowl continuous centrifuge assembly consists of a bowl and conveyor joined through a planetary gear system, designed to rotate the bowl and the conveyor at slightly different speeds. The solid cylindrical bowl, or shell, is supported between two sets of bearings and includes a conical section at one end. This section forms the dewatering beach over which the helical conveyor screw pushes the sludge solids to outlet ports and then to a sludge cake discharge hopper. The opposite end of the bowl is fitted with an adjustable outlet weir plate to regulate the level of the sludge pool in the bowl. The centrate flows through outlet ports either by gravity or by a centrate pump attached to the shaft at one end of the bowl. Sludge slurry enters the unit through a stationary feed pipe extending into the hollow shaft of the rotating bowl and passes to a baffled, abrasion-protected chamber for acceleration before discharge through the feed ports in the rotating conveyor hub into the sludge pool. Due to the centrifugal forces, the sludge pool takes the form of a concentric annular ring on the inside of the bowl. Solids settle through this ring to the wall of the bowl where they are picked up by the conveyor scroll. Separate motor sheaves or a variable speed drive can be used for adjusting the bowl speed for optimum performance.

Bowls and conveyors can be constructed from a large variety of metals and alloys to suit special applications. For dewatering of wastewater sludges, mild steel or stainless steel normally has been used. Because of the abrasive nature of many sludges, hardfacing materials are applied to the leading edges and tips of the conveyor blades, the discharge ports, and other wearing surfaces. Such wearing surfaces may be replaced by welding when required.

In the continuous concurrent solid bowl centrifuge, incoming sludge is carried by the feed pipe to the end of the bowl opposite the discharge. Centrate is skimmed off and cake proceeds up beach for removal. As a result, settled solids are not disturbed by incoming feed.

In the disc centrifuge the incoming stream is distributed between a multitude of narrow channels formed by stacked conical discs. Suspended particles have only a short distance to settle, so that small and low density particles are readily collected and discharged continuously through fairly small orifices in the bowl wall. The clarification capability and throughput range are high, but sludge concentration is limited by the necessity of discharging through orifices of 0.050 inches to 0.100 inches in diameter. Therefore, it is generally considered a thickener rather than a dewatering device.

In the basket centrifuge, flow enters the machine at the bottom and is directed toward the outer wall of the basket. Cake continually builds up within the basket until the centrate, which overflows a weir at the top of the unit, begins to increase in solids. At that point, feed to the unit is shut off, the machine decelerates, and a skimmer enters the bowl to remove the liquid layer remaining in the unit. A knife is then moved into the bowl to cut out the cake which falls out the open bottom of the machine. The unit is a batch device with alternate charging of feed sludge and discharging of dewatered cake.

Technology Status - Solid bowl and disc centrifuges are in widespread use. Basket centrifuges are fully demonstrated for small plants, but not widely used.

Applications - Solid bowl and disc types are generally used for dewatering sludge in larger facilities where space is limited or where sludge incineration is required. Basket type is used primarily for partial dewatering at small plants. Disc centrifuges are more useful for thickening and clarification than dewatering.

Limitations (7) - Centrifugation requires sturdy foundations because of the vibration and noise that result from centrifuge operation. Adequate electric power must also be provided since large motors are required. The major difficulty encountered in the operation of centrifuges has been the disposal of the centrate, which is relatively high in suspended, nonsettling solids. With disc type units, the feed must be degritted and screened to prevent pluggage of discharge orifices.

Typical Equipment/No. of Mfrs. (10) - Centrifuge/8; Sludge feed pump/7; Solids conveyor/7; Centrate pumps/40.

Performance (8) - Solid bowl centrifuge solids recovery = 50 to 75 percent without chemical addition and 80 to 95 percent with chemical addition. Solids concentration = 15 to 40 percent depending on type of sludge. For basket centrifuges solids capture = 90 to 97 percent without chemical addition and cake solids concentrations = 9 to 14 percent. Disc centrifuges can dewater a 1 percent sludge to six percent solids concentration.

Design Criteria - Each installation is site specific and dependent upon a manufacturers' product line. Maximum capacities of about 100 tons/h of dry solids are available in solid bowl units with diameters up to 54 inches and power requirements up to 175 hp. Disc units are available with capacities up to 400 gal/min of concentrate.

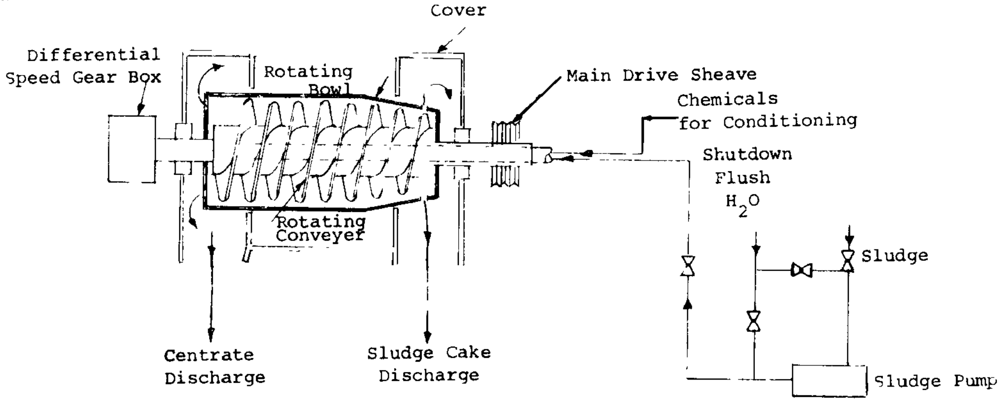
Unit Reliability - Pluggage of discharge orifices is a problem on disc type units if feed to the centrifuge is stopped, interrupted, or reduced below a minimum value. Wear is a serious problem with solid bowl centrifuges.

Environmental Impact - Centrate is relatively high in suspended, non-settling solids which, if returned to treatment units, could reduce effluent quality from primary settling system. Noise may require some control measures.

References - 3, 7, 8, 10

CENTRIFUGAL DEWATERING FACT SHEET 6.3.1

FLOW DIAGRAM -



ENERGY NOTES - Energy requirements in the form of electricity can be highly site specific due to the sizing and type of centrifuges used. For the cost examples below, an energy usage of approximately 18,000 kWh/yr/ton of dry solids/d for lime sludges and 31,500 for biological sludges are noted.

COSTS* - ENR = 2475

Design Basis: Construction costs include centrifuges (solid bowl), with minimum of one spare; sludge pumps and piping; cake conveyors; internal electrical and building cost.

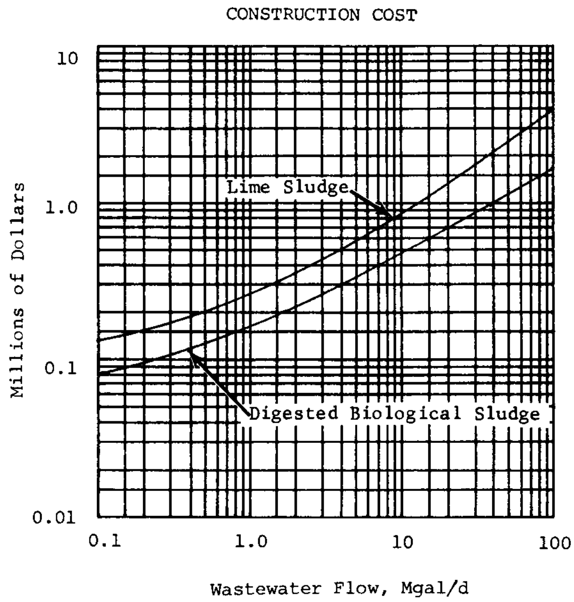
Sludge quantity = 4,500 lb/Mgal at 10 percent solids for lime sludge and 900 lb/Mgal at 4 percent for digested biological sludge.

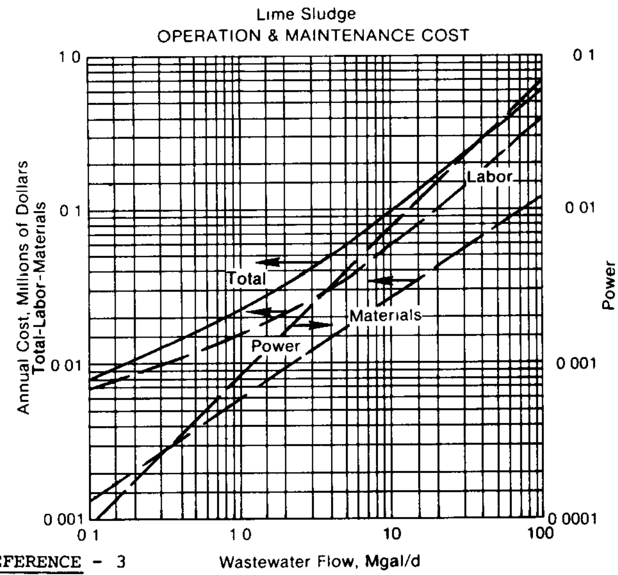
Operation = 8 h/d

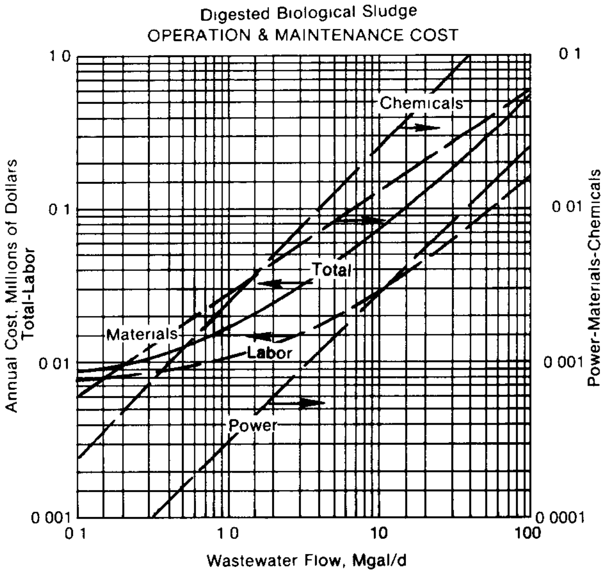
Costs do not include centrate handling.

For biological sludge, cationic polymer cost is based on 10 lb/ton dry basis.

Power cost = $0.02/kWh.







REFERENCE - 3

*To convert construction cost to capital cost see Table A-2.

DRYING BEDS, SLUDGE FACT SHEET 6.3.2

Description - Drying beds are used to dewater sludge both by drainage through the sludge mass and by evaporation from the surface exposed to the air. Collected filtrate is usually returned to the treatment plant. Drying beds usually consist of 4 to 9 inches of sand which is placed over 8 to 18 inches of graded gravel or stone. The sand typically has an effective size of 0.3 to 1.2 mm and a uniformity coefficient of less than 5.0. Gravel is normally graded from 1/8 to 1.0 inch. Drying beds have underdrains that are spaced from 8 to 20 feet apart. Underdrain piping is often vitrified clay laid with open joints, has a minimum diameter of 4 inches, and has a minimum slope of about 1 percent.

Sludge is placed on the beds in an 8 to 12 inch layer. The drying area is partitioned into individual beds, approximately 20 ft wide by 20 to 100 ft long, of a convenient size so that one or two beds will be filled by a normal withdrawal of sludge from the digesters. The interior partitions commonly consist of two or three creosoted planks, one on top of the other, to a height of 15 to 18 inches, stretching between slots in precast concrete posts. The outer boundaries may be of similar construction or earthen embankments for open beds, but concrete foundation walls are required if the beds are to be covered.

Piping to the sludge beds is generally made of cast iron and designed for a minimum velocity of 2.5 ft/s. It is arranged to drain into the beds and provisions are made to flush the lines and to prevent freezing in cold climates. Distribution boxes are provided to divert sludge flow to the selected bed. Splash plates are used at the sludge inlets to distribute the sludge over the bed and to prevent erosion of the sand.

Sludge can be removed from the drying bed after it has drained and dried sufficiently to be spadable. Sludge removal is accomplished by manual shoveling into wheelbarrows or trucks or by a scraper or front-end loader. Provisions should be made for driving a truck onto or along the bed to facilitate loading. Mechanical devices can remove sludges of 20 to 30 percent solids while cakes of 30 to 40 percent generally require hand removal.

Paved drying beds with limited drainage systems permit the use of mechanical equipment for cleaning. Field experience indicates that the use of paved drying beds results in shorter drying times as well as more economical operation when compared with conventional sandbeds because, as indicated above, the use of mechanical equipment for cleaning permits the removal of sludge with a higher moisture content than in the case of hand cleaning. Paved beds have worked successfully with anaerobically digested sludges but are less desirable than sandbeds for aerobically digested activated sludge.

Common Modifications - Sandbeds can be enclosed by glass. Glass enclosures protect the drying sludge from rain, control odors and insects, reduce the drying periods during cold weather, and can improve the appearance of a wastewater treatment plant.

Wedge wire drying beds have been used successfully in England. This approach prevents the rising of water by capillary action through the media and the construction lends itself well to mechanical cleaning. The first United States installations have been made at Rollinsford, New Hampshire, and in Florida. It is possible, in small plants, to place the entire dewatering bed in a tiltable unit from which sludge may be removed merely by tilting the entire unit mechanically.

Technology Status - Over 6,000 plants use open or covered sandbeds.

Applications - Sandbeds are generally used to dewater sludges in small plants. They require little operator attention or skill.

Limitations - Air drying is normally restricted to well digested or stabilized sludge, because raw sludge is odorous, attracts insects, and does not dry satisfactorily when applied at reasonable depths. Oil and grease clog sandbed pores and thereby seriously retard drainage. The design and use of drying beds are affected by weather conditions, sludge characteristics, land values and proximity of residences. Operation is severely restricted during periods of prolonged freezing and rain.

Typical Equipment/No. of Mfrs. (83) - Front-end loader/16; Scraper/42.

Performance - A cake of 40 to 45 percent solids may be achieved in two to six weeks in good weather and with a well digested waste activated, primary or mixed sludge. With chemical conditioning, dewatering time may be reduced by 50 percent or more. Solids contents of 85 to 90 percent have been achieved on sand beds, but normally the times required are impractical.

Design Criteria- Open bed area = 1.0 to 1.5 ft^2/capita (primary digested sludge); 1.75 to 2.5 ft^2/capita (primary and activated sludge); 2.0 to 2.5 ft^2/capita (alum or iron precipitated sludge). Experience has shown that enclosed beds require 60 to 75 percent of the open bed area. Solids loading rates vary from 10 to 28 lb/ft^2/yr for open beds and 12 to 40 lb/ft^2/yr for closed beds. Sludge beds should be located at least 200 ft from dwellings to avoid odor complaints due to poorly digested sludges.

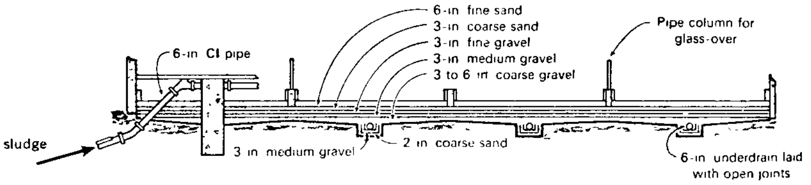
Environmental Impact - Land requirements are large. Odors can be a problem with poorly digested sludges and inadequate buffer zone areas.

References - 3, 7, 8, 22, 83

DRYING BEDS, SLUDGE

FACT SHEET 6.3.2

FLOW DIAGRAM -



ENERGY NOTES (4) - $E_T = E_{mechanical\ scraping} + E_{sand\ replacement} + E_{pumping}$ (when required)

E_{ms} is estimated to be 3.2 X 10^6 Btu/yr/Mgal/d plant flow @ 900 lb dry solids/Mgal plant flow.
E_{sr} is estimated to be 10 percent of the mechanical scraping or .32 X 10^6 Btu/Mgal/d plant flow.

$$E_{pumping} = \frac{1140\ (\text{Mgal/d X TDH})}{\text{Wire to Water Efficiency}}$$

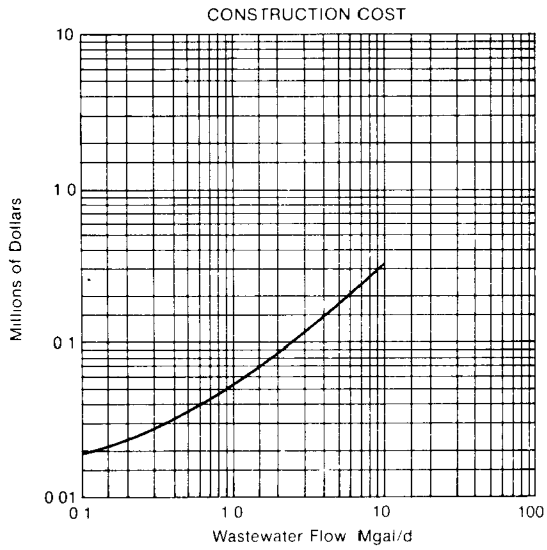
With a sludge flow of 0.5 X 10^6 gal/d, a TDH of 40 ft and a wire-to-water efficiency of 60 percent, the pumping energy requirement would be 38,000 kWh/yr.

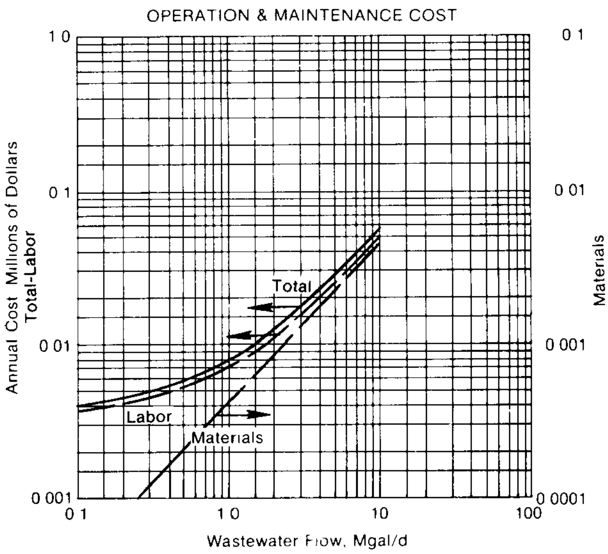
COSTS* - Service Life: 20 years. ENR = 2475

1. Construction costs include: sand beds, sludge inlets, underdrains, cell dividers, sludge piping, underdrain return, and other structural elements of the beds. All costs are in mid-1976 dollars.
2. Bed loading: 900 lb of sludge/Mgal; 20 lb/ft^2/yr.

Adjustment Factor - To adjust costs for bed loading rates, sludge quantities, or characteristics, enter curve at effective flow (Q_E).

$$Q_E = Q_{DESIGN} \times \frac{\text{New Design Sludge Mass}}{900\ \text{lb/Mgal}} \times \frac{20\ \text{lb/ft}^2\text{/yr}}{\text{New Design Bed Loading}}$$





REFERENCES - 3, 4

*To convert construction cost to capital cost see Table A-2.

FILTER, BELT

FACT SHEET 6.3.3

Description (8) - Belt filters consist of an endless filter belt that runs over a drive and guide roller at each end like a conveyor belt. The upper side of the filter belt is supported by several rollers. Above the filter belt is a press belt that runs in the same direction and at the same speed; its drive roller is coupled with the drive roller of the filter belt. The press belt can be pressed on the filter belt by means of a pressure roller system whose rollers can be individually adjusted horizontally and vertically. The sludge to be dewatered is fed on the upper face of the filter belt and is continuously dewatered between the filter and press belts. After having passed the pressure zone, further dewatering in a reasonable time cannot be achieved by only applying static pressures. However, a superimposition of shear forces can effect this further dewatering. The supporting rollers of the filter belt and the pressure rollers of the pressure belt are adjusted in such a way that the belts and the sludge between them describe an S-shaped curve. Thus, there is a parallel displacement of the belts relative to each other due to the differences in the radii. After further dewatering in the shear zone, the sludge is removed by a scraper.

Some units consist of two stages where the initial draining zone is on the top level followed by an additional lower section wherein pressing and shearing occur. A significant feature of the belt filter press is that it employs a coarse mesh, relatively open weave, metal medium fabric. This is feasible because of the rapid and complete cake formation obtainable when proper flocculation is achieved. Belt filters do not need vacuum systems and do not have the sludge pickup problem occasionally experienced with rotary vacuum filters. The belt filter press system includes auxiliaries such as polymer solution preparation equipment and automatic process controls.

Common Modifications - Some belt filters include the added feature of vacuum boxes in the free drainage zone. About 6 inches Hg vacuum are applied to obtain higher cake solids. A "second generation" of belt filters have extended shearing or pressure stages that produce substantial increases in cake solids, but are more costly.

Technology Status (8, 118) - 67 units were installed in Europe as of 1971. At that time, several units were also being installed in the United States. In 1975 a belt filter press was installed in a 0.9 Mgal/d (average) plant in Medford Township, NJ.

Applications - Hard-to-dewater sludges can be handled more readily. Low cake moisture permits incineration of primary/secondary sludge combinations without auxiliary fuel. A large filtration area can be installed in a minimum of floor area.

Limitations - To avoid penetration of the filter belt by sludge, it is usually necessary to coagulate the sludge (generally with synthetic, high polymeric flocculants).

Typical Equipment/No. of Mfrs. (10, 23) - Belt filter/7; Chemical feed equipment/25; Cake conveyors/7; Sludge Pumps/7

Performance (206) - The following table shows performance achieved in pilot studies:

Feed Solids %	Secondary:Primary Ratio	Polymer dosage (1)	Pressure lb/in^{2}g (2)	Cake Solids %	Solids Recovery %	Capacity (3)
9.5	100% primary	1.6	100	41	97-99	2706
8.5	1:5	2.4	100	38	97-99	2706
7.5	1:2	2.7	25-100	33-38	95-97	1485
6.8	1:1	2.9	25	31	95	898
6.5	2:1	3.1	25	31	95	858
6.1	3:1	4.1	25	28	90-95	605
5.5	100% secondary	5.5	25	25	95	546

(1) pounds per ton dry solids
(2) pounds per square inch, gauge
(3) pound dry solids per hour per meter

In addition, reports from the Medford, NJ plant indicate that belt filter solids capture of 98 percent or more can be achieved with filtrate TSS under 100 p/m. Sludge is dewatered from 96 to 97 percent moisture to 81 to 83 percent moisture. Polymer addition has been 5 to 6 gal/ton. (118)

Design Criteria (117) - The following loadings are based on active belt area:

Sludge Type	Sludge Loading gal/ft^2/h	Dry Solids Loading lb/ft^2/h
Raw Primary	27-34	13.5-17
Digested Primary	20-24	20.5-24
Digested Mixed/Secondary	13-17	6.7-8.4

Environmental Impact - Relatively high chemical and energy requirements.

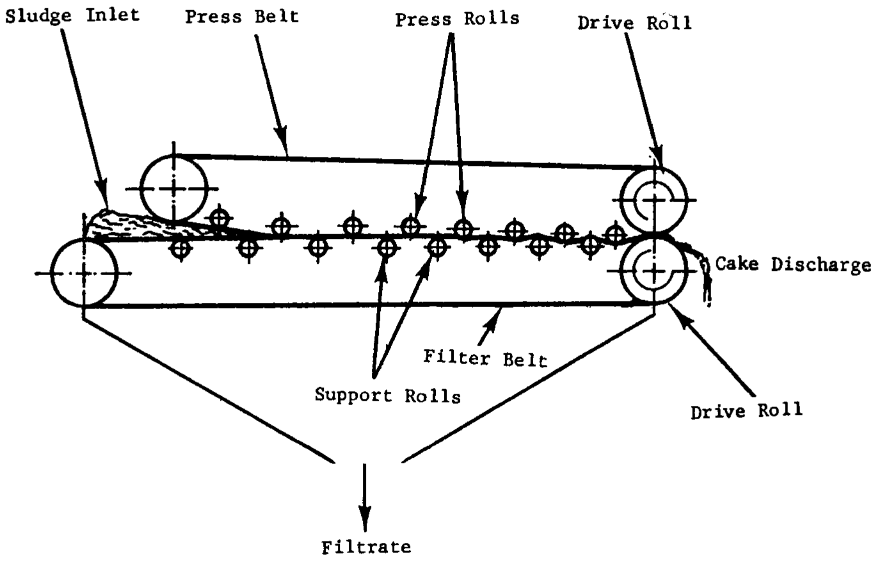
Unit Reliability (118) - Almost one year of trouble-free operation had been achieved on the Medford, NJ plant as of October, 1977. The two meter wide filter belt showed only slight discoloration and remained clean and free from blinding or other signs of wear.

References - 8, 10, 23, 117, 118, 125, 206

FILTER, BELT

FACT SHEET 6.3.3

FLOW DIAGRAM -



ENERGY NOTES (125) -

Plant Loading (lb dry solids/d)	Machine Capacity (lb dry solids/d)	Energy Usage kWh/ton dry solids
16,000	24,000	13
40,000	60,000	8
66,000	99,000	7

COSTS* - 1977 dollars; ENR Index = 2577
Type of sludge: Primary and secondary (anaerobically digested) - 5 percent solids concentration.
Sludge production: 7 d/wk
Dewatering operation: 7 d/wk; 16 h/d
Construction costs include belt filter press, sludge feed pumps, polymer pumps, and control panels.
Labor cost: $15/manhour. Power cost: $0.02/kWh.

Plant Sludge Loading (lb dry solids/d)	Construction Cost	Power Cost	Labor Cost	Maintenance Cost
16,000	$ 97,000	$ 800/yr	$11,000/yr	$1400/yr
40,000	120,000	1200/yr	11,000/yr	1700/yr
66,000	165,000	1700/yr	11,000/yr	2300/yr

REFERENCES - 8, 125

*To convert construction cost to capital cost see Table A-2.

FILTER PRESS, DIAPHRAGM

FACT SHEET 6.3.4

Description - The diaphragm filter press is a recent extension of filter press technology to increase the throughput of a press and provide a higher solids content in wastewater filter cake. (See Fact Sheet 6.3.5 for discussion of conventional filter presses.) The press makes use of a rubber diaphragm with pressurized water to provide a high pressure on the partially dewatered sludge cake in the press after conventional dewatering methods have been used.

This diaphragm provides the support for the filter cloth on one side of the press cavity. Filtration of the sludge is accomplished by charging the chambers of the press with sludge under pump pressure in the conventional manner, but at a generally lower pressure, and allowing a cake to develop. The time alloted to this cycle is dependent upon the characteristics of the sludge, but is scheduled to continue only as long as high filtration rates are in progress. This cycle usually is in the 10 to 30 minute range. The pump pressurizing system is then turned off, and water pressure is applied inside the diaphragm. This pressure, in the 200 psi range, applies a uniform pressure over the cake and further reduces the water content. The squeezing cycle has been shown to substantially reduce the overall cycle time for the press, yet produces a low moisture content cake. The filter cake produced is thinner than in the conventional press but has a uniform moisture content in contrast to the conventional press. The reduction in operating time for the sludge pumps is reported to substantially reduce wear and the required maintenance. The pressurized water for the diaphragm actuation is a closed recycle system; therefore, components operate under predictable conditions and no effluent is produced. Diaphragm presses are designed to make use of a number of automation features to reduce labor and recycle time.

Common Modifications - Opening of the filter press to allow simultaneous discharge of filter cake from all cavities. Rejection of the sludge cake by physical movement of the filter cloth by vibration or actual movement of the cloth in a forced rejection mode by partial withdrawal of the filter cloth loop. Automatic washing of filter cloths at each cycle or as conditions dictate. Air purging of feed and filtrate lines between cycles. Full automation of press operation.

Technology Status - The diaphragm filter press originates as Japanese or European technology. Several hundred presses were reported to be in operation in Japan's wastewater industry. The press is new to the United States and is being demonstrated by the use of portable pilot units. Fourteen full-scale units are to be scheduled for installation in 1979.

Applications - Dewatering of a wide variety of wastewater sludges to a high level of solids content. Production of an auto-combustible filter cake. Used where a large filtration area is required in a minimum of floor area.

Limitations - Relatively high operator skill is required. Life of filter cloths and diaphragms is limited. Moisture content of sludge highly dependent upon proper sludge conditioning.

Typical Equipment/No. of Mfrs. (148) - Diaphragm filter presses/2. (10) - Sludge pumps/7; cake conveyors/7; sludge conditioning tanks/3.

Performance (210) - Pilot test runs on full scale diaphragm presses using a 2:1 mix of secondary to primary sludge has shown cake solids in the 34 to 42 percent range. Lime addition at 12 to 25 percent and $FeCl_3$ at 4 to 8.5 percent were used as a chemical sludge conditioner. Cycle times ranged from 5 to 20 minutes pumping and 8 to 30 minutes squeeze.

Chemicals Required - For sludge conditioning, when necessary, lime, $FeCl_3$ and other materials found by test to be suitable for the sludge being processed.

Design Criteria - Filter areas = 5 to 40 ft^2/chamber, cake thickness 1/2 to 3/4 inch, sludge yield 0.4 to 0.8 lb/ft^2 of filter area, total cycle time 20 to 50 minutes.

Process Reliability - Reliability is expected to be high and similar to that of conventional filter presses. Process expected to show greater tolerance to impact of hard-to-dewater sludges.

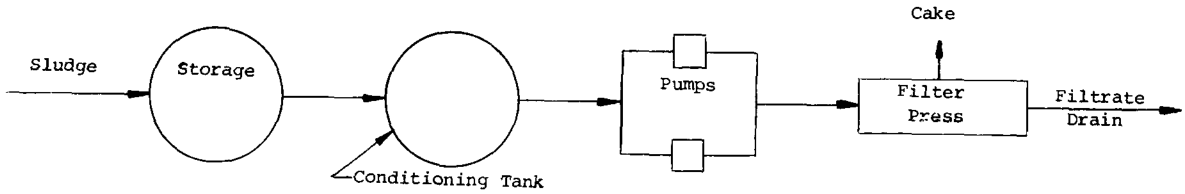
Environmental Impact - Consistent production of a high solids cake, even with hard-to-dewater sludge, can be expected to aid in an environmentally optimum disposal of sludge.

References - 10, 148, 210

FILTER PRESS, DIAPHRAGM

FACT SHEET 6.3.4

FLOW DIAGRAM -



ENERGY NOTES (210) - Energy requirements per dry ton for the process based on the assumptions below are: 37 kWh/ton for press operation + 29.7 kWh/ton for operation of the lime and $FeCl_3$ systems, sludge pumping, sludge conditioning equipment and the cake conveyors, resulting in a total power requirement of 66.7 kWh/ton.

COSTS* (210) - A cost estimate has been derived for use of a diaphragm filter press in a large multiple press installation with a sludge cake production of 250 dry ton/d. Sludge was assumed to be a mix of 2:1 secondary to primary with a feed solids of 5 percent. Sludge conditioning was assumed to be lime at 20 percent and $FeCl_3$ at 7 percent dry sludge solids. Lime cost was assumed at $44/ton and $FeCl_3$ at $130/ton. Pricing is based on the largest size presses available. The total number includes one spare. The capital cost (1978 dollars) includes the chemical feed system, sludge feed pumps, dewatering unit with all necessary accessories and a conveyor system to transport cake to the next process. The total installation cost was obtained by utilizing a multiplication factor of 3 which includes installation, piping, utilities, building and engineering. Labor is assumed at $21,000/manyear. ENR Index = 2577

Cost Summary	
Capital Cost	$19,500,000
Lime System	1,000,000
$FeCl_3$ System	500,000
Conveyors	2,000,000
Total	$23,000,000

Annual Costs	
Amortization at 9%	$ 2,070,000
Chemicals	1,633,000
Power at 66.7 kWh/ton and $0.04/kWh	243,000
Water 12 x 10^6 gallons	6,400
Labor - Operation	504,000
Maintenance -	
Cloth and diaphragm replacement-materials	312,000
Labor replacement	31,500
Equipment maintenance at 2% of purchase cost	153,000
Total annual costs	$ 4,953,000
Unit cost/dry ton of sludge cake	$ 54.28

REFERENCE - 210

*To convert construction cost to capital cost see Table A-2.

CONVENTIONAL FILTER PRESS FACT SHEET 6.3.5

Description - The conventional filter press for dewatering wastewater sludges is the recessed plate press. This press consists of vertical recessed plates up to 5 ft in diameter (or 5 ft on a side, if square) which are held rigidly in a frame and which are pressed together between a fixed and moving end. On the face of each individual plate is mounted a filter cloth. The sludge is fed into the press at pressures up to 225 lb/in^2g and passes through feed holes in the trays along the length of the press. The water passes through the cloth, while the solids are retained and form a cake on the surface of the cloth. Sludge feeding is stopped when the cavities or chambers between the plates are completely filled. Drainage ports are provided at the bottom of each press chamber. The filtrate is collected in these, taken to the end of the press, and discharged to a common drain. At the commencement of a processing cycle, the drainage from a large press can be in the order of 2,000 to 3,000 gallons per hour. This rate falls rapidly to about 500 gallons per hour as the cake begins formation and, when the cake completely fills the chamber, the rate is virtually nothing. The dewatering step is completed when the filtrate is near zero. At this point, the pump feeding sludge to the press is stopped, and any back pressure in the piping is released through the bypass valve. The electrical closing gear is then operated to open the press. The individual plates are next moved in turn over the gap between the plates and the moving end. This allows the filter cakes to fall out. The plate moving step can be either manual or automatic. When all the plates have been moved and the cakes released, the complete pack of plates is then pushed back by the moving end and closed by the electrical closing gear. The valve to the press is then opened, the sludge feed pump started, and the next dewatering cycle commences. Thus, a cycle includes the time required for filling, pressing, cake removal, media washing, and press closing.

A monofilament filter media is now used which, unlike multifilament filter cloth, resists blinding in service. Many systems utilize an efficient precoat system which deposits a protective layer of porous material (fly ash, cement kiln dust, buffing dust) on the filter media to prevent blinding and to facilitate cake release.

While pressure filters with a total effective filtration area of 2,500 ft^2 were once considered large, today's units with an effective filtration area of 4,500 ft^2 are not uncommon.

Until recently, pressure filters, with few exceptions, operated at a maximum pressure differential of 100 lb/in^2. Extensive studies during the early 1960's showed that pressure differentials of up to 225 lb/in^2 produced filter cake solids concentration well in excess of 50 percent. Some commercially available systems now operate near these pressures. As a result of these greater pressures, filter presses offer several advantages, such as higher cake solids concentrations, improved filtrate clarity, improved solids capture, and reduced chemical consumption.

Common Modifications - Various weaves and materials for the filter media, precoating materials, and methods, mechanical plate shifting and washing devices.

Technology Status - Experience in United States with pressure filtration of wastewater sludges is limited. Plate presses have been used in European wastewater plants for many years. Industry has made use of the process for many years.

Applications - Dewatering of sludges prior to incineration. Dewatering of hard-to-handle sludges. Used where a large filtration area is required in a minimum floor area.

Limitations - Batch discharge requires equalization of pressed cake production prior to incineration. Life of filter cloth is limited. Presses must normally be installed well above floor level so that cakes can drop onto conveyors or trailers. Cake must be delumped prior to incineration.

Typical Equipment/No. of Mfrs. (10) - Filter press/12; sludge pumps/7; cake conveyors/7; sludge conditioning tanks/3.

Performance - With input sludges of varying types having a TSS of 1 to 10 percent, typical filter press production data show cake solids concentrations of 50 percent with 100 to 250 percent (on dry solids basis) fly ash conditioning and cycle times of 1.5 to 2.0 h. Cake solids concentrations of 45 percent have been achieved with chemical conditioning (5 to 7.5 percent $FeCl_3$ and 10 to 15 percent lime) and cycle times of 1.0 to 2.0 h. In general, cakes of 25 to 50 percent solids concentrations are achieved.

Chemicals Required - Lime, flyash, $FeCl_3$, alum polymers and other conditioners are used depending upon the sludge type and characteristics.

Design Criteria - Chamber Volume 0.75 to 2.8 ft^3/chamber; Filter Areas = 14.5 to 45 ft^2/chamber; No. Chambers = up to 100; Sludge Cake Thickness = 1 to 1½ in; Sludge Feed Rate = approximately 2 $lb/cycle/ft^2$ (dry solids basis).

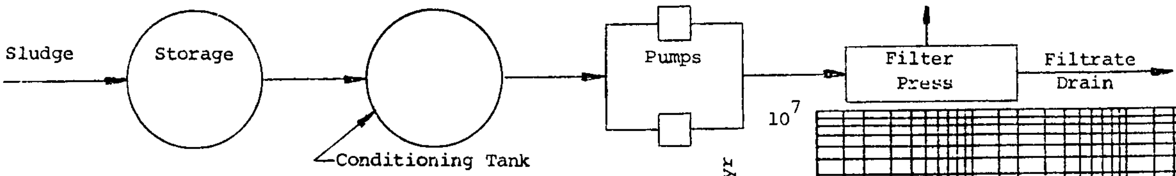
Unit Reliability - Pressure filter plate warpage has been a major problem. Plate gasket deterioration (sometimes caused by plate warpage) has also been a problem requiring maintenance.

References - 8, 10, 64

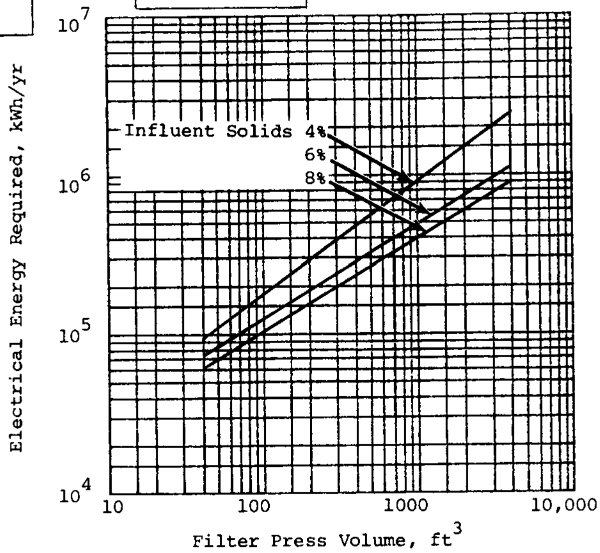
CONVENTIONAL FILTER PRESS

FACT SHEET 6.3.5

FLOW DIAGRAM -



ENERGY NOTES (4) - Power consumption based on continuous operation, 225 lb/in^2 operating pressure. Curve includes feed pump (hydraulically driven, positive displacement piston pump), opening and closing mechanism.

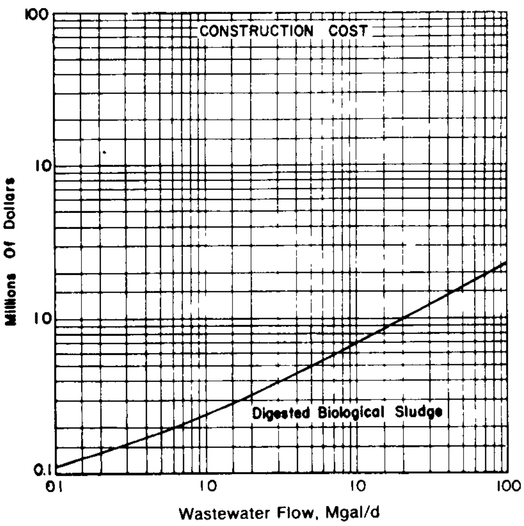


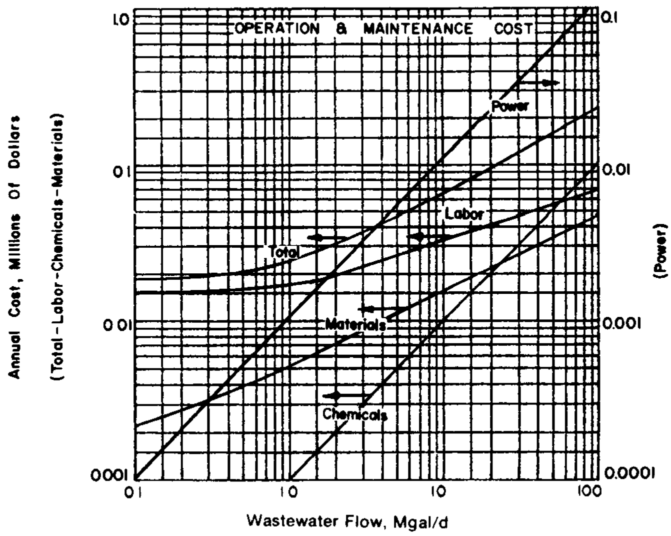
COSTS* (3) - ENR Index = 2475; Service life = 15 years.

1. Construction cost for biological sludge includes filter presses, pressure pumps, conveyor equipment, chemical feed and storage facilities, conditioning tanks, sludge storage tanks, and building.
2. Sludge loading: digested primary + secondary = 900 lb/Mgal @ 2.5%
3. Cake characteristics: density = 68 lb/ft^3; solids content = 40%.
4. Operations: For 0.1 to 1 Mgal/d plant = 20 cycles/wk
   For 1 to 10 Mgal/d plant = 48 cycles/wk
   For 10 to 100 Mgal/d plant = 84 cycles/wk
5. Conditioning chemicals: $FeCl_3$ = 35 lb/Mgal; CaO = 90 lb/Mgal
6. For filter press costs for lime sludge, please refer to reference 3.

Adjustment Factor - To develop cost for sludge quantities, concentration, characteristics or cycles per week different than those used to develop these curves, enter curve at effective flow (Q_E).

$$Q_E = Q_{DESIGN} \times \frac{\text{New Design Sludge Mass}}{900 \text{ lb/Mgal}} \times \frac{\text{New Design Cycles Per Week}}{\text{Original Design Cycles Per Week}} \times \frac{\text{New Design Cycle Time}}{2 \text{ hours}}$$





REFERENCES - Curves derived from references 3 and 4.

*To convert construction cost to capital cost see Table A-2.

THICKENING, DISSOLVED AIR FLOTATION FACT SHEET 6.3.6

Description and Common Modifications - In a Dissolved Air Flotation (DAF) system, a recycled subnatant flow is pressurized from 30 to 70 lb/in^2g and then saturated with air in a pressure tank. The pressurized effluent is then mixed with the influent sludge and subsequently released into the flotation tank. The excess dissolved air then separates from solution, which is now under atmospheric pressure, and the minute (average diameter 80 microns) rising gas bubbles attach themselves to particles which form the floating sludge blanket. The thickened blanket is skimmed off and pumped to the downstream sludge handling facilities while the subnatant is returned to the plant. Polyelectrolytes are frequently used as flotation aids, to enhance performance and create a thicker sludge blanket. A description of the DAF process in general is presented in Fact Sheet 3.1.6.

Technology Status - DAF is the most common form of flotation thickening in use in the United States and has been used for many years to thicken waste activated sludges, and to a lesser degree to thicken combined sludges. DAF has widespread industrial wastewater applications.

Applications - The use of air flotation is limited primarily to thickening of sludges prior to dewatering or digestion. Used in this way, the efficiency of the subsequent dewatering units can be increased and the volume of supernatant from the subsequent digestion units can be decreased. Existing air flotation thickening units can be upgraded by the optimization of process variables, and by the utilization of polyelectrolytes. Air flotation thickening is best applied to waste activated sludge. With this process, it is possible to thicken the sludge to 6 percent solids, while the maximum concentration attainable by gravity thickening without chemical addition is 2 to 3 percent solids. The DAF process can also be applied to mixtures of primary and waste activated sludge. DAF also maintains the sludge in aerobic condition and potentially has a better solids capture than gravity thickening. There is some evidence that activated sludges from pure oxygen systems are more amenable to flotation thickening than sludges from conventional systems.

Limitations - DAF has high operating costs (primarily for power for aeration and chemicals) and is therefore generally limited to waste activated sludges. The variability of sludge characteristics requires that some pilot work be done prior to design of a DAF system.

Typical Equipment/No. of Mfrs. (23) - Dissolved air flotation units/24; Air compressors/8.

Performance (26) - A summary of data from various air flotation units indicates that solids recovery ranges from 83 to 99 percent at solids loading rates of 7 to 48 $lb/ft^2/d$.

A summary of operating data from 14 sewage treatment plants (8) is as follows: Influent suspended solids 3,000 to 20,000 mg/l (median 7,300), supernatant suspended solids 31 to 460 mg/l (median 144), suspended solids removal 94 to 99+ percent (median 98.7), float solids 2.8 to 12.4 percent (median 5.0), loading 1.3 to 7.7 $lb/h/ft^2$ (median 3.1), flow 0.4 to 1.8 $gal/min/ft^2$ (median 1.0).

Chemicals Required - Flotation aids (generally polyelectrolytes) are usually used to enhance performance.

Residuals Generated - Supernatant (effluent) quality: Approximately 150 mg/l SS, returned to mainstream of the treatment plant.

Design Criteria - Pressure 30 to 70 lb/in^2g; effluent recycle ratio 30 to 150 percent of influent flow; air to solids ratio 0.02 lb air/lb solids; solids loading 5 to 55 $lb/ft^2/d$ (depending on sludge type and whether flotation aids are used); polyelectrolyte addition (when used) 5 to 10 lb/ton of dry solids; solids capture 70 to 98+ percent; total solids, unthickened sludge 0.3 to 2.0 percent, thickened solids 3 to 12 percent; hydraulic loading 0.4 to 2.0 $gal/min/ft^2$.

Sludge Type	Feed Solids Concentration (Percent)	Typical Loading Rate Without Polymer (lb/sq ft/day)	Typical Loading Rate With Polymer (lb/sq ft/day)	Float Solids Concentration (Percent)
Primary + WAS	2.0	20	60	5.5
Primary + (WAS + $FeCl_3$)	1.5	15	45	3.5
(Primary + $FeCl_3$) + WAS	1.8	15	45	4.0
WAS	1.0	10	30	3.0
WAS + $FeCl_3$	1.0	10	30	2.5
Digested Primary + WAS	4.0	20	60	10.0
Digested Primary + (WAS + $FeCl_3$)	4.0	15	45	8.0
Tertiary, Alum	1.0	8	24	2.0

Reliability - DAF systems are reliable from a mechanical standpoint. Variations in sludge characteristics can affect process (treatment) reliability, and may require operator attention.

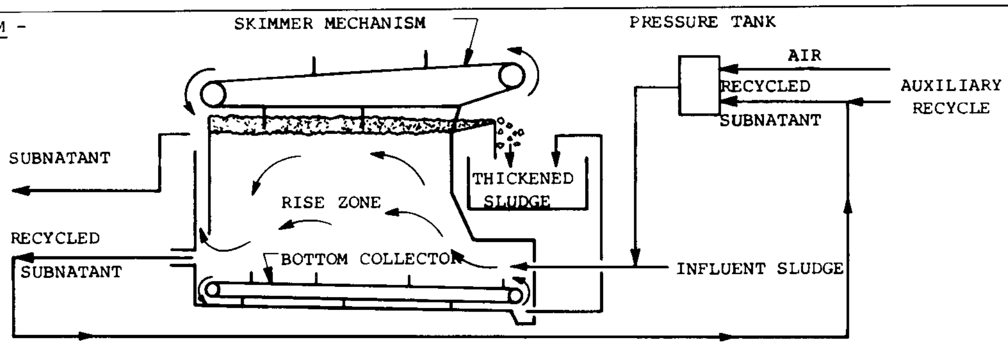
Environmental Impact - Requires less land than gravity thickeners. A subnatant stream is returned to the head of the treatment plant, although it should be compatible with other wastewater. The air released to the atmosphere may strip volatile organic material from the sludge. The volume of sludge requiring ultimate disposal may be reduced, although its composition will be altered if chemical flotation aids are used. The air compressors will require shielding to control the noise generated.

References - 3, 7, 8, 23, 26, 95, 111

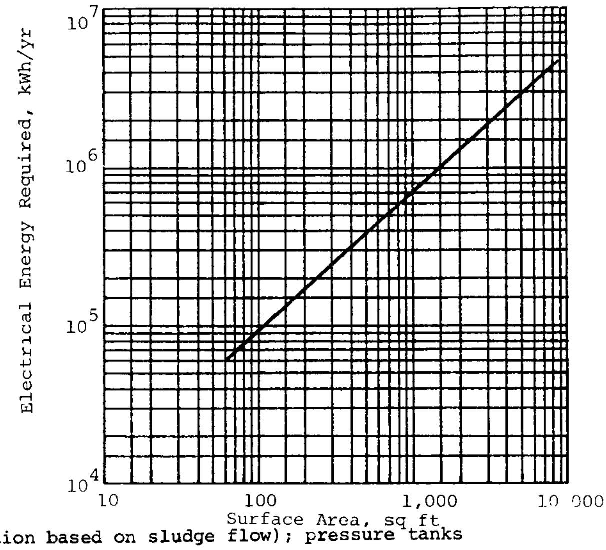
THICKENING, DISSOLVED AIR FLOTATION

FACT SHEET 6.3.6

FLOW DIAGRAM -



ENERGY NOTES (4) - See table in design section of 6.3.6 for typical loading rates.

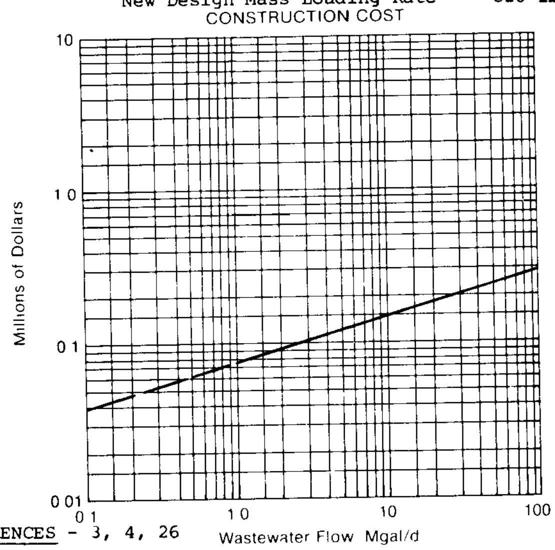


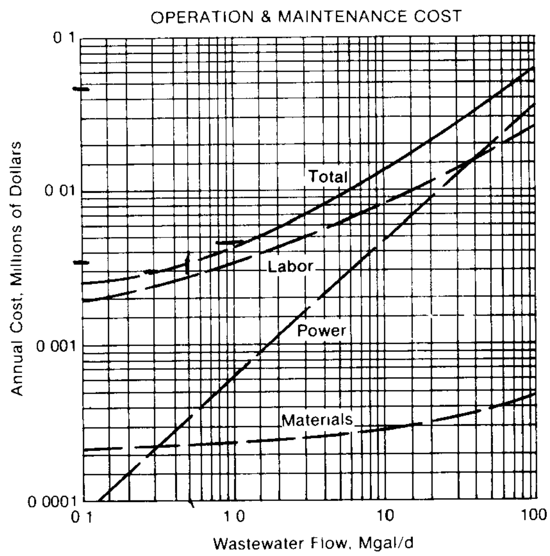
COSTS* (3) - Assumptions:

1. Construction costs include: flotation chamber (2-h detention based on sludge flow); pressure tanks (60 lb/in^{2}g); recycle pumps (100% recycle).
2. Costs for thickening of secondary sludge only: 820 lb/Mgal.
3. Loading rate = 2 lb/ft^2/h
4. Operating hours: 0.1 and 1 Mgal/d = 40 h/wk; 10 Mgal/d = 100 h/wk; 100 Mgal/d = 168 h/wk.

Adjustment Factor: To determine costs at loading rates or sludge quantities other than above, enter curve effective flow Q_E.

$$Q_E = Q_{DESIGN} \times \frac{2\ \text{lb/ft}^2\text{/h}}{\text{New Design Mass Loading Rate}} \times \frac{\text{New Design Sludge Mass}}{820\ \text{lb/d/Mgal}}$$





REFERENCES - 3, 4, 26

*To convert construction cost to capital cost see Table A-2.

THICKENING, GRAVITY — FACT SHEET 6.3.7

Description - Thickening of sludge consists of the removal of supernatant, thereby reducing the volume of sludge that requires disposal or further treatment. Gravity thickening takes advantage of the difference in specific gravity between the solids and water.

A gravity thickener normally consists of two truss-type steel scraper arms mounted on a hollow pipe shaft keyed to a motorized hoist mechanism. A truss-type bridge is fastened to the tank walls or to steel or concrete columns. The bridge spans the tank, and supports the entire mechanism. The thickener resembles a conventional circular clarifier with the exception of having a greater bottom slope. Sludge enters at the middle of the thickener and the solids settle into a sludge blanket at the bottom. The concentrated sludge is very gently agitated by the moving rake which dislodges gas bubbles and prevents bridging of the sludge solids. It also keeps the sludge moving toward the center well from which it is removed. Supernatant liquor passes over an effluent weir around the circumference of the thickener. It has been shown that in the operation of gravity thickeners it is desirable to keep a sufficiently high flow of fresh liquid entering the concentrator to prevent septic conditions and resulting odors from developing.

Gravity thickening is characterized by zone settling. The four basic settling zones in a thickener are:

.The clarification zone at the top containing the relatively clear supernatant.

.The hindered settling zone where the suspension moves downward at a constant rate and a layer of settled solids begins building from the bottom of the zone.

.The transition zone characterized by a decreasing solids settling rate.

.The compression zone where consolidation of sludge results solely from liquid being forced upward around the solids.

Common Modifications - Tanks can be square or round, with the round variety being much more prevalent. Tanks can be manufactured of concrete or steel. Chemicals can be added to aid in the sludge dewatering.

Technology Status - Has been in wide use for many years.

Typical Equipment/No. of Mfrs. (23) - Sedimentation Equipment/28; Chemical feed equipment/25.

Applications - Used to thicken primary, secondary, and digested sludges.

Limitations - Does not perform satisfactorily on most waste activated, mixed primary-waste activated, and alum or iron sludges. Is highly dependent on the dewaterability of the sludges being treated.

Performance - (No chemical conditioning)

Type of Sludge	Solids Surface Loading ($lb/d/ft^2$)	Thickened Sludge Solids Concentration (%)
Primary	20 to 30	8 to 10
Waste Activated	5 to 6	2.5 to 3
Trickling filter	8 to 10	7 to 9
Limed tertiary	60	12 to 15
Primary and activated	6 to 10	4 to 7
Primary and trickling filter	10 to 12	7 to 9
Limed primary	20 to 25	7 to 12

Chemicals Required - Lime (CaO) and/or polymers may be added to aid in the dewatering and settling of the sludge. Chlorine can be added to prevent septicity.

Residuals Generated - Supernatant volume is directly related to the increase in solids concentration in the thickener. The supernatant will contain varying amounts of solids, ranging from tens to hundreds of milligrams per liter.

Design Criteria - See "Performance." Detentions of one to three days are usually used. Sludge blankets of at least three feet are common. Side water depths of at least ten feet are general practice.

Unit Process Reliability - Gravity thickeners are mechanically reliable, but are greatly affected by the quality of sludge received. Therefore, they may be upset due to a radical change in the raw wastewater or digested sludge quality.

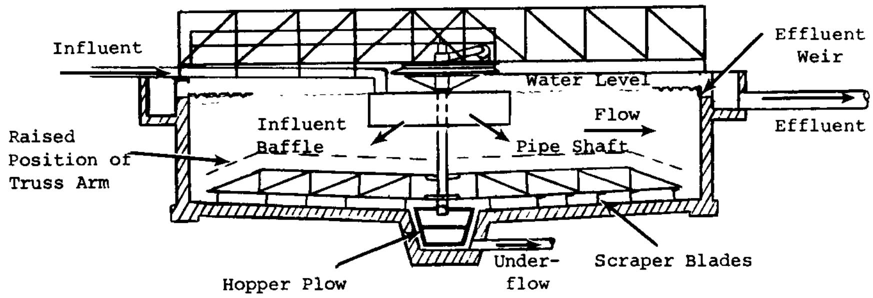
Environmental Impact - Requires relatively little use of land. The supernatant will need disposal. This can be accomplished by recycling it to the head end of the plant for further treatment. Odor problems frequently result from septic conditions.

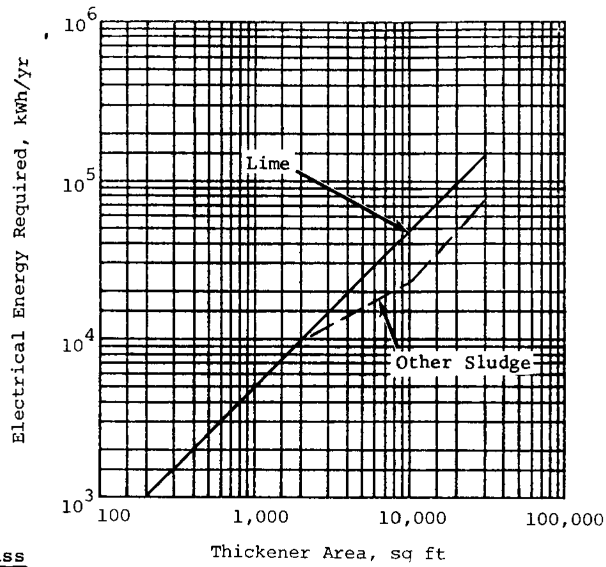
References - 8, 26, 34

THICKENING, GRAVITY

FACT SHEET 6.3.7

FLOW DIAGRAM -





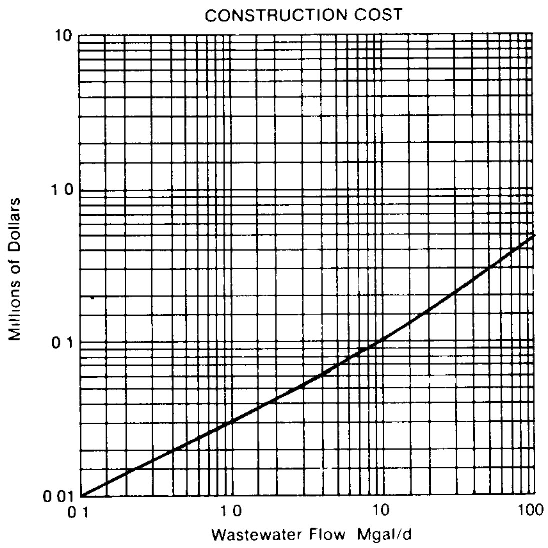
ENERGY NOTES - Assumptions:
Design basis included in "Performance".

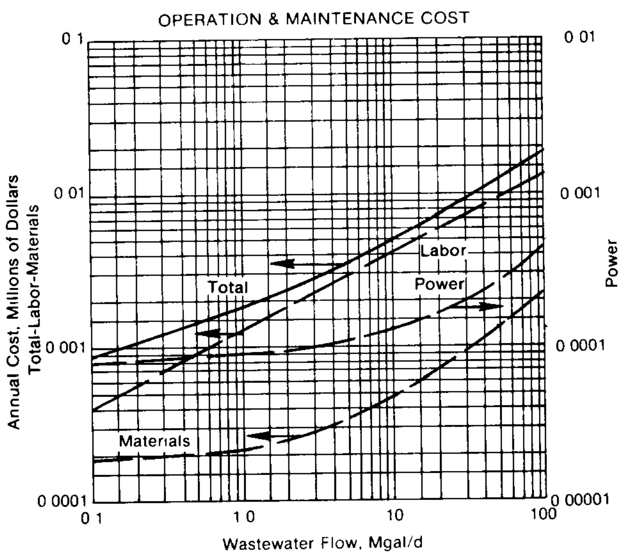
COSTS* - Assumptions: ENR Index = 2475

1. Construction costs include thickener and all related mechanical equipment. Pumps are not included.
2. Costs are based on thickening of secondary sludge (820 lb/Mgal; loading = 6 $lb/ft^2/d$). See adjustment factors for other sludge loadings.
3. O&M costs do not include polymer addition.

Adjustment Factor: To adjust costs for alternative sludge quantities, concentrations, and thickening properties, enter curves at effective flow (Q_E).

$$Q_E = Q_{DESIGN} \times \frac{6\ lb/ft^2/d}{\text{New Design Mass Loading}} \times \frac{\text{New Design Sludge Mass}}{820\ lb/Mgal}$$





REFERENCES- 3, 4, 8

*To convert construction cost to capital cost see Table A-2.

CENTRIFUGAL THICKENING FACT SHEET 6.3.8

Description (8) - Centrifuges may be used to thicken municipal sludges. They use centrifugal force to increase the sedimentation rate of sludge solids. The three most common types of units are the continuous solid bowl type, the disc type, and the basket type. Refer to Fact Sheet No. 6.3.1 for unit descriptions.

Technology Status (8) - There has been limited use of centrifuges for thickening excess activated sludges (EAS). Field trials have been conducted at two facilities. Disc type units have been selected for three treatment plants.

Applications (8) - Centrifuges may be used for thickening of excess activated sludge where space limitations or sludge characteristics make other methods unsuitable. Further, if a particular sludge can be effectively thickened by gravity or by flotation thickening without chemicals, centrifuge thickening is not economically feasible.

Limitations (8) - Centrifugal thickening processes can have significant maintenance and power costs. Adequate chemical conditioning may be required in order to achieve 90 percent solids capture and 4 percent solids concentration with activated sludge in a bowl type unit. Disc type units require prescreening to prevent pluggage of discharge nozzles, especially if flow is interrupted or reduced. Rotating parts of disc units must be manually cleaned every two weeks. (144)

Typical Equipment/No. of Mfrs. - See Fact Sheet No. 6.3.1.

Performance (8) - Typical performance data for the disc, basket, and solid bowl centrifuges when they are employed in the thickening of EAS, are presented in the following table. Note that chemical addition is not always required. In general, underflow solids concentration from disc units is lower than from solid bowl units (3 to 5 percent versus 5 to 7 percent). (144).

Type of Sludge	Centrifuge Type	Capacity (gal/min)	Feed Solids (%)	Underflow Solids (%)	Solids Recovery (%)	Polymer Requirement (lb/ton)
EAS	Disc	150	0.75-1.0	5-5.5	90+	None
EAS	Disc	400	-	4.0	80	None
EAS (after Roughing Filter)	Disc	50-80	0.7	5-7	93-87	None
EAS (after Roughing Filter)	Disc	60-270	0.7	6.1	97-80	None
EAS	Basket	33-70	0.7	9-10	90-70	None
EAS	Solid Bowl	10-12	1.5	9-13	90	-
EAS	Solid Bowl	75-100	0.44-0.78	5-7	90-80	None
EAS	Solid Bowl	110-160	0.5-0.7	5-8	65	None
					85	Less than 5
					90	5-10
					95	10-15

Design Criteria - See Fact Sheet No. 6.3.1. Maximum available capacity per unit is 500 to 600 gal/min for disc units and 400 gal/min for solid bowl units. (144,145)

Unit Reliability - Pluggage of discharge orifices is a problem on disc type units if feed to the centrifuge is stopped, interrupted, or reduced below a minimum value.

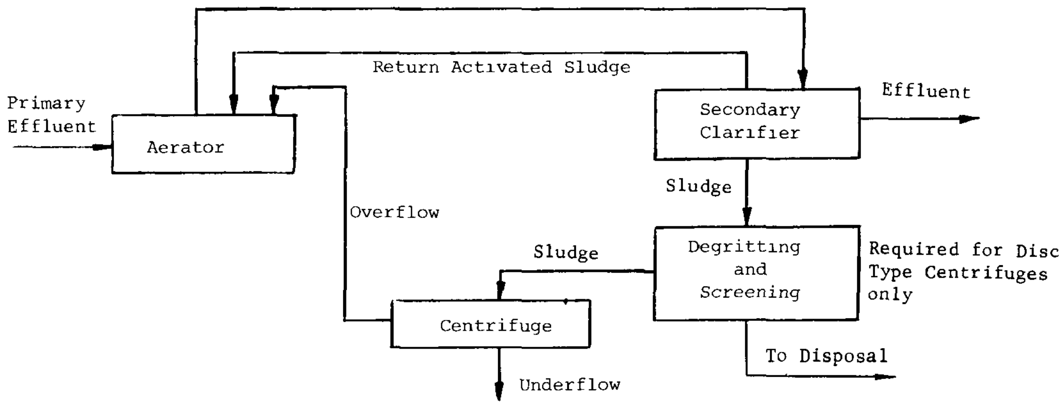
Environmental Impact - For some sludges, odor controls may be required. Noise control is always required.

References - 8, 144, 145

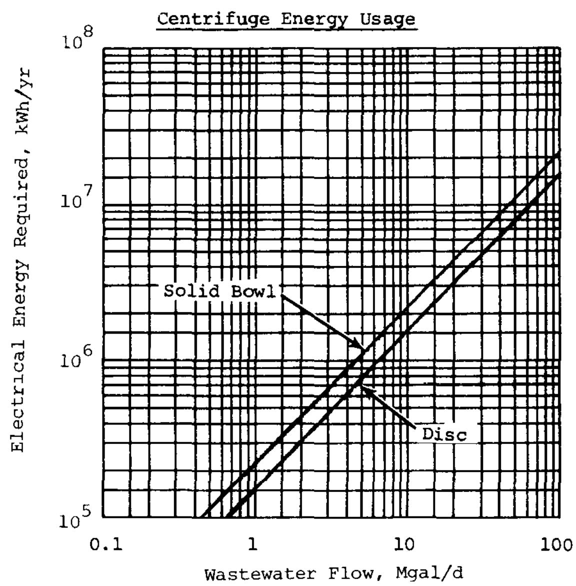
CENTRIFUGAL THICKENING

FACT SHEET 6.3.8

FLOW DIAGRAM -



ENERGY NOTES - Assumptions: Energy usages are based on 820 lb of solids at 0.8% concentration (waste activated sludge) per Mgal entering centrifuge. Values shown are for centrifuge drive motors only and are considered accurate within ± 50%.



COSTS* (144, 145) - Construction cost: For disc centrifuge include the centrifuge, drive motor, screens, strainer, pumps, and degritting system. Construction costs for solid bowl unit include the centrifuge and drive motor only. All units are designed to handle 820 lb/Mgal of dry solids at 0.8% concentration. Power cost: $0.02/kWh; ENR Index: 2829 (August 1978). Labor cost: $15/manhour. Polymer costs not included. Solid bowl centrifuge will probably require polymer.

	Influent Sludge Flow	Construction Cost	Annual Operating and Maintenance Costs		
	gal/min		Power[1]	Material	Labor
Disc Centrifuge	100 to 150	$115,000	$ 6,300	$2,000	$12,000
	150 to 300	$173,000	$12,600	$3,000	$12,000
	300 to 550	$230,000	$23,100	$6,000	$12,000
Solid Bowl Centrifuge	50 to 60	$104,000	$ 3,400	$1,800	$ 8,500
	Up to 150	$200,000	$ 8,500	$3,500	$ 8,500
	Up to 400	$374,000	$22,700	$6,500	$ 8,500

Note [1] - Power cost is based on maximum influent sludge flow shown. Only centrifuge drive requirements are considered.

REFERENCES - 144, 145

*To convert construction cost to capital cost see Table A-2.

VACUUM FILTRATION, SLUDGE | FACT SHEET 6.3.9

Description (8) - Vacuum filters are used to dewater sludges so as to produce a cake having the physical handling characteristics and moisture contents required for subsequent processing. A rotary vacuum filter consists of a cylindrical drum rotating partially submerged in a vat or pan of conditioned sludge. The drum is divided radially into a number of sections, which are connected through internal piping to ports in a valve body (plate) at the hub. This plate rotates in contact with a fixed valve plate with similar ports, which are connected to a vacuum supply, a compressed air supply, and an atmospheric vent. As the drum rotates each section is thus connected to the appropriate service. Various operating zones are encountered during a complete revolution of the drum. In the pickup or form section, vacuum is applied to draw liquid through the filter covering (media) and form a cake of partially dewatered sludge. As the drum rotates the cake emerges from the liquid sludge pool, while suction is still maintained to promote further dewatering. A lower level of vacuum often exists in the cake drying zone. If the cake tends to adhere to the media, a scraper blade may be provided to assist removal.

The three principal types of rotary vacuum filters are the drum type, coil type, and the belt type. The filters differ primarily in the type of covering used and the cake discharge mechanism employed. Cloth media are used on drum and belt types while stainless steel springs are used on the coil type. Infrequently, a metal media is used on belt types. The drum filter also differs from the other two in that the cloth covering does not leave the drum but is washed in place, when necessary. The design of the drum filter provides considerable latitude in the amount of cycle time devoted to cake formation, washing, and dewatering; while it minimizes inactive time.

A variation of the conventional drum filter is the top feed drum filter. In this case, sludge is fed to the vacuum filter through a hopper located above the filter. The potential advantages are that gravity aids in cake formation; capital costs may be lower since the feed hopper is smaller and no sludge agitator and related drive equipment are required; and "blinding" of the media may be reduced.

The coil type vacuum filter uses two layers of stainless steel coils arranged in corduroy fashion around the drum. After a dewatering cycle, the two layers of springs leave the drum and are separated from each other so that the cake is lifted off the lower layer of springs and discharged from the upper layer. Cake release is essentially free of problems. The coils are then washed and reapplied to the drum. The coil filter has been and is widely used for all types of sludge. However, sludge with particles that are both extremely fine and resistant to flocculation dewater poorly on coil filters.

Media on the belt type filter leaves the drum surface at the end of the drying zone and passes over a small diameter discharge roll to facilitate cake discharge. Washing of the media next occurs before it returns to the drum and to the vat for another cycle. This type filter normally has a small diameter curved bar between the point where the belt leaves the drum and the discharge roll which aids in maintaining belt dimensional stability. In practice it is frequently used to insure adequate cake discharge.

A great many types of filter media are available for the belt and drum filters. There is some question whether increases in yield due to operating vacuums greater than 15 inches of mercury are justifiable. The cost of a greater filter area must be balanced against the higher power costs for higher vacuums. An increase from 15 to 20 inches of vacuum is reported to have provided about 10 percent greater yield in three full-scale installations.

Common Modifications - Chemical conditioning is often employed to agglomerate a large number of small particles. It is almost universally applied with mixed sludges.

Technology Status - Is the most common method of mechanical sludge dewatering utilized in the United States.

Applications - Generally used in larger facilities where space is limited, or when incineration is necessary for maximum volume reduction.

Limitations - Relatively high operating skill required. Operation is sensitive to type of sludge and conditioning procedures. As raw sludge ages (3 to 4 hours) after thickening, vacuum filter performance decreases. Poor release of the filter cake from the belt is occasionally encountered. Chemical conditioning costs can sometimes be extremely large if a sludge is hard to dewater.

Typical Equipment/No. of Mfrs. (10, 77) - Rotary vacuum filter/11; Vacuum pump/27; Filtrate receiver/10; Filtrate pump/40; Sludge conditioning apparatus/3; Sludge conveyors/7.

Performance (8, 10) - Solids capture ranges from 85 to 99.5 percent and cake moisture is usually 60 to 90 percent depending on feed type, solids concentration, chemical conditioning, machine operation and management. Dewatered cake is suitable for landfill, heat drying, incineration or land spreading.

Chemicals Required (10) - $FeCl_3$ and/or lime, or polymer dosing is a function of type of sludge and vacuum filter characteristics.

Design Criteria (8) - Typical loadings in pounds dry solids/h/ft^2 are 7 to 15 for raw primary sludges, 4 to 7 for digested primary sludges, and 3.5 to 5 for mixed digested sludges. The loading is a function of feed solids concentrations, subsequent processing requirements and chemical preconditioning.

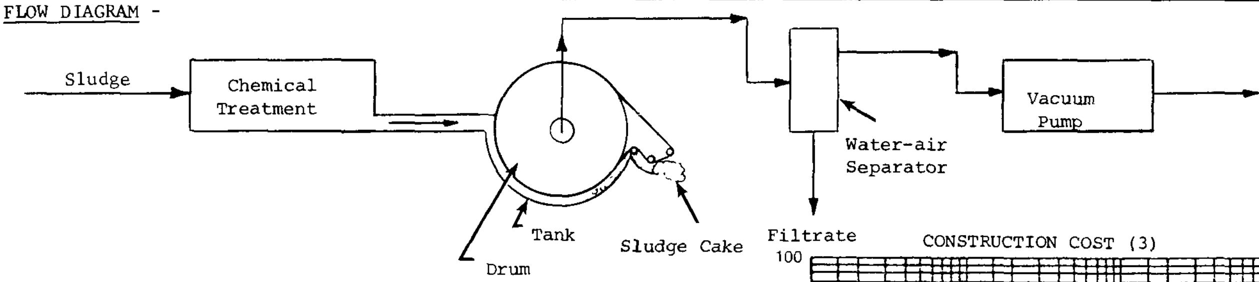
Environmental Impact - Relatively high chemical and energy requirements.

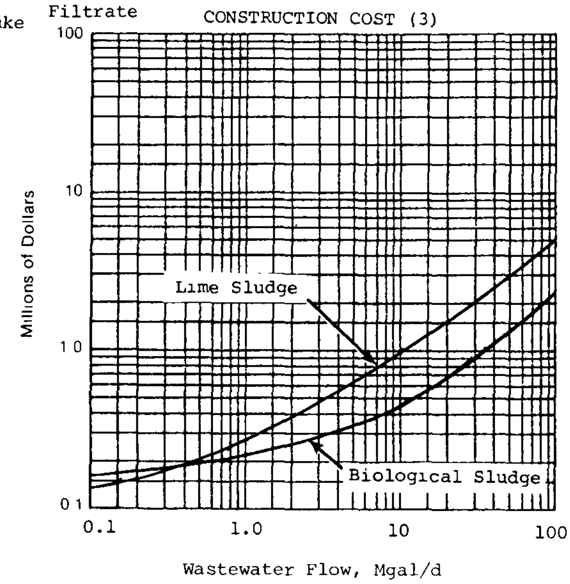
Unit Process Reliability - Large doses of lime may require frequent washings of drum filter media. Remedial measures are frequently required to obtain operable cake releases from belt filters. High operating skill required to maintain high level of reliability.

References - 3, 8, 10, 77

VACUUM FILTRATION, SLUDGE FACT SHEET 6.3.9

FLOW DIAGRAM -

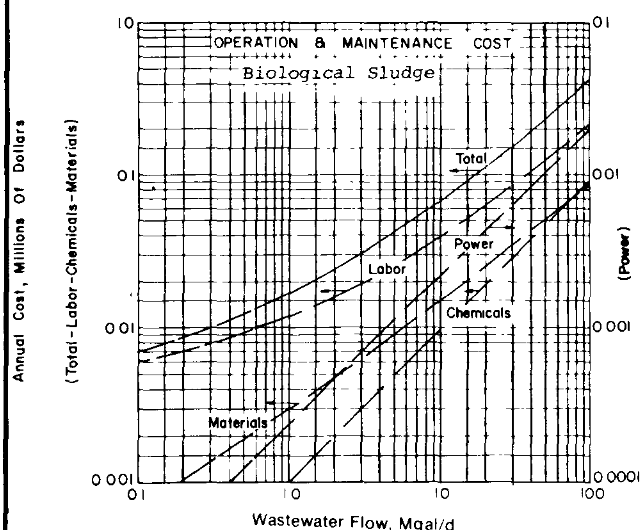


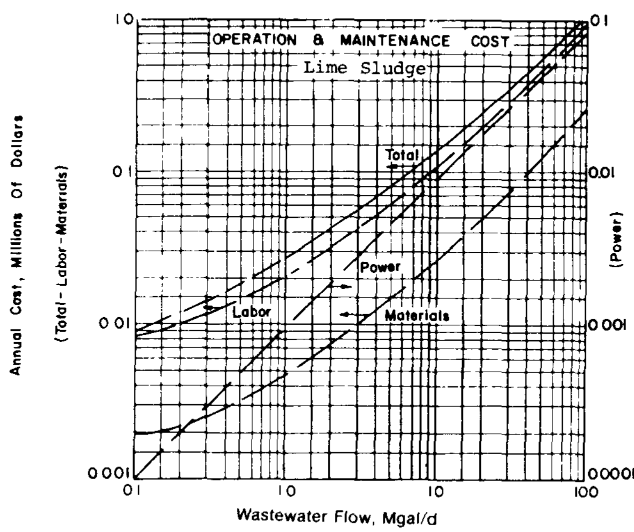


ENERGY NOTES - Assumptions:
Electrical energy for operation of the vacuum pumps, filtrate and other pumps and mechanical equipment can be estimated on the basis of 11,000 kWh/yr/Mgal/d for biological sludge and 42,000 kWh/yr/Mgal/d for lime sludge.

COSTS * - ENR-2475 Assumptions:

Design Basis:
Construction costs include: pumps, internal piping and electrical controls, mechanical equipment, conveyors, and sludge cake storage hopper, building, chemical handling and storage facilities. Costs are for dewatering of combined primary and secondary digested sludge consisting of 900 lb dry solids/Mgal plant flow or lime sludge consisting of 4,500 lb dry solids/Mgal plant flow.
Filter yield = 5 lb/ft^2 for biological sludge and 8 lb/ft^2 for lime sludge.
Operation time (excluding downtime for maintenance): 6 h/d for 1 Mgal/d plant or less; 12 h/d for 10 Mgal/d plant; 18 h/d for a 100 Mgal/d plant.
Chemical dosage: $FeCl_3$ = 35 lb/Mgal; CaO = 90 lb/Mgal.
Power Cost: $0.02/kWh.





REFERENCES - 3

*To convert construction cost to capital cost see Table A-2.

DIGESTION, AEROBIC — FACT SHEET 6.4.1

Description - Aerobic digestion is a method of sludge stabilization in an open tank that can be regarded as a modification of the activated sludge process. Microbiological activity beyond cell synthesis is stimulated by aeration, oxidizing both the biodegradable organic matter and some cellular material into CO_2, H_2O and NO_3. The oxidation of cellular matter is called endogenous respiration and is normally the predominant reaction occurring in aerobic digestion. Stabilization is not complete until there has been an extended period of primarily endogenous respiration (typically 15 to 20 days). Major objectives of aerobic digestion include odor reduction, reduction of biodegradable solids and improved sludge dewaterability. Aerobic bacteria stabilize the sludge more rapidly than anaerobic bacteria, although a less complete breakdown of cells is usually achieved. Oxygen can be supplied by surface aerators or by diffusers. Other equipment may include sludge recirculation pumps and piping, mixers and scum collection baffles. Aerobic digestors are designed similarly to rectangular aeration tanks and use conventional aeration systems, or employ circular tanks and use an eductor tube for deep tank aeration.

Common Modifications - Both one and two tank systems are used. Small plants often use a one tank batch system with a complete mix cycle followed by settling and decanting (to help thicken the sludge). Larger plants may consider a separate sedimentation tank to allow continuous flow and facilitate decanting and thickening. Air may be replaced with oxygen (see Fact Sheet 6.4.3).

Technology Status - Primarily used in small plants and rural plants, especially where extended aeration or contact stabilization are practiced.

Applications - Suitable for waste primary sludge, waste biological sludges (activated sludge or trickling filter sludge) or a combination of any of these. Advantages of aerobic digestion over anaerobic digestion include, simplicity of operation, lower capital cost, lower BOD concentrations in supernatant liquid, recovery of more of the fertilizer value of sludge, fewer effects from interfering substances (such as heavy metals), and no danger of methane explosions. The process also reduces grease content and reduces the level of pathogenic organisms, reduces the volume of the sludge and sometimes produces a more easily dewatered sludge (although it may have poor characteristics for vacuum filters). Volatile solids reduction is generally not as good as anaerobic digestion.

Limitations - High operating costs (primarily to supply oxygen) make the process less competitive at large plants. The required stabilization time is highly temperature sensitive, and aerobic stabilization may require excessive periods in cold areas or will require sludge heating, further increasing its cost. No useful by-products, such as methane, are produced. The process efficiency also varies according to sludge age, and sludge characteristics, and pilot work should be conducted prior to design. Improvement in dewaterability frequently does not occur.

Typical Equipment/No. of Mfrs. (23) - Sludge handling and control/32; Pumps/34; Mixers/26; Aeration equipment/30.

Performance

	Influent	Effluent	Reduction
Total solids	2 - 7%	3 - 12%	-
Volatile solids	50 - 80% of above		30 - 70% (typical 35 - 45%)
Pathogens			Up to 85%

Physical Chemical and Biological Aids- pH adjustment may be necessary. Depending on the buffering capacity of the system, the pH may drop below 6 at long detention times, and although this may not inhibit the process over long periods, alkaline additions may be made to raise the pH to neutral.

Residuals Generated - Supernatant Typical Quality: SS 100 to 12,000 mg/l, BOD_5 50 to 1700 mg/l, soluble BOD_5 4 to 200 mg/l, COD 200 to 8000 mg/l, Kjeldahl N 10 to 400 mg/l, Total P 20 to 250 mg/l, Soluble P 2 to 60 mg/l, pH 5.5 to 7.7. Digested sludge.

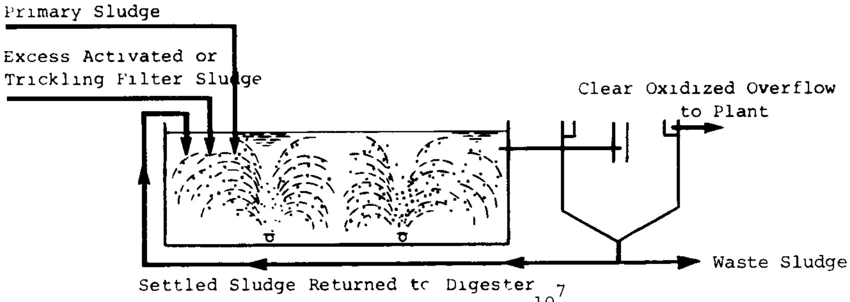
Design Criteria - Solids retention time (SRT) required for 40% VSS reduction: 18 to 20 days at $20^\circ C$ for mixed sludges from AS or TF plant, 10 to 16 days for waste activated sludge only, 16 to 18 days average for activated sludge from plants without primary settling; volume allowance: 3 to 4 ft^3/capita; VSS loading: 0.02 to 0.4 $lb/ft^3/d$; air requirements, 20 to 60 $ft^3/min/1000\ ft^3$; minimum DO: 1 to 2 mg/l; energy for mechanical mixing: 0.75 to 1.25 hp/1000 ft^3; oxygen requirements: 2 lb/lb of cell tissue destroyed (includes nitrification demand), 1.6 to 1.9 lb/lb of BOD removed in primary sludge.

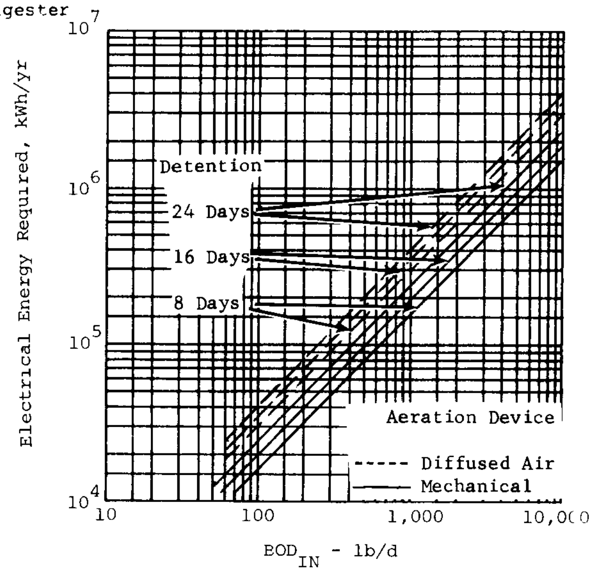
Reliability - Less sensitive to environmental factors than anaerobic digestion. Requires less laboratory control and daily maintenance. Relatively resistant to variations in loading, pH and metals interference. Lower temperatures require much longer detention times to achieve a fixed level of VSS reduction. However, performance loss does not necessarily cause an odorous product. Maintenance of the DO at 1 to 2 mg/l with adequate detention results in a sludge that is often easier to dewater (except on vacuum filters).

Environmental Impact - The supernatant stream is returned to head of plant with high organic loadings. Sludge stabilization reduces the adverse impact of land disposal of sludge. Process has high power requirements. Odor controls may be required.

References - 3, 5, 7, 8, 10, 23, 26, 111, 119

FLOW DIAGRAM





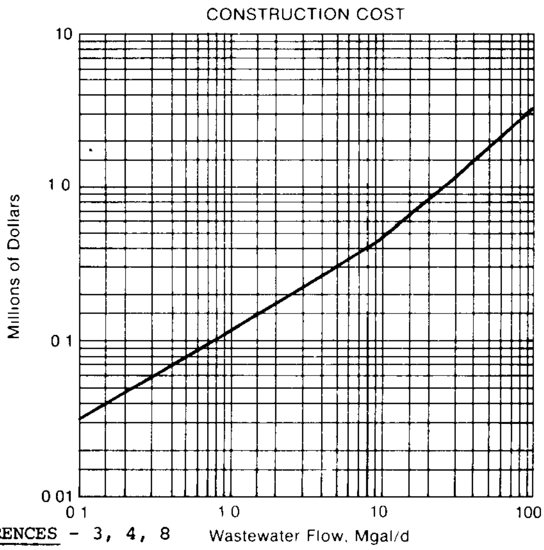
ENERGY NOTES - Assumptions:

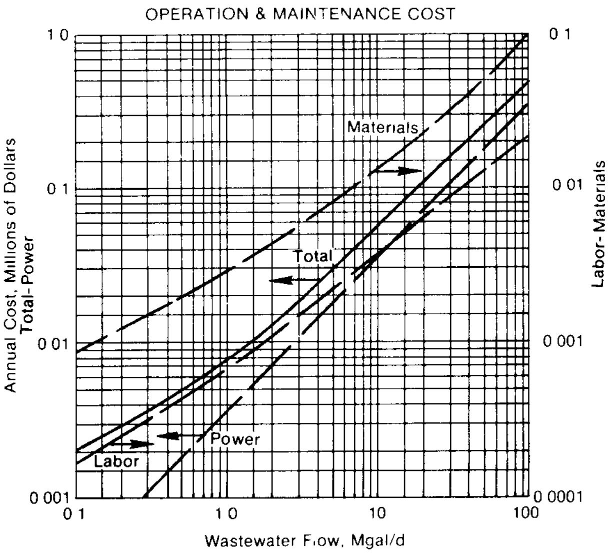
1. Energy based on oxygen supply requirements; mixing assumed to be satisfied.
2. Mechanical aeration based on 1.5 pounds O_2 transfer/hph.
3. Diffused aeration based on 0.9 pounds O_2 transfer/hph.
4. Sludge temperature 20°C.
5. Oxygen requirements for nitrification not included.

COSTS* - Assumptions: ENR Index = 2475

1. Construction costs include basins (20 d detention time), sludge flow = 5,700 gal/Mgal (1900 lb/Mgal at 4 percent), and floating mechanical aerators.
2. Mixing requirement: 134 hp/Mgal sludge; oxygen requirements: 1.6 lb O_2/lb VSS destroyed (nitrification not included).
3. Adjustment Factor: To adjust costs for design factors different from those above, enter curves at effective flow (Q_E).

$$Q_E = Q_{DESIGN} \times \frac{\text{New Design Retention Time}}{\text{20 days}} \times \frac{\text{New Design Sludge Mass}}{\text{1,900 lb/Mgal}} \times \frac{\text{4 percent}}{\text{New Design Sludge Concentration}}$$





REFERENCES - 3, 4, 8

*To convert construction cost to capital cost see Table A-2.

DIGESTION, AUTOTHERMAL THERMOPHILIC AEROBIC (AIR) — FACT SHEET 6.4.2

Description - Autothermal thermophlic aerobic digestion using air is a form of aerobic digestion (See Fact Sheets 6.4.1 and 6.4.3) that operates in the thermophilic temperature range (greater than 45°C) using air as the source of oxygen to aerate the sludge. The operation is autothermal; that is, the heat required for the increase in temperature is supplied completely from the exothermic breakdown of organic and cellular material occurring during aerobic digestion. The increased temperature, in turn, reduces the required retention time for a given amount of solids reduction. The digester tanks are covered and insulated to minimize heat losses from the system.

Common Modifications - Use of oxygen in place of air (See Fact Sheet 6.4.3).

Technology Status - In development stage with essentially no commercial use. One full-scale unit has been operated since May 18, 1977 at the Binghamton-Johnson City, New York wastewater treatment plant, supplemented by laboratory scale batch and continuous reactor experiments. Preliminary results indicate the feasibility of this process from a technical standpoint. Additional operating experience will be required to optimize design conditions and determine the process' competitiveness with other sludge treatment processes. These studies have provided the data presented below.

Applications - Autothermal aerobic digestion can be applied to sludges with solids concentrations of 1.5 percent or greater. More dilute sludges will not reach thermophilic temperatures without supplemental heat. The high temperatures reached in the digester may result in virtually complete destruction of pathogens and eliminate the need for further disinfection. Thermophilic conditions can be reached in most climates and will require a much shorter retention time than unheated aerobic digestion or anaerobic digestion. At temperatures above 50°C, a high degree of digestion and of solids removal can be achieved with less than 8 days' retention. The high temperatures also decrease oxygen requirements because of the inhibition of nitrification. In general, aerobic digestion produces a supernatant with lower organic loadings than anaerobic digestion. The process may improve the settleability and dewatering characteristics of sludge. The simplicity of operation may be suitable for use by small treatment plants. May have application in cold climates where conventional aerobic digestion is ineffective or requires excessively long detention times.

Limitations - The process is not applicable to conventional waste activated sludges (WAS) because of the large amount of heat required to raise WAS (at 0.5 percent solids) to thermophilic temperatures. The process has high operating costs, primarily to supply oxygen. The oxygen transfer efficiencies required to maintain thermophilic conditions with air may be as high as 15 percent, to avoid losing too much heat through the exhaust air. No useful by-products such as methane are produced. The economic data for this process is not well developed, and it is not clear whether the process is competitive with other digestion processes.

Typical Equipment/No. of Mfrs. (23) - Sludge handling and control/32; pumps/34, mixers/26; aeration equipment/30. To achieve the high oxygen transfer efficiencies required, the system used was proprietary in nature; the "Liacom System" by DeLaval, Inc., which utilized a self-aspirating aerator. The digestion tanks will require covers and jacketing to contain the heat.

Performance (143) - Based on full scale system-steady state performance. Selected parameters. 1000 ft^3 reactor.

	Retention Time	
	7.7d	5.4d
TVS loading rate ($lb/ft^3/d$)	0.17	0.26
Treatment efficiency (percent TVS removed)	37.2	22.1
pH Feed sludge	5.4	6.05
pH reactor	7.6	7.9
pH effluent	7.6	7.6
Ambient temperature	25°C	15°C
Sludge feed temperature	20°C	20°C
Reactor temperature	48°C	52°C
Oxygen transfer efficiency	8.7%	15.1%
Airflow	0.91 ft^3/s	0.78 ft^3/s Maximum
Maximum oxidation rate of sludge ($lb/ft^3/day$)	0.43 (laboratory scale data)	

Physical, Chemical and Biological Aids - Air, pH adjustment, if required, mechanical foam cutting.

Residuals Generated - Supernatant. Quality data not provided. See Fact Sheet 6.4.1 for quality of supernatant from mesophilic aerobic digestion with air, which may be similar.

Design Criteria - Temperature: 45 to 70°C; Retention Time: 2 to 10 d. Sufficient data is not available for determination of detailed design criteria.

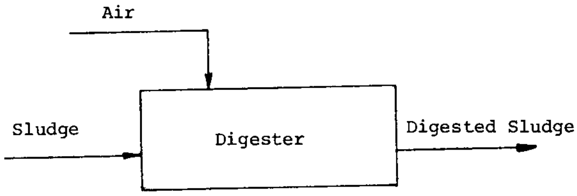
Reliability - The full-scale demonstration project indicated few problems with process or equipment reliability. During winter conditions (ambient: -20°C) the digester remained in the thermophilic range. There were no operational problems with the self-aspirating aerator system. There are indications that the aerobic digestion process is generally more stable than anaerobic digestion and more easily able to recover from extreme conditions.

Environmental Impact - The process requires less space than conventional digestion and, by stabilizing and disinfecting sludge, reduces the adverse impact of land disposal.

References - 23, 143

DIGESTION, AUTOTHERMAL THERMOPHILIC AEROBIC (AIR) FACT SHEET 6.4.2

FLOW DIAGRAM - Single Stage unit is shown. Two or more stages may be preferable with one or more stages operating in a batch mode.



ENERGY NOTES - Energy requirements for O_2 supply and mixing were approximately 3.5 kWh/h for 1000 ft^3 reactor, loaded at 130 to 210 ft^3/d. Ongoing experiments with self-aspirating aerators will provide additional information for determining the energy requirements for air supply and mixing.

COSTS - No cost data for the existing demonstration unit have been developed. However, a single stage digester utilizing thermophilic aerobic digestion will require approximately 60 percent less volume than a mesophilic aerobic digester, but will require insulation and a cover. Other equipment will be similar to that of aerobic digestion (See Fact Sheet 6.4.1). No information on other operating costs is available.

REFERENCES - 143, 147

DIGESTION, AUTOTHERMAL THERMOPHILIC (OXYGEN) — FACT SHEET 6.4.3

Description - Autothermal thermophilic oxygen digestion using oxygen is a form of aerobic digestion (see Fact Sheet 6.4.1) that operates in the thermophilic (more than 45°C) temperature range and utilizes pure oxygen instead of air to aerate the sludge. The operation is autothermal; that is, the heat required for the increase in temperature is supplied completely from the exothermic breakdown of organic and cellular material occurring during aerobic digestion. The increased temperatures, in turn, reduce the required retention times in the digesters to achieve a given amount of SS reduction. The digester tanks are covered to minimize heat losses from the system. Heat losses are also reduced in pure oxygen systems because there is little exhaust gas to remove the heat generated by the process. The equipment for pure oxygen thermophilic aerobic digestion is similar to that of aerobic digestion (Fact Sheet 6.4.1) with the addition of digester covers and an oxygen generator.

Technology Status - Still in development stage with essentially no commercial use. Pilot plant tests have been completed. Two preliminary full scale studies (Denver, Colorado and Speedway, Indiana) have been conducted using pure oxygen aerobic digestion. Both achieved a significant temperature increase in the digester, but both operated in the mesophilic temperature range. Data presented on this process for thermophilic conditions are largely from pilot studies by Union Carbide (138). Several units are in design or construction phase, and additional data will be forthcoming.

Applications - May have greatest applications where pure oxygen activated sludge processes are used. The high temperatures used by the process may result in virtually complete destruction of pathogens, and eliminate the need for further disinfection. In colder climates the process will have much shorter retention times than other digestion processes. At temperatures above 45°C a high degree of digestion can be obtained with less than five days retention. The high temperatures decrease oxygen requirements because of the inhibition of nitrification. In general, aerobic digestion produces a supernatant with lower organic loadings than anaerobic digestion. The danger of methane explosions is also reduced.

Limitations - May not be applicable to conventional unthickened waste activated sludges because of the large amount of heat required to raise WAS (at 0.5 percent solids) to thermophilic temperatures. The process has high operating costs (primarily to supply oxygen). No useful by-products such as methane are produced. Oxygen aerobic digestion in the mesophilic temperature range does not appear to be cost effective, but in the thermophilic range the reduced O_2 requirements and smaller reactor volume may enable the process to be competitive with other forms of digestion, particularly when a pathogen-free sludge is desired.

Typical Equipment/No. of Mfrs. (23) - Sludge handling and control/32; pumps/34, mixers/26; aeration equipment/30; oxygen generators/1.

Performance (138) - Pilot plant results:

Single Stage System	Phase I	Phase IA	Phase II	Phase III
Sludge Description	O_2 step feed	O_2 step feed	O_2 activated sludge	primary + O_2 AS
Temperature (°C)	14 - 18	17 - 19	17.4 - 22	16 - 22
pH	6.0 - 6.3	5.9 - 6.4	5.9 - 6.4	5.5 - 6.1
TSS (mg/l)	25,000 - 33,000	30,000 - 34,000	25,000 - 40,000	-
VSS (mg/l)	21,000 - 27,000	22,000 - 27,000	20,000 - 30,000	-
TS (mg/l)	-	-	-	30,000 - 49,000
TVS (mg/l)	-	-	-	22,000 - 35,000
Retention time (days)	4.2	4.2	4.2	4.0
Digester temperature (°C)	47.3	46.4	50.4	50.2
VSS loading rate ($lb/ft^3/d$)	0.36	0.38	0.37	0.45
VSS reduction (percent)	37	30	40	30

Two Stage System - (multiple test runs combined)

	O_2 Waste Activated Sludge	Primary plus Secondary Sludge
Temperature (°C)	12 - 24	12 - 30
pH	5.9 - 6.9	6.0 - 6.6
TS (mg/l)	26,000 - 50,000	23,000 - 60,000
TVS (mg/l)	18,000 - 38,000	18,000 - 41,000
Retention time (days)	3.7 - 5.0	3 - 5
Digester temperature (°C)	48.7 - 57.8	45.3 - 52.0
VS loading rate ($lb/ft^3/d$)	0.32 - 0.46	0.38 - 0.53
Overall VSS reduction (percent)	29 - 42	30 - 45

Physical, Chemical and Biological Aids - pH adjustment if necessary

Residuals Generated - Supernatant. Quality similar to that of aerobic digestion with air (Fact Sheet 6.4.1).

Design Criteria - Single or two stage systems: Retention time - five days or less, temperature 45 to 60°C. Additional operating results are necessary to develop firm design criteria.

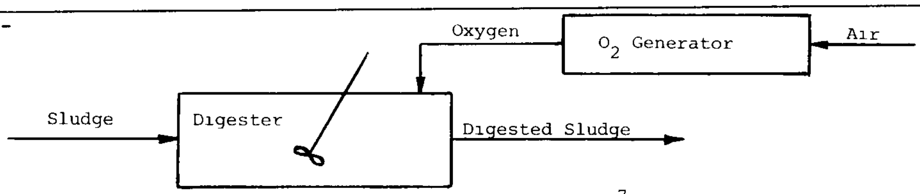
Reliability - Process appears stable and more easily able to recover from extremes than anaerobic digestion.

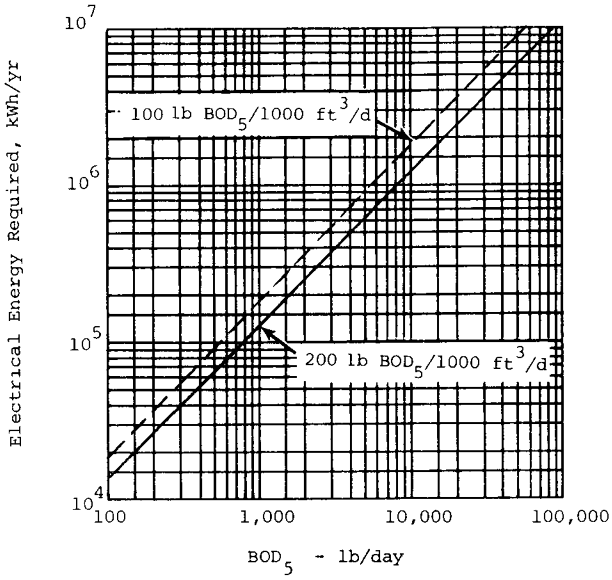
Environmental Impact - Process requires less space than conventional digestion, and by stabilizing and disinfecting sludge reduces adverse impact of land disposal.

References - 23, 119, 138

DIGESTION, AUTOTHERMAL THERMOPHILIC (OXYGEN) FACT SHEET 6.4.3

FLOW DIAGRAM -





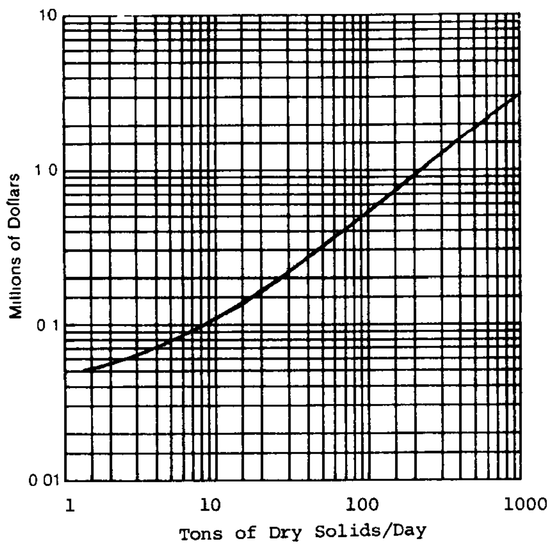
ENERGY NOTES - Assumptions:

1. Mixing requirements: 1.5 hp/1000 ft^3
2. 4.2 lb O_2/hph for cryogenic O_2 generation.
3. No fuel for heating is supplied; process is autothermal.
4. Sludge pumping energy not included.

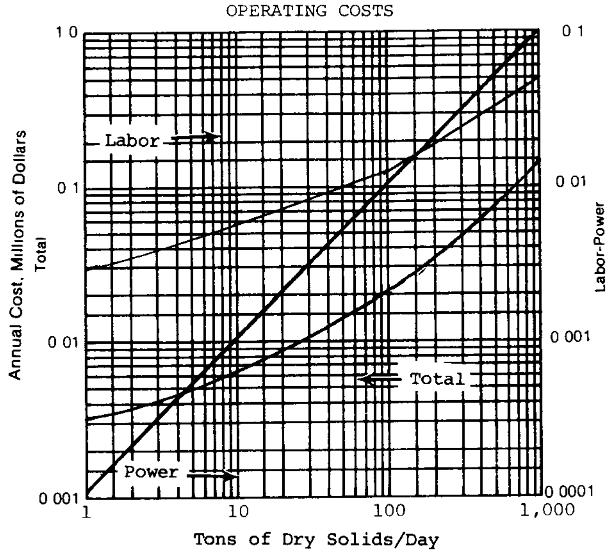
COSTS* - Assumptions: 1973 dollars; ENR = 1895.

1. Based on Speedway, Indiana results. The conditions shown vary somewhat from recommended design criteria which are based on laboratory data.
2. Design Basis - Retention time, 10 d; VSS, 21,000 mg/l; sludge solids, 3.3 percent; mixing requirements, 0.12 hp/1000 gal; electricity @ \$.02/kWh.
3. Construction costs include oxygen generators, digesters, mixers, oxygen dissolution equipment and instrumentation.
4. For plants below 1 Mgal/d, on-site generation of oxygen is not recommended. Purchase of liquid oxygen results in lower capital costs but higher operating costs.

CONSTRUCTION COSTS



OPERATING COSTS



REFERENCE - 119

*To convert construction cost to capital cost see Table A-2.

DIGESTION, TWO STAGE ANAEROBIC — FACT SHEET 6.4.4

Description - A two vessel system of sludge stabilization, where the first tank is used for digestion and is equipped with one or more of the following: heater, sludge recirculation pumps, methane gas recirculation, mixers and scum breaking mechanisms. The second tank is used for storage and concentration of digested sludge and for formation of a supernatant. Anaerobic digestion results in the breakdown of the sludge into methane, carbon dioxide, unusable intermediate organics and a relatively small amount of cellular protoplasm. This process consists of two distinct simultaneous stages of conversion of organic material by acid forming bacteria and gasification of the organic acids by methane forming bacteria. The methane producing bacteria are very sensitive to conditions of their environment and require careful control of temperature, pH, excess concentrations of soluble salts, metal cations, oxidizing compounds and volatile acids. They also show an extreme substrate specificity. Can operate at various loading rates and is therefore not always clearly defined as either standard or high rate. Digester requires periodic cleanout (from 1 to 2 years) due to buildup of sand and gravel on digester bottom.

Technology Status - Widespread use (60 to 70 percent) for primary or primary and secondary sludge in plants having a capacity of 1 Mgal/d or more.

Applications - Suitable for primary sludge or combinations of primary sludge and limited amounts of secondary sludges. Digested sludge is reduced in volume and pathogenic organism content, is less odorous and easily dewatered, and is suitable for ultimate disposal. Advantages over single stage digestion include increased gas production, a clearer supernatant liquor, necessity for heating a smaller primary tank thus economizing in heat, and more complete digestion. Process also lends itself to modification changes, such as to high-rate digestion.

Limitations - Is relatively expensive, about twice the capital cost of single-stage digestion. It is the most sensitive operation in the POTW and is subject to upsets by interfering substances, e.g., excessive quantities of heavy metals, sulfides, chlorinated hydrocarbons. The addition of activated and advanced waste treatment sludges can cause high operating costs and poor plant efficiencies. The additional solids do not readily settle after digestion. Digester requires periodic cleanout due to buildup of sand and gravel on digester bottom.

Typical Equipment/No. of Mfrs. - Sludge handling and control/32, pumps/34, heating equipment/7, digestion tank equipment/18, gas holders/6.

Performance -	Influent	Effluent	Reduction
Total Solids	2 to 7%	2.5 to 12%	33 to 58%
Volatile Solids			35 to 50%
Pathogen			85 to less than 100%
Odor Reduction			--

Sidestream - Gas Production

Quantity - 8 to 12 ft^3/lb volatile solids added, or 12 to 18 ft^3/lb volatile solids destroyed or 0.6 to 1.25 ft^3/cap, or 11 to 12 ft^3/lb total solids digested.

Quality - 65 to 70% methane N_2, H_2, H_2S, NH_3, et al - trace 25 to 30% CO_2 550 to 600 Btu/ft^3

Physical, Chemical and Biological Aids - Heat; maintain pH with lime, also ammonia, soda ash, bicarbonate of soda, and lye are used; addition of powder activated carbon may improve stability of overstressed digesters; precipitate heavy metals with ferrous or ferric sulfate; control odors with hydrogen peroxide.

Residuals Generated -
Supernatant - Quality: SS 200-15,000 mg/l, BOD_5 500-10,000 mg/l, COD 1,000-30,000 mg/l, TKN 300-1,000 mg/l, Total P (50-1,000 mg/l), scum, sludge, gas.

Design Criteria - Solids Retention Times (SRT) required at various temperatures (22)

	Mesophilic Range				
Temperature, ^{o}F	50	67	75	85	95
SRT, days	55	40	30	25	20

Volume Criteria, (ft^3/capita): Primary sludge 1.3-3, Primary and Trickling Filter Sludges 2.6-5, Primary and Waste Activated Sludges 2.6-6. Tank Size (ft): diameter, 20-115; depth, 25-45; bottom slope 1 vertical/4 horizontal. Solids Loading (lb vss/ft^3/d): 0.04-0.40. Volumetric Loading (ft^3/cap/d): 0.038-0.1. Wet Sludge Loading (lb /cap/d): 0.12-0.19. pH 6.7-7.6.

Overall Reliability - Successful operation subject to a variety of physical, chemical and biological phenomena, e.g., pH, alkalinity, temperature, concentrations of toxic substances of digester contents. Sludge digester biomass is relatively intolerant to changing environmental conditions. Under one set of conditions particular concentrations of a substance can cause upsets, while under another set of conditions higher concentrations of the same substance are harmless. Requires careful monitoring of pH, gas production, and volatile acids.

Environmental Impact - Return of supernatant to head of plant, may cause plant upsets. The adverse environmental impact of sludge disposal on land is reduced as a result of the process.

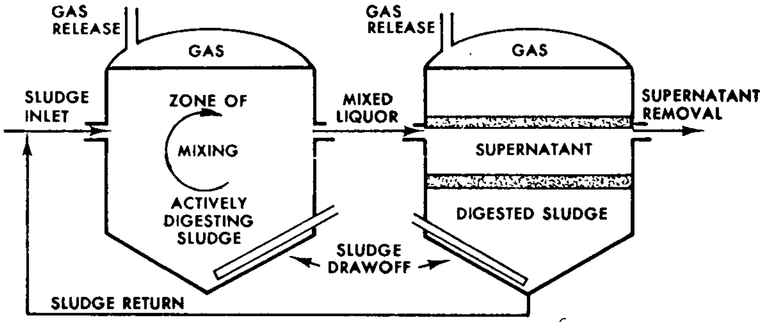
Miscellaneous Information - Digester gas can be used for on-site generation of electricity and/or for any in-plant purpose requiring fuel. Can also be used off-site in a natural gas supply system. Off-site use usually requires treatment to remove impurities such as hydrogen sulfide and moisture. Removal of CO_2 further increases the heat value of the gas. Utilization is more successful when a gas holder is provided.

References - 7, 8, 10, 20, 22, 94

DIGESTION, TWO STAGE ANAEROBIC

FACT SHEET 6.4.4

FLOW DIAGRAM



ENERGY NOTES (4) - Assumptions: Energy is required to heat incoming sludge to digester temperature:

Btu = (lb of influent sludge)(C)(T(°F))

C = specific heat of sludge, 1.0 Btu/lb/°F for 1-10% solids sludge.

Energy is required to compensate for heat losses during the digestion period:

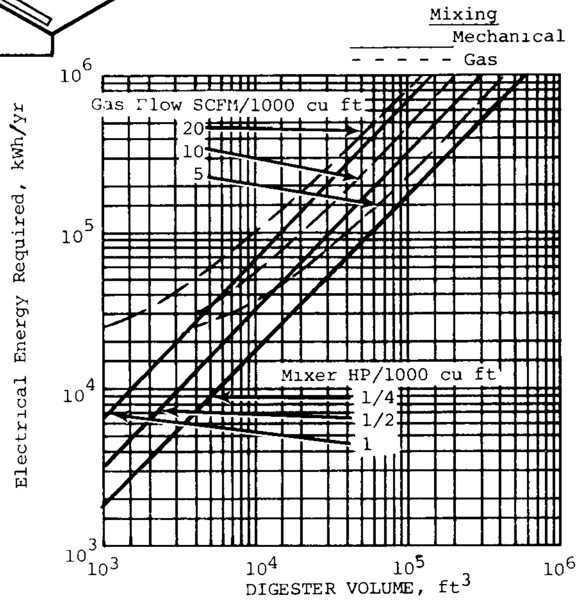
Btu/1000 ft^3 of contents = 2,600/hr

Correction factor for geographical location: Northern U.S. 1.0, Middle U.S. 0.5, Southern U.S. 0.3.

Energy is generated from gas production (based on plant flow):

	Primary Sludge	WAS	Total
Gas Produced, scf/Mgal	5,175	5,670	10,845
Heat Available, MBtu/Mgal	3.1	3.4	6.5

Electrical energy is required for mixing (graph), assuming continuous operation, 20 ft. submergence for release of gas, motor efficiency 85-93%.

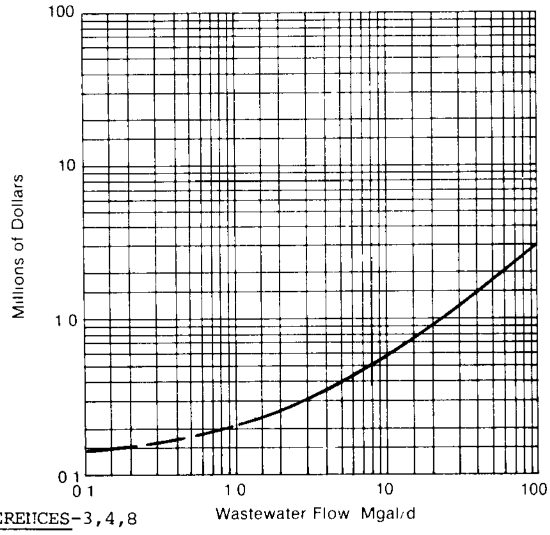


COSTS*(3) (1976 dollars) - Assumptions:

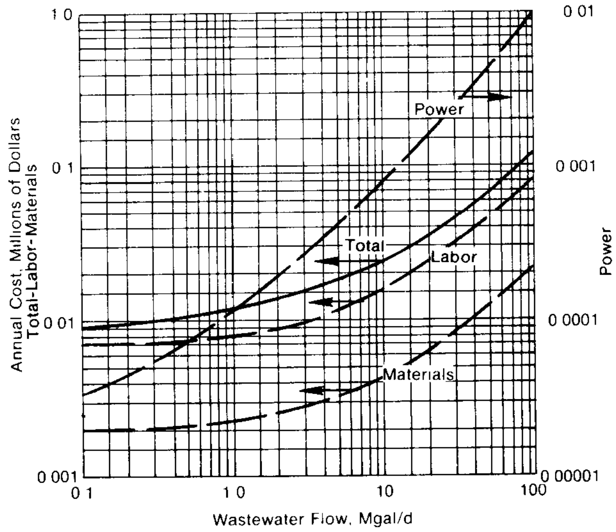
1. Service life is 50 years.
2. Includes digester, heat-exchanger, gas-collection equipment, control building.
3. Feed to digesters is combined primary and secondary and is thickened to 1,900 lb/Mgal at 4% solids (75% volatile); effluent from digesters is 900 lb/Mgal at 2.5% solids; loading rate - 0.16 lb/ft^3/d; operating temperature - 85 to 110°F; digester gas is utilized for heating, excess is not utilized.
4. Power costs = $.02/kWh
5. To adjust costs for loading rates different than those presented here, enter curve at effective flow (Q_E).

$$Q_E = Q_{DESIGN} \times \frac{\text{New Design Sludge Mass}}{1,900 \text{ lb/Mgal}}$$

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES-3,4,8

*To convert construction cost to capital cost see Table A-2.

DIGESTION, TWO STAGE THERMOPHILIC ANAEROBIC — FACT SHEET 6.4.5

Description - Digestion is a fermentation process in which several groups of anaerobic and facultative organisms assimilate and break down organic matter into primarily CO_2 and methane. The process takes place in two tanks in series; the first for digestion and the second for storage and concentration of sludge and formation of a supernatant. Thermophilic digestion operates at a temperature of approximately 46 to 57°C (115 to 135°F). The methane-producing bacteria essentially control the process and are very sensitive to pH, excess concentrations of soluble salts, metal cations, temperature, and substrate concentration. For additional details on anaerobic digestion see Fact Sheet 6.4.4.

Technology Status - Full-scale studies of thermophilic digestion are in progress at the Hyperion plant (Los Angeles, California) and serve as the basis for the data presented.

Applications - Thermophilic digestion may be a viable alternative to mesophilic anaerobic digestion for primary or combined primary and waste activated sludges (WAS). The high cost of heating the sludge may rule out its use on WAS alone. Thermophilic digestion enhances sludge dewaterability and methane production and achieves a greater reduction of volatile solids, and reduces polymer dosage and pathogens.

Limitations - The higher temperatures require additional heat input; however, this may be offset by higher methane production. Thermophilic bacteria are more sensitive to loading and temperature changes than mesophilic bacteria and more severe temperature limitations. Thermophilic digestion may solubilize some heavy metals, and the resulting recycle supernatant streams are higher in certain metals and in organic loadings than those from mesophilic operations. The digestion process itself is relatively expensive, and is highly sensitive to interferences such as heavy metals, sulfides and chlorinated hydrocarbons. There is some new data on thermophilic digestion as applied to WAS or a combination of WAS and primary sludge, but analysis is not complete. Thermophilic digestion requires additional operator expertise and attention because of process sensitivities.

Typical Equipment/No. of Mfrs. (23) - Physically similar to conventional anaerobic digestion. Sludge handling and control/32; pumps/34; heating equipment for digestors/7; digestion tank equipment/18; gas holders/6.

Performance (124) -

	Influent	Effluent	Reduction	Notes
Total Solids (percent)	6.1	2.1	66%	Includes reductions from dilution
Volatile Solids (Percent)	78	65	70%	with steam used to heat sludge.
pH	5.1	7.6		
Alkalinity (mg/l)	1600	4100		
Temperature, °F	77°	120°		

Other: Gas production 12.7 ft^3/lb VS added; gas quality 63 percent methane; volatile solids in sludge 600 mg/l; detention time 18.2 days. Salmonella and virus removals are greatly increased over mesophilic digesters, but ascaris removals were negligible in both cases.

Effect of thermophilic digestion on dewatering (124):

Dewatering Method	Feed Rate	Chemical Dosage (lb/ton)	Solids Capture (Percent)	Cake (Percent) Solids)	Centrate SS (mg/l)
Solid bowl centrifuge	25 gal/min	8	92	32	1100
Basket bowl centrifuge	40 gal/min	6	38	31	14,000

Physical, Chemical and Biological Aids - Heat, lime for maintaining pH, sodium bicarbonate, ammonia, soda ash, caustic, etc., nutrients to aid digestion if required, inorganic salts for metal precipitation, hydrogen peroxide for odor control, polyelectrolytes for subsequent thickening.

Residuals Generated - Data on separate supernatant stream is not available (see Fact Sheet 6.4.4 for supernatant from mesophilic range). Filtrate quality (in mg/l) SS 1000, TDS 1500, COD 2700, N(total) 1400, PO_4 700, grease 1400, copper, cadmium, zinc, nickel, chromium, all measurable at less than 1 mg/l.

Design Criteria - Solids retention times required at various temperatures (22) - 20 d at 100°F, 15 d at 110 to 130°F. Loading rate 0.1 to 0.2 lb VS/ft^3/d, pH 6.6 to 7.4, tank diameter 20 to 115 ft, center depth 25 to 45 ft, minimum bottom slope 1 vertical to 4 horizontal. Process design criteria are not fully developed and require more operating experience with various sludges and under different environmental conditions.

Overall Reliability - Limited operating data indicates a great deal of complexity of operation. The process requires a long time to achieve steady state conditions, and maintenance of these conditions is subject to a variety of physical, chemical, and biological phenomena such as pH, alkalinity, temperature, interfering substances, loadings, etc. High operator attention and monitoring required.

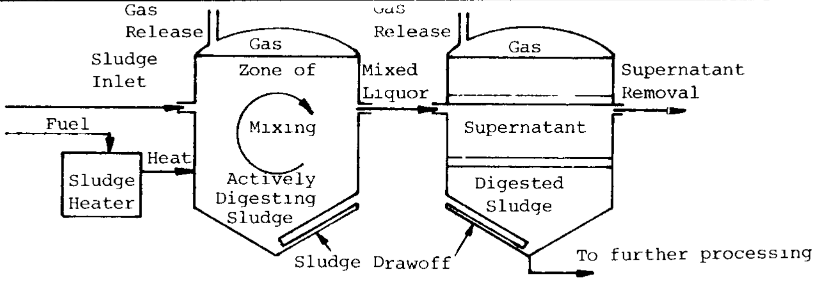
Environmental Impact - Recycle streams sent to head of plant may cause upsets. Reduced sludge generation reduces the adverse impact on the environment. Boiler blowdown and air pollutants from boiler fuel may result.

References - 7, 8, 10, 22, 23, 26, 124, 136

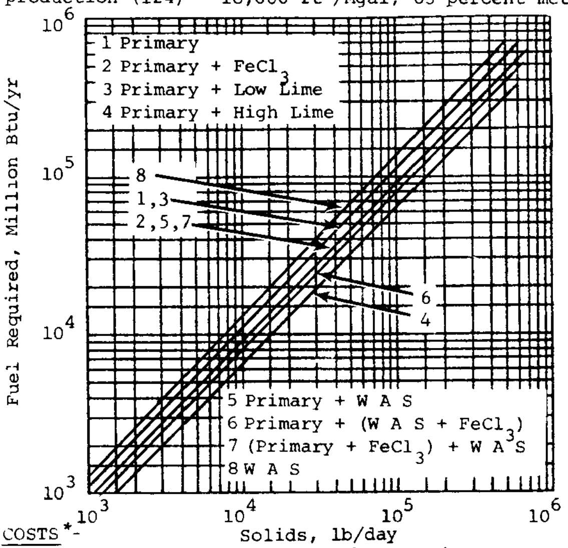
DIGESTION, TWO STAGE THERMOPHILIC ANAEROBIC

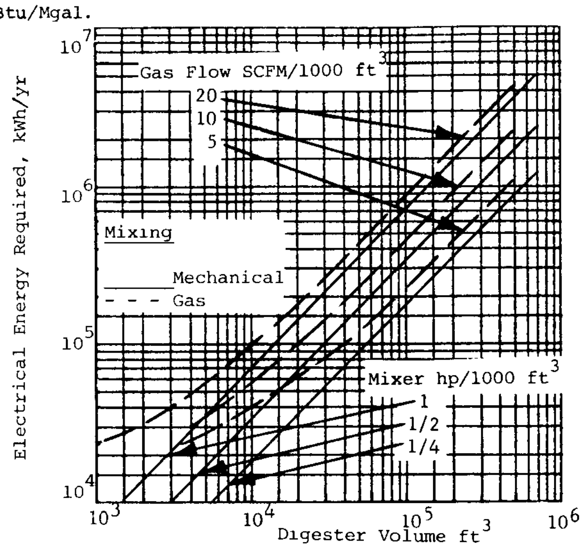
FACT SHEET 6.4.5

FLOW DIAGRAM -



ENERGY NOTES - Fuel requirements shown are for northern states. For central locations, multiply by 0.5; for southern locations, multiply by 0.3; digester temperature = 130°F; energy credits for anaerobic digester gas production (124) = 18,000 ft^3/Mgal; 63 percent methane; 6.8 MBtu/Mgal.

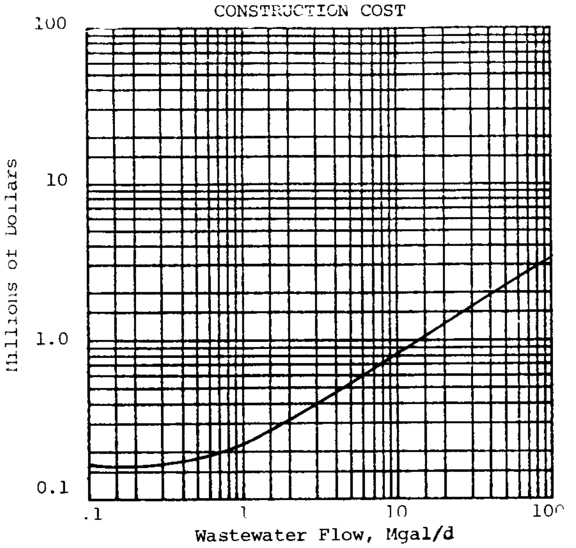


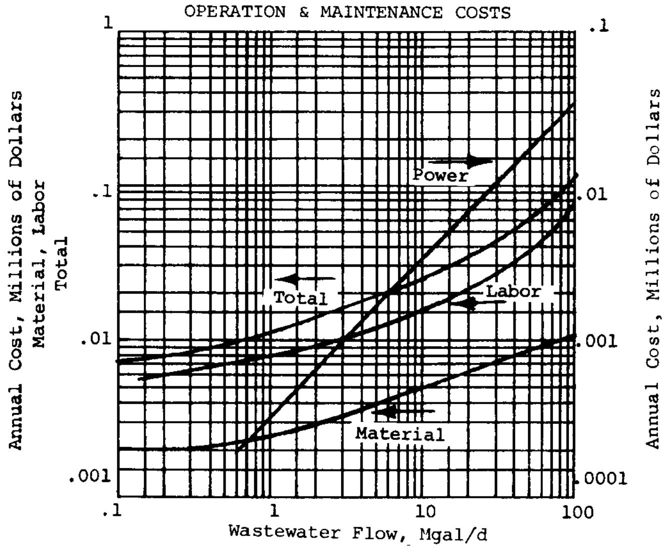


COSTS*-

1. Costs include: digester, heat-exchanger, gas-collection equipment, control building (ENR Index = 2475).
2. Feed to digesters is combined primary and is thickened feed = 1,900 lb/Mgal at 4 percent solids (75 percent volatile).
3. Effluent from digesters is 900 lb/gal; at 2.5% solids; loading rate = 0.16 lb VSS/ft^3/d; operating temperature = 130°F.
4. Adjustment Factor: To adjust costs for loading rates different than those presented here, enter curve at effective flow (Q_E).

$$Q_E = Q_{DESIGN} \times \frac{\text{New Design Sludge Mass}}{1{,}900 \text{ lb/Mgal}}$$





REFERENCES - 3, 4, 8, 124 Costs adjusted from mesophilic operation to thermophilic operation from references.

*To convert construction cost to capital cost see Table A-2.

DISINFECTION (HEAT) FACT SHEET 6.4.6

Description - Heating to pasteurization temperatures is a well known method of destroying pathogenic organisms that has been applied successfully to disinfecting sludge. Pasteurization implies heating to a specific temperature for a time period sufficient to destroy undesirable organisms in sludge and to make sludge suitable for land disposal on cropland. Usually heat is applied at 70 to 75°C for a period of 20 to 60 minutes. Treatment can be applied to raw liquid sludge (thickened or unthickened), or stabilized or digested sludge.

Pasteurization is usually a batch process, consisting of a reactor to hold sludge, a heat source, and heat exchange equipment, pumping and piping and instrumentation for automated operation. Pasteurization has little effect on sludge composition or structure because the sludge is only heated to a relatively moderate temperature.

Technology Status - Not widely used. More common in Europe than in the United States. In West Germany and Switzerland, there are regulations (actually seldom followed) that require pasteurization when sludge is spread on pastures during summer growth periods. May find increased application with the renewed interest of land disposal of sludges.

Applications (119) - Can be applied to a wide variety of sludges in various forms. Pasteurization may be redundant where sludges are treated by other processes which destroy pathogenic matter. Largest potential application is to otherwise untreated sludges which are disposed of on land. Studies show that liquid sludge need only be cooled to 60°C for application to land with no adverse effects from temperature. Small treatment plants can pasteurize liquid digested sludge in a tank truck with steam injection.

Limitations - Pasteurization has little or no effect on metals or other toxic materials. Pasteurized but undigested sludges still have considerable risk of foul smelling fermentation after land applications. Limited data is available on interferences and other process controls required for optimizing the process. Heating unthickened sludge requires excessive amounts of heat. Because of the low temperatures involved, heat recovery is not cost effective unless the sludge flow is at least 50,000 gal/d. At this level, one-stage heat recuperation may be cost effective. Two stage recuperation is not cost effective until a flow of over 100,000 gal/d of sludge is reached.

Typical Equipment/No. of Mfrs. (23) - Sludge handling and control/32; Heating equipment/7; Instrumentation/9.

Performance (111,119) - Seventy-five degrees Centigrade for 60 minutes will reduce coliform indicators below 1,000 counts per 100 ml. Seventy degrees Centigrade for 30 to 60 minutes is effective for destroying pathogens in digested sludge. Seventy degrees Centigrade for 20 minutes is effective for destroying pathogens in raw sludge. Heat treatment also appears to destroy viruses. The table below indicates the time required for 100 percent elimination of various typical pathogenic organisms found in sludge at various temperatures:

	Temperature °C				
Organism	50	55	60	65	70
Time Required for 100% Reduction (minutes)					
Cysts of Entamoeba histolytica	5				
Eggs of Ascaris lumbricoides	60	7			
Brucella abortus		60		3	
Corynebacterium diphtheriae		45			4
Salmonella typhosa			30		4
Escherichia coli			60		5
Micrococcus pyrogene var. aureus					20
Mycobacterium tuberculosis var.					20
Viruses					25

See Reference 119 for detailed experimental data on destruction of pathogens as a function of time and temperature.

Physical, Chemical and Biological Aids - Heat, typical boiler feedwater pretreatment chemicals (scale and/or corrosion).

Residuals Generated - Boiler blowdown, air pollution from the boiler.

Design Criteria - Temperature 70 to 75°C; time 20 to 60 minutes; heat required 4-6 x 10^6 Btu/ton of sludge solids. Two units or more are usually designed in parallel so one unit can be filling while the other is holding sludge for the required length of time. Units can share a common boiler.

Unit Process Reliability - Mechanical and process reliability high. Pasteurization can be fully automated and requires minimum operator attention. There is little operating experience in the United States.

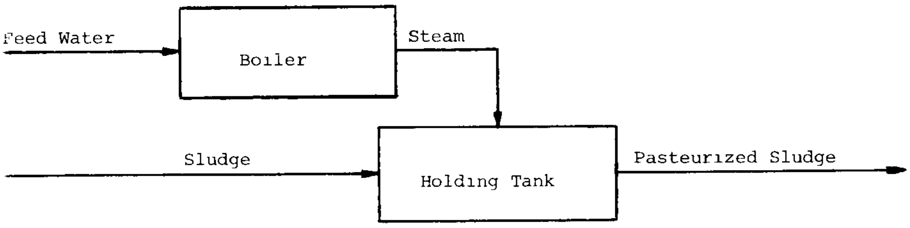
Environmental Impact - Reduces the adverse impact of sludge disposal to cropland. If steam injection is used to heat the sludge, chemicals used for feedwater pretreatment must be acceptable for land spreading of sludge.

Miscellaneous Information - Digested sludge heat can reduce the need for supplemental energy. Methane from anaerobic digestion can provide the required fuel for pasteurization.

References - 8, 23, 111, 119

DISINFECTION (HEAT) FACT SHEET 6.4.6

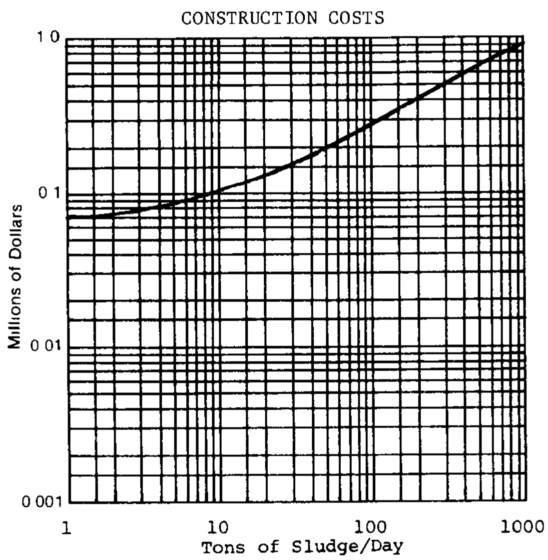
FLOW DIAGRAM -

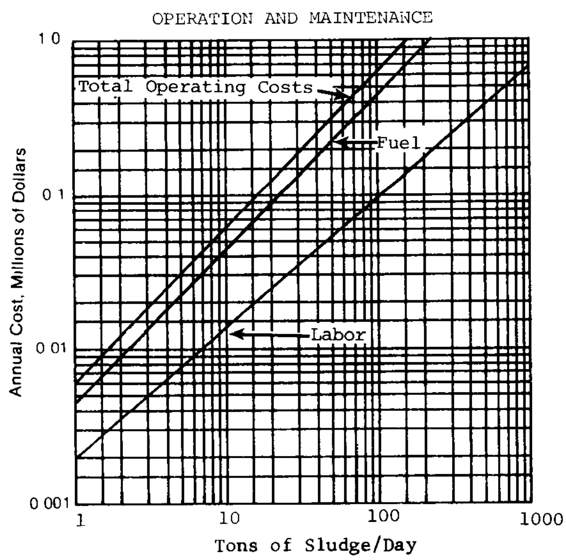


ENERGY NOTES - Fuel requirements for heating (119); 4.6 X 10^6 Btu/ton of sludge (assuming 5 percent solids and 53° temperature rise requirement). At 250 tons/d or more, heat recovery may reduce the fuel requirement; anaerobic digesters could provide this energy. Electrical requirements. Approximately 14 kWh/ton of sludge for pumps and mixing.

COSTS* (1978) - Assumptions: ENR Index = 2776

1. Design Basis: Sludge temperature, 17°C; sludge solids, 5 percent; pasteurization temperature, 70°C; pasteurization time, 1 h.
2. Construction cost includes: steam boiler, pasteurization tanks, sludge pumping and automatic controls.
3. Single tank up to 10 tons of sludge solids per day; two tanks above.
4. Labor was estimated at $6/ton of sludge solids for small plants, decreasing to $2/ton of sludge solids for very large plants.
5. Fuel, $2.80/MBtu.





REFERENCES - 111, 119

*To convert construction cost to capital cost see Table A-2.

HEAT TREATMENT OF SLUDGE

FACT SHEET 6.4.7

Description and Common Modifications - The heat treatment process involves heating sludge to 144 to 210°C for short periods of time under pressure of 150 to 400 lb/in^{2}g. It is essentially a conditioning process which prepares sludge for dewatering on vacuum filters or filter presses without the use of chemicals. In addition, the sludge is sterilized and generally stabilized and rendered inoffensive. Heat treatment results in coagulation of solids, a breakdown in the cell structure of sludge and a reduction of the water affinity of sludge solids.

Several proprietary variations exist for heat treatment. In these systems, sludge is passed through a heat exchanger into a reactor vessel, where steam is injected directly into the sludge to bring the temperature and pressure into the necessary ranges. In one variation air is also injected into the reactor vessel with the sludge. The detention time in the reactor is approximately 30 minutes. After heat treatment, the sludge passes back through the heat exchanger to recover heat, and then is discharged to a thickener-decant tank. The thickened sludge may be dewatered by filtration or centrifugation to a solids content of 30 to 50 percent. The sludge may be ground prior to heat treatment.

Technology Status - The process of heat treating sludge was first introduced in 1935, but has only become common during the last decade. About 100 units are currently in operation in the United States.

Applications - Heat treatment is practiced as a sludge conditioning method to reduce the costs of sludge dewatering and ultimate disposal. The benefits of heat treatment include: (1) Improved dewatering characteristics of treated sludge without chemical conditioning; (2) Generally innocuous and sterilized sludge suitable for ultimate disposal by a variety of methods including land application in some cases; (3) few nuisance problems, (4) suitable for many types of sludge which cannot be stabilized biologically; (5) reduction in subsequent incineration energy requirements; and (6) reduction in size of subsequent vacuum filters and incinerators.

Limitations - The process has very high capital and operating costs, and may not be economical at small treatment plants. Specialized supervision and maintenance are required due to the high temperatures and pressures involved. Expensive material costs are necessary to prevent corrosion and withstand the operating conditions. Heavy metal concentrations in sludges are not reduced by heat treatment and further treatment of sludges with high metals concentrations may be required if the sludge is to be applied to crop land. The sludge supernatant and filtrate recycle liquor are strongly colored and contain a very high concentration of soluble organic compounds and ammonia nitrogen, and in some cases must be pretreated prior to return to the head of the treatment plant.

Typical Equipment/No. of Mfrs. - Complete heat treatment systems are generally proprietary, and the most common systems are supplied by five manufacturers. The major equipment common to these processes are grinders, sludge feed pumps and handling equipment, heat exchangers, reactors, boilers, and separators.

Performance - Heat treatment is a conditioning process, and is intended to enhance the performance of subsequent operations. Within the process itself pathogens are destroyed and 30 to 40 percent of the VSS are solubilized. Dewatering efficiency can be increased to a solids capture of over 95 percent and a solids content of up to 50 percent.

Physical, Chemical and Biological Aids - Heat; Chemicals for dewatering are not normally required. Corrosion control aids may be required for the boiler and/or the process.

Residuals Generated - Sidestream (recycle liquor) 50 percent of sludge flow (by volume); quality - BOD, 5,000 to 15,000 mg/l; COD, 10,000 to 30,000 mg/l; NH_3-N, 500 to 800 mg/l; P, 140 to 250 mg/l; TSS, 9,000 to 12,000 mg/l; VSS, 8,000 to 10,000 mg/l; pH, 4 to 6.

This stream is generally amenable to biological treatment but can contribute up to 30 to 50 percent of the organic loading to a treatment plant. If the plant has not been designed for this additional load, pretreatment prior to return may be necessary. Some non-condensable gases may be generated which will require combustion or disposal. Boiler blowdown and/or water treatment residuals (for boiler feedwater) may result.

Design Criteria - Temperature 140 to 210°C, pressure 150 to 400 lb/in^{2}g, detention time 30 to 90 minutes, steam consumption 600 lb/1000 gal of sludge.

Overall Reliability - Limited operating data is available. Mechanical and process reliability appear adequate after some initial operational problems. Careful operator attention is required.

Environmental Impact - Recycle liquor sent to head of plant can cause plant upsets due to very high organic loadings. The process can result in offensive odor production if proper odor control is not practiced. A colored effluent may also result, requiring additional processing where discharge standards prohibit this condition.

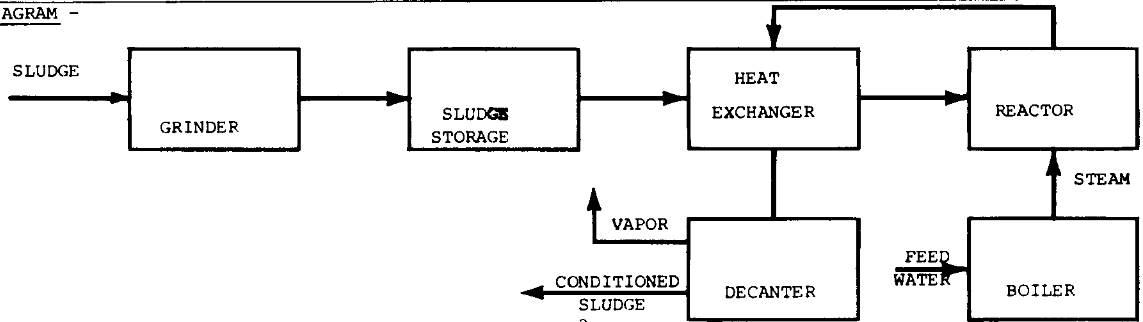
Miscellaneous Information - The composition of the recycle liquor can vary among the various processes. Some liquors may contain a high proportion of non-biodegradable matter. This matter is largely humic acids, which can give rise to unpleasant odors and taste if present in water which has been chlorinated prior to use for domestic supply. If industrial wastes of various types are included in the wastewater to be treated, the actual chemical composition of the liquor resulting from heat treatment of the sludge should be determined by a detailed chemical analysis. A possible treatment process for a highly polluted liquor can consist of filtration, aeration and activated carbon adsorption for non-biodegradable organics.

References - 3, 7, 8, 26, 31, 95, 111, 199

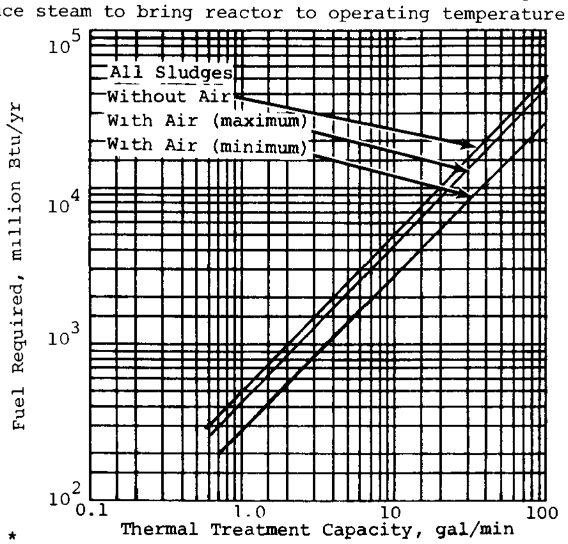
HEAT TREATMENT OF SLUDGE

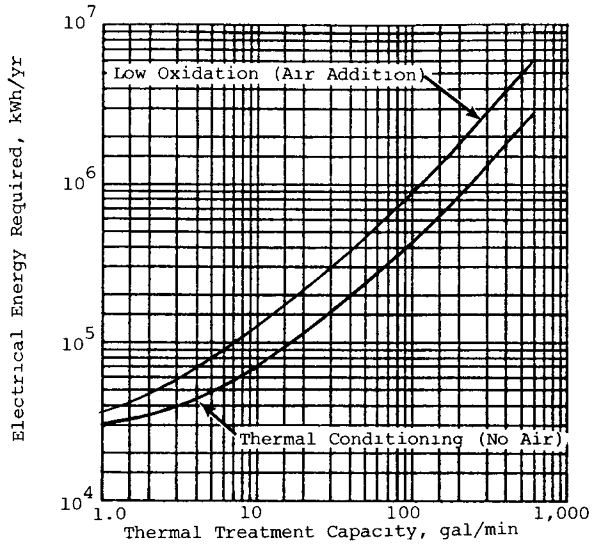
FACT SHEET 6.4.7

FLOW DIAGRAM -



ENERGY NOTES - Assumptions: Reactor Conditions; 300 lb/in^{2}g at 350°F; Heat exchangers T = 50°F; continuous operation; electrical includes all pumping, grinding, air compressing and post thickening drives; fuel is to produce steam to bring reactor to operating temperature.



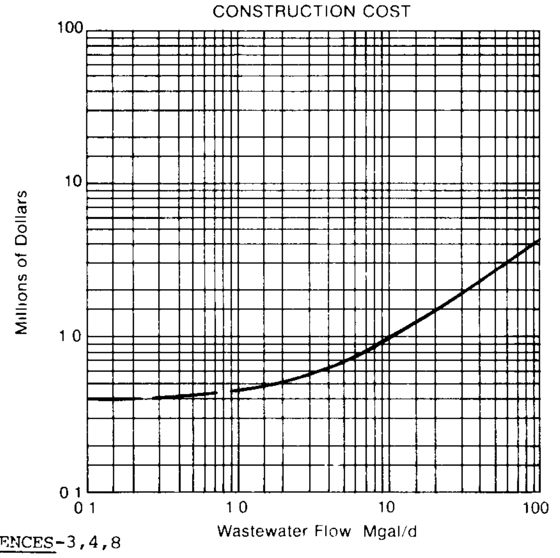


COSTS* - Construction costs include: sludge feed pumps, grinders, heat exchangers, reactors, boilers, gas separators, and buildings. Costs are related to average wastewater flow by the following: Sludge quantity = 1900 lb/ Mgal (undigested, combined thickened primary plus secondary sludge); solids concentration = 4.5 percent; sludge flow = 3.8 gal/min/Mgal/d based on 8,000 operating h/yr. Fuel costs are for steam generation. ENR Index = 2475

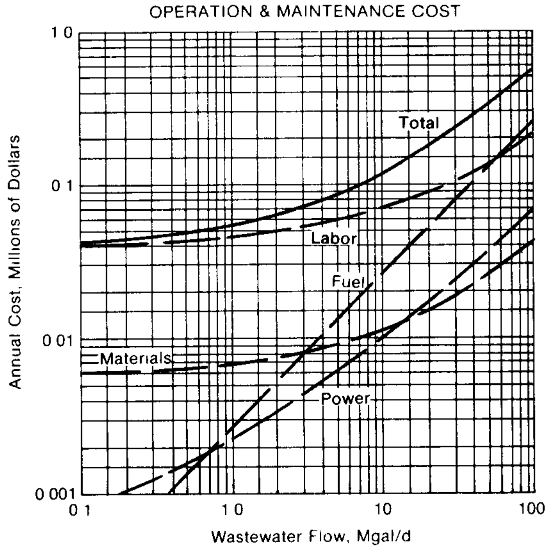
Adjustment Factor: To adjust costs for design factors different than for those above, enter curve at effective flow (Q_E).

$$Q_E = Q_{DESIGN} \times \text{(New Design Sludge Mass)}/(1{,}900\ \text{lb/Mgal})$$

CONSTRUCTION COST



OPERATION & MAINTENANCE COST



REFERENCES-3,4,8

*To convert construction cost to capital cost see Table A-2.

LIME STABILIZATION FACT SHEET 6.4.8

Description - The addition of lime, in sufficient quantities to maintain a high pH stabilizes sludge and destroys pathogenic bacteria. Lime stabilized sludges dewater well on sandbeds without odor problems. Sludge filterability can also be improved with the use of lime. Lime is also used prior to land application of sludges. Mixing of lime with liquid sludges is best accomplished with air mixing. For a detailed description of lime handling and feeding systems, see Fact Sheet No. 5.1.5.

Applications - Lime addition to raw or digested sludges to a stable (several hours) pH of over 12 or greater effectively stabilizes sludge for land application. Pathogens viruses and bacteria are destroyed, but worm eggs are resistant. Disinfection is superior to that obtained by mesophilic anaerobic digestion. Hydrated lime is often used in conjunction with metal salts to improve dewaterability. Though lime has some slight dehydration effect on colloids, its use in conditioning is mainly for pH control, odor reduction, disinfection and filter aid effect.

Limitations - Lime treatment produces essentially no organic destruction. Therefore caution is required when sludge cake disposal to land is practiced. Disposal in thick layers could create a situation where the pH could fall to near 7 prior to the sludge drying out, causing regrowth of organisms and resulting noxious odors. Maintenance of a pH of 11 for two weeks or more can minimize these problems. Lime handling and feed systems can require a high degree of operator attention.

Technology Status - Lime has been in widespread use for over 100 years, and the shipping, handling and feeding of lime is a well proven technology. Polymers recently have been replacing lime in some sludge conditioning applications prior to mechanical dewatering. Lime may have an increasing role as land application of sludges becomes more common.

Typical Equipment/No. of Mfrs. (23, 97) - Bins/over 50; Hoppers/over 40; Conveyors and elevators/over 50; Lime slakers/6; Chemical feed equipment/25; pH instrumentation/over 50; Sludge handling and control/32.

Performance (8) - A full scale study indicated the following effects of lime treatment on pathogenic bacteria (initial pH = 12.5, maintained above pH = 11.5 for 24 hours). Units - organisms/100 ml of sample.

Sludge	Salmonella	Fecal Strep.	Fecal Coli
Raw primary	62	39×10^7	8.3×10^3
Limed raw primary	Less than 3	6×10^3	5.9×10^3
Waste activated sludge	6	1×10^7	2.7×10^7
Limed waste activated	Less than 3	6.7×10^3	1.6×10^4
Septage	6	6.7×10^5	1.5×10^7
Limed septage	Less than 3	6.7×10^2	2.6×10^2

The effect of lime stabilization on vacuum filterability of sludge from a laboratory test is presented below (Filter leaf test yield: $lb/h/ft^2$).

Sludge	Al^{+++} Dose (mg/l)			Fe^{+++} Dose (mg/l)	
Before lime addition	.98	.94	.95	1.06	1.57
After lime addition	1.97	2.10	2.58	1.57	2.40

Note: Cake moisture (before and after) in all cases was essentially unchanged at 4.0 lb water/lb dry solids $\pm$ 10 percent.

Chemicals Required - Lime (CaO or $Ca(OH)_2$)

Residuals Generated - None

Design Criteria (73) - Lime requirements to raise pH in sludges are as follows:

Sludge - Percent Solids	1%	2%	3%	3.5%	4.4%
pH=11 $Ca(OH)_2$ dosage, mg/l	1400	2500	3700	6000	8200
pH=12 $Ca(OH)_2$ dosage, mg/l	2600	4300	5000	9000	9500

Lime dosage required to maintain sludge at pH greater than or equal 11.0 for at least 14 days.

Sludge Type	Dose, lb $Ca(OH)_2$/ton
Primary	200 - 300
Septage	200 - 600
Biological	600 - 1000
Al(Secondary) Precipitation	800 - 1200
Fe(Secondary) Precipitation	700 - 1200
Al(Primary & Secondary) Precipitation	500 - 800

Unit Process Reliability - Highly reliable from a process standpoint. However, above average operator attention and cleaning requirements are necessary to maintain the mechanical reliability of the lime feed.

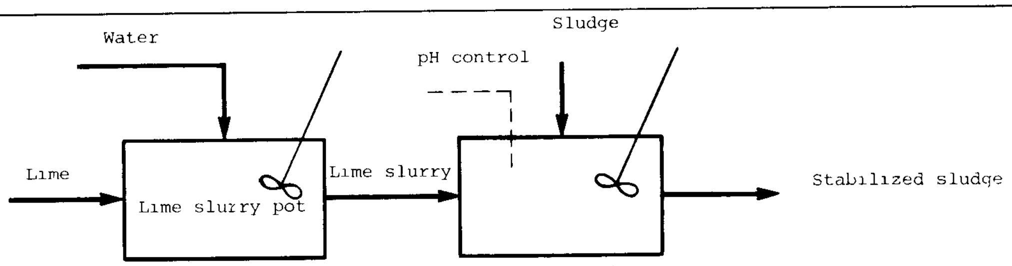
Environmental Impact - The volume of sludge generated may be increased, although lime can reduce the pathogenic bacteria and odor of sludge rendering it more suitable for land disposal. Improved dewaterability can result in less land use demand through smaller sized sand bed requirements. Disposal of sludge with high pH.

References - 3, 7, 8, 23, 26, 73

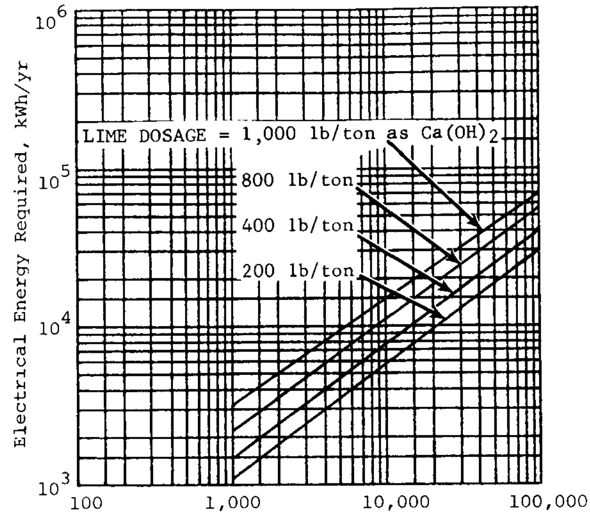
LIME STABILIZATION

FACT SHEET 6.4.8

FLOW DIAGRAM -

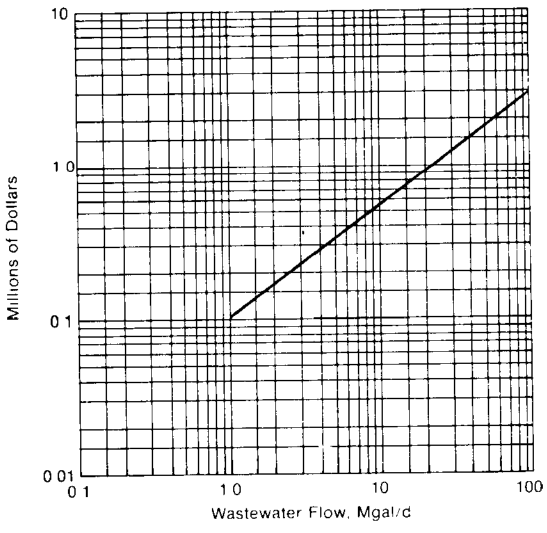


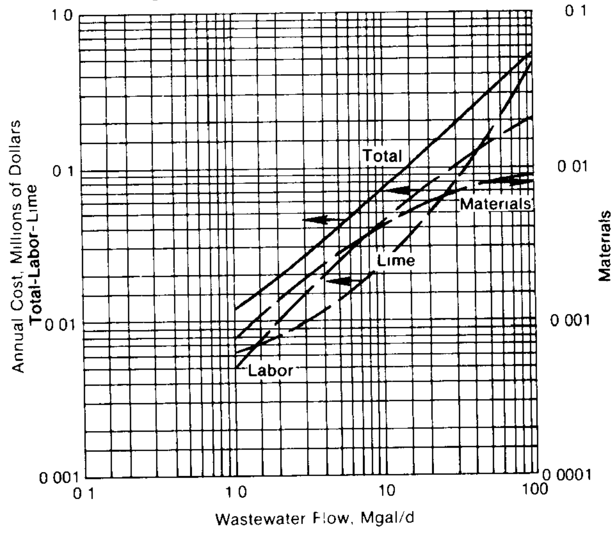
ENERGY NOTES - Assumptions: Pump feed of slaked lime; mix lime and sludge for 60 seconds at G = 600/s; sludge pumping not included.



COSTS* - January 1978 dollars; ENR Index = 2672

1. Construction cost includes: bulk lime storage bin (hydrated lime for 1 Mgal/d; pebble quicklime for 4 and 40 Mgal/d), augers, volumetric feeder, slurry tank, lime slaker, sludge mixing & thickening tank, sludge grinder, transfer pumps, all weather treatment building, and sludge holding lagoon with 60 day detention time.
2. Operation and Maintenance Costs; labor rates are $6.50 per hour; lime costs are $44.50 per ton for 46.8 percent CaO hydrated lime and $40 per ton for 85 percent CaO quicklime.
3. Lime dosage required per unit dry solids as 100 percent $Ca(OH)_2$ is 0.20 lb/lb.





REFERENCES-4,73,232

*To convert construction cost to capital cost see Table A-2.

AEROBIC TREATMENT AND ABSORPTION BED | FACT SHEET 7.1.1

Description - An aerobic treatment unit followed by a soil absorption bed is an on-site system for the treatment and disposal of domestic wastewater. Various aerobic suspended and fixed growth processes are available alternatives to the conventional septic tank (see Fact Sheet 7.1.6). The activated sludge process employs high concentrations of microorganisms under aerobic conditions in a batch or flow-through, extended aeration operation. Forced air diffusion or mechanical aeration is followed by clarification, whereby the biomass is separated from the treated wastewater. A portion of the separated biomass is recycled back to the aeration chamber in the flow-through mode. Fixed film treatment processes employ a large surface area upon which microorganisms will grow and over which wastewater is distributed so that the biomass may contact and metabolize pollutants within the waste streams. Aeration may be provided by natural convection, mechanical aeration, or forced air ventilation. A solid-liquid separation step normally follows, along with recycling of treated wastewater back to the fixed media. Examples of fixed film systems include the packed tower, rotating contactor, and submerged media system. Treated effluent can then be discharged to a soil absorption field for disposal. Distribution piping surrounded by gravel is buried in a seepage bed or a series of absorption trenches, designed on the basis of site and soil characteristics. Wastewater is spread throughout the field and conducted into the subsoil. (See Fact Sheet 7.1.6)

Modifications - The aerobic unit may be preceded by a septic tank or trash trap to remove grease, floating solids, and large debris or a surge tank to equalize flow. Clarifiers, tube and plate settlers, or surface filtration are alternatives for solids separation following aeration. Solids return in flow-through operations can be provided by either gravity, air lift pumps, or draft tubes.

Technology Status - Aerobic units are used extensively in package plants for institutional and commercial on-site treatment, but their share of the individual home treatment market is quite small.

Typical Equipment/No. of Mfrs. - Package aerobic unit, including tank, aeration equipment, and controls/more than 20; distribution piping/locally supplied.

Applications - Used as alternative to the conventional septic tank for on-site treatment of household wastewater. Aerobic units, when properly operated and maintained can result in a higher effluent quality than septic tanks and can reduce clogging in coarse (sandy) soils. Although pretreatment can potentially be improved, subsurface drainage beds should be limited to sites with recommended soil depths and permeability, as with septic tanks.

Limitations - On-site aerobic processes potentially produce a higher degree of treatment than septic tanks, but periodic carryover of solids due to sludge bulking, toxic chemical addition, or excessive sludge buildup can result in substantial variability in effluent quality. Regular, semi-skilled operation and maintenance is required to ensure proper functioning of moderately complex equipment, and inspections every two months are recommended. Power is required to operate aeration equipment and pumps. Absorption beds are dependent upon site and soil conditions, and are generally limited to sites with percolation rates less than 60 min/in, depth to water table or bedrock of 2 to 4 ft, and level or slightly sloping topography. (See Fact Sheet 7.1.6).

Performance - Aerobic units can achieve higher BOD removals than septic tanks, but SS removals, which are highly dependent on the solids separation methods utilized, are similar. Nitrification is normally achieved, but little reduction in phosphorus is effected. Field studies indicate that suspended growth units can provide from 70 to 90 percent BOD_5 and SS reductions for combined household wastewater, yielding effluent BOD_5 and SS concentrations in the range of 30 to 70 mg/l and 40 to 100 mg/l, respectively. Limited data for fixed growth units tested with municipal or synthetic wastewater show effluent BOD_5 and SS concentrations of 30 to 50 mg/l and 40 to 60 mg/l, respectively (149). A properly designed and constructed soil absorption bed will effectively remove pollutants, including bacteria, viruses, and heavy metals, by natural adsorption in the soil zone adjacent to the field. However, nitrate movement through many soils to groundwater may be substantial.

Chemicals Required - None.

Residuals Generated - Excess sludge containing organics, grease, hair, grit, and pathogens must be removed from aerobic units and disposed of every 8 to 12 months. If a septic tank is used for pretreatment, sludge may be wasted to the tank, reducing offsite pumping frequency.

Design Criteria - Design peak flow: 75 gal/d/person. Commercial designs must be evaluated in light of site specific requirements. The absorption area requirements shown on Fact Sheet 7.1.6 apply for finer textured soils; some size reduction is possible for coarser soil types with aerobic treatment.

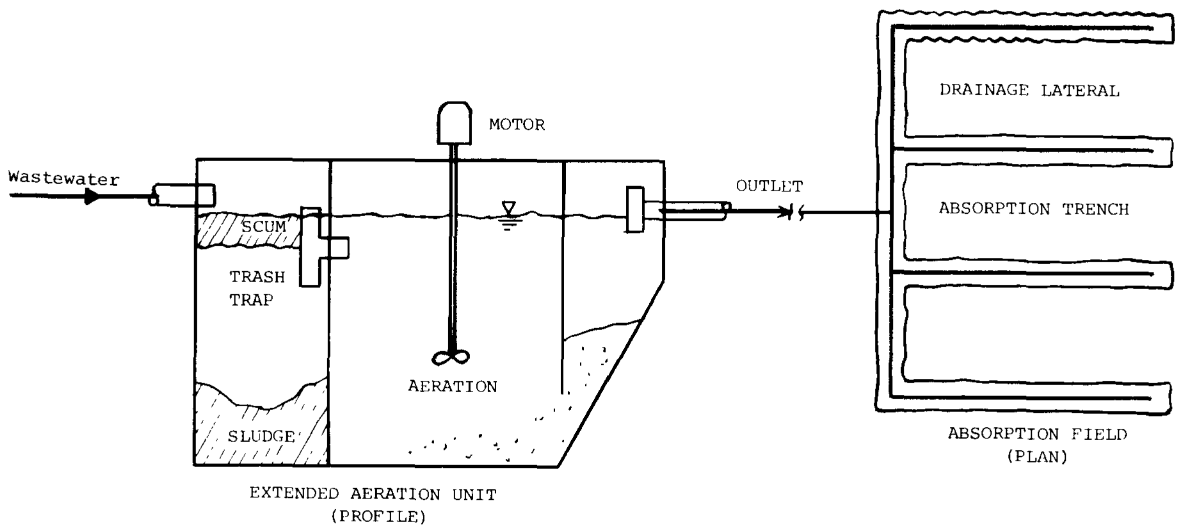
Reliability - Aerobic processes are sensitive to microbial upsets and effluent quality is dependent upon supervised operation. Proper design and maintenance of mechanical equipment is necessary for effective treatment.

Environmental Impact - Sludge is generated, requiring approved treatment and disposal. Effluent can contaminate groundwaters when pollutants are not effectively removed by the aerobic unit or the soil system. Aeration equipment can be noisy. Poorly maintained units may produce odors.

References - 14, 149, 152, 160

AEROBIC TREATMENT AND ABSORPTION BED | FACT SHEET 7.1.1

FLOW DIAGRAM -



ENERGY NOTES - 700 to 3,600 kWh/yr for aeration and pumping.

COSTS* - 1978 dollars; ENR Index = 2776. The following are cost estimates for a household aerobic unit and soil absorption system:

Aerobic treatment unit, including design, permit and installation with 20 year service life for shell and 10 years for equipment	\$1,000 to \$3,500
Soil absorption system (300 to 750 ft^2) with 20 to 30 year service life (\$1 to \$2.10/ft^2)	375 to 2,100
Construction costs	\$1,375 to \$5,600
Maintenance of aerobic unit, including sludge removal (routine and unscheduled)	\$ 50 to \$ 150
Power (\$0.02/kWh)	15 to 75
Annual operating costs	\$ 65 to \$ 225

Soil absorption system construction cost includes excavation, gravel, pipe, backfill, and miscellaneous labor. This cost can vary significantly, depending upon site and soil characteristics, size and type of bed, and local material and labor costs.

REFERENCES - 103, 152

*To convert construction cost to capital cost see Table A-2.

AEROBIC TREATMENT AND SURFACE DISCHARGE — FACT SHEET 7.1.2

Description - Surface discharge of aerobically treated domestic wastewater is an alternative on-site disposal method that can be used when the conventional soil absorption system would be inadequate as a treatment and disposal medium. If an appropriate receiving water is available, the level of treatment required may vary depending on local regulations, stream water quality requirements, and other site-specific conditions. Numerous field studies have shown that well-maintained aerobic units produce effluents containing concentrations somewhat in excess of secondary treatment requirements of 30 mg/l of BOD_5 and SS. To attain this standard, some form of additional treatment is necessary. Granular filtration, with its simplicity and low operation and maintenance requirements, has proven effective for this purpose. Various aerobic suspended and fixed growth processes are available as alternatives to the conventional septic tank. The activated sludge process in batch or flow-through extended aeration designs and fixed film processes, which distribute wastewater over large surface areas of microorganisms, can produce higher quality effluents than septic tanks if properly maintained and operated (see Fact Sheet 7.1.1). The intermittent sand filter, successfully tested in the field, consists of a 2 to 3 ft deep sand bed which remains aerobic and removes SS and dissolved organics. The filter surface is flooded intermittently with pretreated wastewater at intervals which permit the surface to drain between applications. Filtrate is collected by underdrains for final discharge. A sand filter preceded by aerobic treatment does not normally require alternating units, as is necessary for a filter following septic tank pretreatment. However, the filter surface with accumulated solids should be removed and replaced with clean sand every 6 months. Alternative filters are described in Fact Sheet 7.1.8.

Modifications - A septic tank to remove grease, floating solids, and large debris or a surge tank to equalize flow may precede an aerobic unit. A dosing pump and chamber can be used to distribute effluent over the filter surface. Covered, insulated filters are used in areas with extended periods of sub-freezing weather. Disinfection of filtrate or nutrient removal may be required to comply with direct discharge standards (see Fact Sheet 7.1.3).

Technology Status - Many aerobic treatment units followed by filtration for surface discharge are in operation in the U. S. today. The available field data on performance are meager, however.

Typical Equipment/No. of Mfrs. - Package aerobic unit, including tank, aeration equipment, and controls/more than 20; dosing tank and pump/more than 5; distribution and underdrain piping/locally supplied.

Applications - Direct discharge of effluent from an aerobic unit-sand filter system is an on-site option that can be utilized where unfavorable site or soil conditions render subsurface disposal impractical or infeasible and where a receiving water is available.

Limitations - Studies under household conditions have shown that aerobic units are not as stable as conventional septic tanks and periodic biological and hydraulic upsets can result in substantial variability in quality of filter influent. Although the effluent qualities of aerobic unit-sand filter and septic tank-sand filter systems have shown to be similar for comparable loading conditions, the difference in influent organic strength can affect filter operation in terms of required surface area, length of loading and resting periods, and maintenance. The higher level of organic removal is obtainable with regular maintenance of aeration equipment and pumps. Filter surfaces need to be restored or replaced when clogging occurs to avoid serious ponding conditions. Discharge permits, with sampling and inspection, may be required by regulatory authorities.

Performance (14) - Effluent quality data from field studies of an extended aeration unit-intermittent sand filter system with 3.8 gal/d/ft^2 average loading rate, 0.19 mm effective size, and 3.31 uniformity coefficient:

Parameter	Aerobic Unit Effluent	Sand Filter Effluent
BOD_5, mg/l	31.0	3.5
TSS, mg/l	41.0	9.4
Total nitrogen (N), mg/l	37.8	34.8
Ammonia-nitrogen, mg/l	1.4	0.3
Nitrate-nitrogen, mg/l	32.3	33.8
Total phosphorus (P), mg/l	29.5	20.3
Fecal coliforms, log_{10}#/l	5.3	4.0
Fecal streptococci, log_{10}#/l	4.4	3.2

Chemicals Required - None, unless chemical disinfection is required.

Residuals Generated - Sand with putrescible organic matter must be removed from filter surface when clogging occurs. Excess sludge from aerobic unit should be wasted every 8 to 12 months. (see Fact Sheet 7.1.1)

Design Criteria - General: Design peak flow = 75 gal/d/person. Aerobic unit: Available commercial designs must be evaluated with site specific requirements. Intermittent sand filter: design loading rate = 5 gal/d/ft^2; effective size = 0.2 to 0.6 mm; uniformity coefficient less than 4.0.

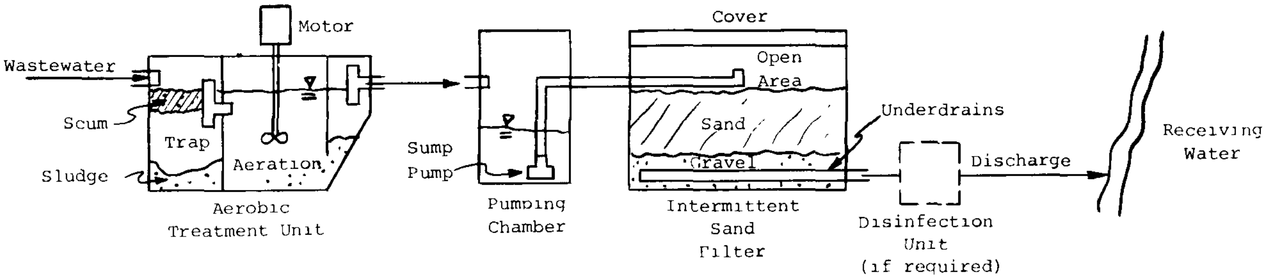
Reliability - Aerobic units are subject to biological upsets due to toxic chemical addition, surge flows, or cold climates. Semi-skilled O&M is necessary to ensure proper functioning of moderately complex equipment. Sand filtration is a relatively reliable process which is not greatly affected by normal pretreatment variations.

Environmental Impact - Potential for nutrient or pathogen addition to surface waters. Poorly maintained aerobic units may produce odors. Disposal of excess sludge and sand residuals is required.

References - 14, 103, 152, 162

AEROBIC TREATMENT AND SURFACE DISCHARGE FACT SHEET 7.1.2

FLOW DIAGRAM -



ENERGY NOTES - 700 to 3600 kWh/yr for operation of aerobic unit. 50 to 250 kWh/yr for sump pump.

COSTS* - 1978 dollars; ENR Index = 2776. The following are cost estimates for an on-site surface discharge system consisting of an aerobic treatment unit, pumping chamber, and intermittent sand filter with gravity discharge:

Construction cost:	
Aerobic treatment unit, including installation	\$1,000 to \$3,500
Pumping chamber with 1/2 hp sump pump and controls to dose filter (optional, often included in design)	600 to 1,000
Intermittent sand filter, 50 ft^2 surface area, with 25 ft gravity discharge line (See Fact Sheet 7.1.8)	500 to 750
Total	\$2,100 to \$5,250
Annual operation and maintenance cost:	
Maintenance of aerobic unit (including sludge removal) and pumping chamber (routine and unscheduled repairs)	\$ 50 to \$ 150
Periodic raking and replacement of sand surface to restore hydraulic capacity of filter (every 6 months)	75 to 100
Power for aeration and pumping (\$0.02/kWh)	15 to 80
Total	\$ 140 to \$ 330

Critical factors determining the cost of a sand filter include the type of filter, the amount of required surface area, and the availability of quality filter sand, which is sensitive to location. Also, available package filter units may significantly reduce the construction cost cited above, as can the type of aerobic unit. However, the performance of such units will not be comparable to the performance cited in this fact sheet. The cost of surface discharge depends on site specific factors such as distance to the receiving water, ease of excavation, and local material and labor costs. This cost increases if further pumping is required and effluent monitoring is included.

REFERENCES - 103, 162

*To convert construction cost to capital cost see Table A-2.

DISINFECTION FOR ON-SITE SURFACE DISCHARGE — FACT SHEET 7.1.3

Description - Direct discharge to an available receiving water is an on-site alternative for the disposal of domestic wastewater, as discussed in Fact Sheet 7.1.8. The required level of treatment depends upon stream water quality requirements, local regulations, and other site-specific conditions. A properly maintained aerobic treatment unit or septic tank followed by a polishing sand filter is capable of producing an effluent that complies with secondary treatment standards of 30 mg/l BOD_5 and SS. However, disinfection may be required to reduce total and fecal coliform levels below the maximums of 1000/100 ml and 200/100 ml, respectively, recommended for recreational waters.(14) Disinfection methods that have proven effective against bacterial and viral pathogens for on-site application include tablet chlorination, iodine crystals, and ultraviolet irradiation.

The stacked-solid tablet feeder, with a hypochlorite storage chamber and flow-through mixing provision, followed by a contact chamber is a typical chlorination system for small waste flows. Iodine, which is only slightly soluble in water, is normally used in the crystalline form. A saturator holding crystals serves as the feed device. The appropriate dosage to be added to the effluent can be controlled by pumping a designated sidestream through the iodinator and reblending it with the main flow. An ultraviolet disinfection unit for on-site application consists of a high intensity lamp in a radiation chamber, through which a thin layer of wastewater is injected for treatment. Ultraviolet light is germicidal in the wave length range of 230 to 300 nm, with optimum efficiency at 257 nm. The dosage of UV irradiation required depends on lamp intensity, wastewater transmissivity, exposure time and flow pattern through the unit.

Modifications - A dry feed chlorination system can be improved with the use of a surge tank and siphon or pump for more accurate dosage control. Ultraviolet units can be equipped with automatic cleansing devices for lamp sleeves to maintain radiation transmission and with meters to measure intensity.

Technology Status - Chlorination of wastewater has been practiced for many years. Iodine and ultraviolet irradiation, which have been shown to be effective water supply disinfectants, are relatively new for on-site wastewater treatment applications.

Typical Equipment/No. Mfrs. - Dry feed chlorinator/approx. 10; iodine saturator/more than 2; UV disinfection unit with controls/approx. 6.

Applications - These on-site disinfection methods are used to destroy disease-causing organisms in the effluents from household treatment units prior to disposal by direct discharge to meet environmental and public health requirements.

Limitations - Dry feed chlorinators with gravity flow-through provisions lack sufficient dosage control, which can cause excessive levels of residual chlorine to be present in final effluents. Field evaluations found the actual dosage to be an inverse function of flow rate with an average dosage of 20 mg/l.(103) Overdosing may result from the variability of influent flows, causing a wide range in chlorine residuals. The presence of chlorinated organic compounds could render disinfected effluents environmentally undesirable for surface discharge. More expensive iodine is less subject to excessive overdosing, but the environmental effect of residuals is uncertain. Power is required by UV units for lamp operation and pumping, but residual toxicity potential is eliminated when this disinfection method is compared to the other options. Both iodination and chlorination units must be periodically inspected and recharged to insure sufficient protection against public health risks caused by insufficient dosing. Homeowner performance of these tasks has been shown to be unacceptable.

Performance - Currently available, well maintained (by central authority) dry feed chlorinators, iodine saturators, and UV units have been shown to provide consistently high levels of disinfection (greater than 97 percent reduction of indicator organisms) of domestic wastewaters following aerobic or septic tank treatment and slow sand filtration. Bacteria are readily killed, while viruses, spores, and cysts are somewhat more resistant. With proper halogen dosage and contact time or sufficient ultraviolet exposure, water quality objectives (less than 200 fecal coli/100 ml) are achievable.

Chemicals Required - Calcium hypochlorite tablets, iodine crystals.

Design Criteria - Typical halogen dosage requirements for sand filtered effluents range from 1 to 5 mg/l for chlorine and 5 to 10 mg/l for iodine. Contact chambers for small flow systems should be designed to provide 30 minutes of contact time at peak flow (reasonable chamber sizes are 30 to 40 gal). Disinfection requirements for UV irradiation are based on total exposure of the liquid to the UV light energy. USPHS minimum exposure requirements for drinking water are 16,000 mW sec/cm^2. All disinfection units should be housed for protection from the elements and vandals.

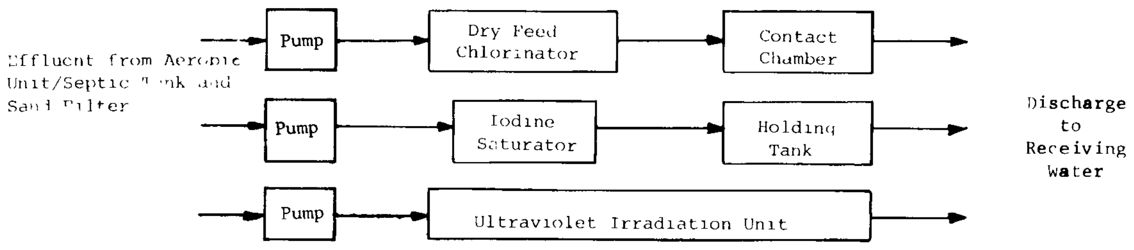
Reliability - Proper maintenance of on-site units by central authorities is necessary for effective disinfection. Tablet chlorinators require chemical refills two to four times per year, but more frequent feed chamber cleaning may be necessary to prevent tablet caking. UV units require periodic lamp replacement (every 7,500 hours of continuous operation) and cleaning of accumulated materials (at least 3 times per year) to restore transmissivity of the UV lamp and sleeve. Iodination units require yearly inspection and crystal replenishment.

Environmental Impact - Chlorine disinfection can result in the production of toxic chlorinated organics in final effluents being discharged to surface waters.

References - 14, 103, 149, 152, 162

DISINFECTION FOR ON-SITE SURFACE DISCHARGE — FACT SHEET 7.1.3

FLOW DIAGRAM -



DISINFECTION METHODS

ENERGY NOTES - Dry feed chlorinators normally employ gravity flow-through mixing. Minimum power (50 to 250 kWh/yr) required for small pump used with iodine saturator. Field studies indicate that power requirements for a UV unit (2 to 4 gal/min with 15 W lamp) range from 25 kWh/yr for intermittent operation (70 min/d) to 550 kWh/yr for continuous operation.

COSTS* - 1978 dollars; ENR Index - 2776. The following cost estimates are presented to illustrate the major components of three on-site disinfection methods for the individual household. (Labor cost $7.50/h, including fringe benefits):

I. Dry feed chlorination system with gravity flow-through mixing:

Construction cost:		Annual operation and maintenance cost:	
Chlorination unit with tablet feed chamber housing, piping, and contact chamber (The high end of the cost range reflects pumping.)	$200-$800	Chlorine tablets ($1.98/lb)	$15-35
		Routine maintenance requirements (2 to 4 h/yr)	15-30
Total	$200-$800	Total	$30-65

II. Iodination system with pump to maintain flow and pressure through the iodine saturator:

Construction cost:		Annual operation and maintenance cost:	
Iodine saturator with pump and holding tank	$600-1,000	Iodine crystals (3-5 lb/yr @ $11.95/lb)	$35-60
		Routine maintenance requirements 1-3 h/yr)	9-20
		Power for pumping ($0.02/kWh)	1-5
Total	$600-1,000	Total	$45-85

III. Ultraviolet disinfection unit with 15W lamp and 3 gal/min operation:

Construction cost:		Annual operation and maintenance cost:	
UV disinfection unit with controls, surge tank, and pump	$800-1,500	Maintenance requirements, including lamp replacement and radiation chamber cleaning	$69-120
		Power for pumping and UV operation ($0.02/kWh)	1-10
Total	$800-1,500	Total	$70-130

NOTE - See Fact Sheet 7.1.2 and 7.1.8 for cost and energy data on aerobic and septic tank treatment followed by sand filtration.

REFERENCES - 103, 149, 152

*To convert construction cost to capital cost see Table A-2.

EVAPORATION LAGOONS FACT SHEET 7.1.4

Description - The evaporation lagoon may be described as an open holding facility which depends solely on climatic conditions such as evaporation, precipitation, temperature, humidity, and wind velocity to effect dissipation (evaporation) of on-site wastewater. Individual lagoons may be considered as an alternate means of wastewater disposal on individual pieces of property. The basic impetus to consider this system is to allow building and other land uses on properties which have soil conditions not conducive to the workability and acceptability of the conventional on-site drainfield or leachbed disposal systems.

Generally, if the annual evaporation rate exceeds the annual precipitation, this method of disposal may at least be considered. The deciding factor then becomes the required land area and holding volume. It should be noted that for unlined on-site installations such as homes and small industrial applications, there may also be a certain amount of infiltration or percolation in the initial period of operation. However, after a time, it may be expected that solids deposition will eventually clog the surface to the point where infiltration is eliminated. The potential impact of wastewater infiltration to the groundwater, and particularly on-site water supplies, should be evaluated in any event and, if necessary, lagoon lining may be utilized to alleviate the problem.

Often preceded by septic tanks or aerobic units in order to provide a more acceptable influent to and minimize sludge removal from the lagoon.

Technology Status - The "technology" of evaporation is well developed in terms of our scientific understanding and application of climatological and meteorologic data.

Applications - The on-site utilization of evaporation lagoons for the disposal of domestic wastewater, from homes and smaller industrial or commercial facilities may be applicable where access to a municipal sanitary sewer is not available; where subsurface methods are not feasible (see Fact Sheets 7.1.5, 7.1.6, and 7.1.7); and where effluent polishing for surface discharge is not practical (see Fact Sheet 7.1.8).

Limitations - Local health ordinances; potential for odors and health hazard when not properly designed; land area requirements; dependence on meteorologic and climatological conditions. May require provision to add makeup water to maintain a minimum depth during dry, hot seasons. Public access restrictions are necessary.

Performance - The performance of evaporation lagoons is necessarily site-specific; therefore, the following data are presented on the basis of net annual evaporation rate which may exist in a certain area:

Net Annual Evaporation (inches) (true annual evaporation - annual precipitation)	Lagoon Performance (gal of water evaporated/ft^2/yr)
5	3.1
10	6.2
15	9.4
20	12.5
40	24.9
60	37.4

Residuals Generated - Periodic pump out of accumulated sludge is required from pretreatment unit and/or lagoon.

Design Criteria (170) - The hydraulic loading is the primary sizing criteria for an individual home total retention lagoon. In order to size the system properly the following information is needed:

a. Anticipated flow of wastewater;
b. Evaporation rates (10-yr minimum of monthly data)
c. Precipitation rates " " " "

The rate of wastewater flow may be anticipated to be in the range of 50 gallons per person per day, depending on individual site location. Precipitation and evaporation data for most areas can be readily found in weather bureau records. A 12-month mass balance should be utilized to properly determine design sizing. Design criteria include: depth 2 to 4 ft; level bottom; banks more than 2 feet higher than maximum water level.

The following tables are taken from an individual retention system design for Spokane County, Washington, and are presented here to illustrate the procedure utilized in the design of a 60.5 foot diameter lagoon.

Water Mass Balance Analysis

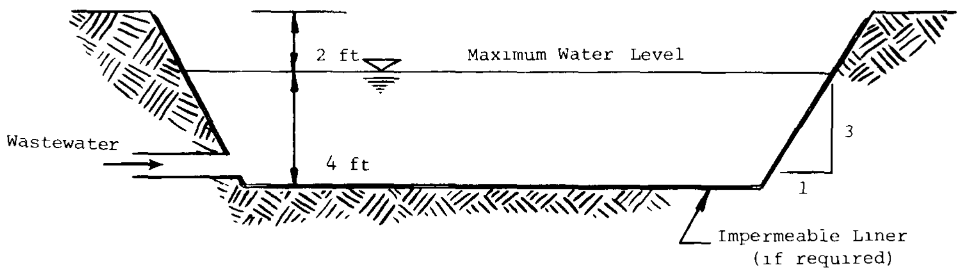
Month	Gallons Wastewater Flow	Average Evap (in.)	Average Precip.	Net Evaporation Inches	Net Evaporation Gal/ft^2	ft^2 to Evap Wastewater	Excess Evap Gals
April	5400	5.54	1.0	4.54	2.83	1908	2694
May	5580	7.79	1.0	6.79	4.23	1319	5757
June	5400	9.26	1.2	8.06	5.02	1076	8052

Process Reliability - Good, however should be closely controlled to prevent health hazard.

Environmental Impact - Potential odors; potential health hazard; land area requirements may be large; may adversely affect surrounding property values.

Reference - 170

FLOW DIAGRAM -



ENERGY NOTES _ Lagoon is gravity fed from source. Where pumping is required, energy requirements may be approximated by using the following equation: kWh/yr = .0019 x gal/d x discharge head ft, assuming a wire to water efficiency of 60 percent.

COSTS* - 1978 dollars; ENR Index = 2776. Land costs associated with the individual total retention lagoon are site specific and not listed here. Typical excavation and liner (plastic) costs associated with a two-bedroom residence may be estimated as follows:

Construction cost	Unit Price	Cost
Excavation and hauling (750 yd^3)	$\$0.76/yd^3$	$ 570
Liner (10 mil PVC) (21,000 ft^2)	$\$0.11/ft^2$	2,310
Supervision and hand labor		820
Subtotal		$3,700

(To the above must be added fencing, septic tank and ancillary costs)

Operating Costs- Septic Tank Pumpout

Pumping of septic tank	$10/yr

Maintenance costs of lagoons not included.

REFERENCE - 170

*To convert construction cost to capital cost, see Table A-2.

EVAPOTRANSPIRATION SYSTEMS FACT SHEET 7.1.5

Description - Evapotranspiration (ET) is a means of on-site wastewater disposal that may be utilized in some localities where site conditions preclude soil absorption. Evaporation of moisture from the soil surface and/or transpiration by plants is the mechanism of ultimate disposal. Thus, in areas where the annual evaporation rate equals or exceeds the rate of annual added moisture from rainfall and wastewater application, ET systems can provide a means of liquid disposal without danger of surface or groundwater contamination.

If evaporation is to be continuous, three conditions must be met. First, there must be a continuous supply of heat to meet the latent heat requirement (approximately 590 cal/g of water evaporated at 15°C). Second, a vapor pressure gradient must exist between the evaporative surface and the atmosphere to remove vapor by diffusion, convection, or both. Meteorological factors, such as air temperature, humidity, wind velocity, and radiation influence both energy supply and vapor removal. Third, there must be a continuous supply of water to the evaporative surface. The soil material must be fine textured enough to draw up the water from the saturated zone to the surface by capillary action but not so fine as to restrict the rate of flow to the surface. Evapotranspiration is also influenced by vegetation on the disposal field and can theoretically remove significant volumes of effluent in late spring, summer, and early fall, particularly if large silhouette, good transpiring bushes and trees are present.

A typical ET bed system consists of a 1½ to 3 foot depth of selected sand over an impermeable plastic liner. A perforated plastic piping system with rock cover is often used to distribute pretreated effluent in the bed. The bed may be square-shaped on relatively flat land, or a series of trenches on slopes. The surface area of the bed must be large enough for sufficient ET to occur to prevent the water level in the bed from rising to the surface.

Beds are preceded by septic tanks or aerobic units to provide the necessary pretreatment.

Common Modifications - Given the proper subsurface conditions, systems can be designed to perform as both evapotranspiration and absorption beds (See Fact Sheet 7.1.6). Nearly 3/4 of all the ET beds in operation were designed to use both disposal methods. Mechanical evaporators have been developed, but not used at full scale.

Technology Status - There are estimated to be 4,000 to 5,000 year-round evapotranspiration beds in operation in the United States, particularly in the semi-arid regions of the Southwest.

Typical Equipment/No. of Mfrs. (100) - Liner/24; septic tank and distribution piping/locally supplied; aerobic unit/more than 20.

Applications - Used as an alternative to subsurface disposal in areas where these methods are either undesirable due to groundwater pollution potential or not feasible due to certain geological or physical constraints of land. The ET system can also be designed to supplement soil absorption for sites with slowly permeable soils. The use of ET systems for summer homes extends the range of application, which is otherwise limited by annual ET rates. Since summer evaporation rates are generally higher and plants with high transpiration rates are in an active growing state, many areas of the country can utilize ET beds for this seasonal application.

Limitations - The use of an evapotranspiration system is limited by climate and its effect on the local ET rate. In practice, lined ET bed systems are generally limited to areas of the country where pan evaporation exceeds annual rainfall by at least 24 inches. The decrease of ET in winter at middle and high latitudes greatly limits its use. Snow cover reflects solar radiation, which reduces ET. In addition, when temperatures are below freezing, more heat is required to change frozen water to vapor. When vegetation is dormant, both transpiration and evaporation are reduced. An ET system requires a large amount of land in most areas. Salt accumulation may eventually eliminate vegetation and thus, transpiration. Bed liner (where needed) must be kept water-tight to prevent the possibility of groundwater contamination. Therefore, proper construction methods should be employed to keep the liner from being punctured during installation.

Performance - Performance is a function of climate conditions, volume of wastewater, and physical design of the system. Evapotranspiration is an effective means of domestic wastewater disposal.

Chemicals Required - None

Residuals Generated - See Fact Sheet 7.1.6.

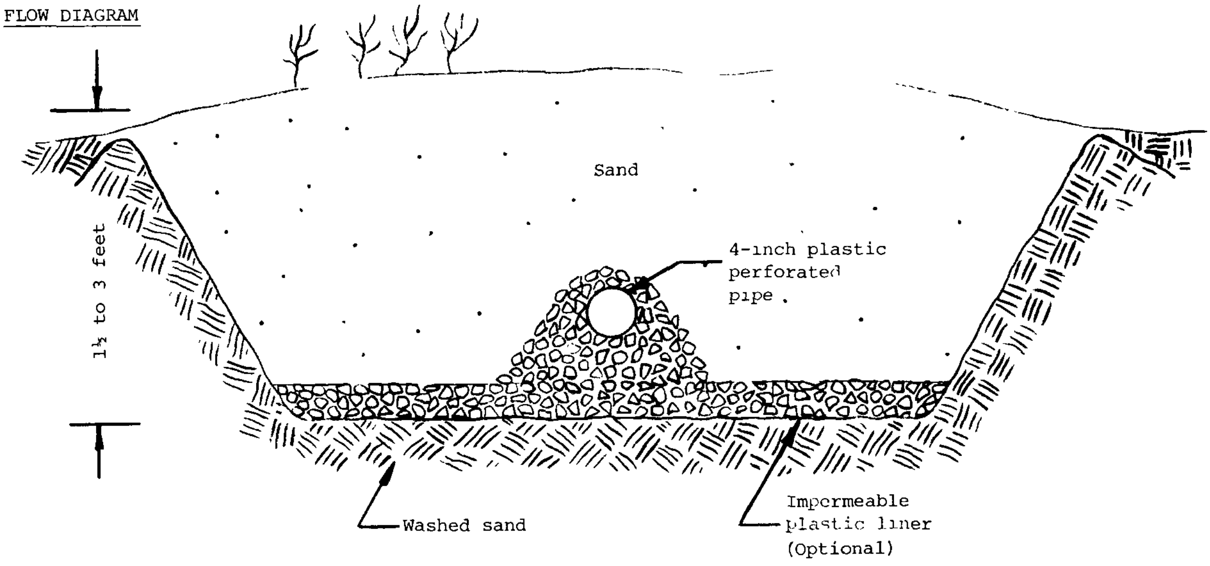
Design Criteria - Design of an evapotranspiration bed is based on the local annual weather cycle. The total expected inflow based on household wastewater generation rate and on rainfall (use a 10 year expectancy year to provide sufficient surface area) is compared with an average design evaporation value established from the annual pattern. A mass balance is used to establish the storage requirements of the bed. Vegetative cover can substantially increase the ET rate during the summer growing season; but may reduce evaporation during the non-growing season. Uniform sand in the size range of D_{50} of approximately 0.10 mm is capable of raising water about 3 ft. Liner (polyethylene) thickness typically greater than or equal to 10 mil. Surface runoff must be excluded from the bed proximity by proper lot grading.

Reliability - An ET system that has been properly designed and constructed is an efficient method for the disposal of pretreated wastewater and requires a minimum of maintenance.

Environmental Impact - Healthy vegetative covers aesthetically pleasing. Large land requirement conserves open space, but limits use of land.

References - 14, 36, 103

FLOW DIAGRAM



Typical Evapotranspiration Bed

ENERGY NOTES -
No energy required, nor headloss of any value incurred.

COSTS* - 1978 dollars; ENR Index - 2776.

The following site specific costs serve to illustrate the major components of an evapotranspiration bed in Boulder, Colorado with an annual net ET rate in the range of 0.04 gal/d/ft². A 200 gal/d household discharge would require a 2 ft deep bed with an area of approximately 5,000 ft².

Construction cost:		
Building sewer with 1000 gal septic tank, design and permit (with aerobic unit add $300 to $2,800)		$ 700
Excavation and hauling (375 yd³)		1,030
Liner (5,200 ft²)		670
Distribution piping (625 ft)		300
Sand (340 yd³) and gravel (38 yd³)		1,800
Supervision and labor		500
	Total	$5,000
Annual operation and maintenance cost:		
Pumping septage from septic tank (every 3-5 years) (with aerobic unit add $60 to $205/yr)		$ 5-20
	Total	$ 5-20

The construction cost for this particular system would be approximately $1.00/ft², which is consistent with a reported national range of $0.75 to $1.60/ft². The cost of an evapotranspiration bed is highly dependent upon local material and labor costs. As shown, the cost of sand is a significant portion of the cost of the bed. The restrictive sand size requirement makes availability and cost sensitive to location.

REFERENCE - 103

*To convert construction cost to capital cost see Table A-2.

SEPTIC TANK ABSORPTION BED — FACT SHEET 7.1.6

Description - A septic tank followed by a soil absorption bed is the traditional on-site system for the treatment and disposal of domestic wastewater from individual households or establishments. The system consists of a buried tank where wastewater is collected and scum, grease, and settleable solids are removed by gravity separation, and a sub-surface drainage system where clarified effluent percolates into the soil. Precast concrete tanks with a capacity of 1000 gallons are commonly used for household systems. Solids are collected and stored in the tank, forming sludge and scum layers. Anaerobic digestion occurs in these layers, reducing the overall volume. Effluent is discharged from the tank to one of three basic types of subsurface systems, adsorption trenches, seepage bed, or seepage pits. Sizes are usually determined by percolation rates, soil characteristics, and site size and location. Distribution pipes are laid in a field of absorption trenches to leach tank effluent over a large area. Required absorption areas are dictated by state and local codes. Trench depth is commonly about 24 inches to provide minimum gravel depth and earth cover. Clean, graded gravel or similar aggregate, varying in size from ½ to 2½ inches, should surround the distribution pipe and extend at least two inches above and six inches below the pipe. The maintenance of at least a 2 ft separation between the bottom of the trench and the high water table is required to minimize groundwater contamination. Piping typically consists of agricultural drain tile, vitrified clay sewer pipe, or perforated, non-metallic pipe. Absorption systems having trenches wider than 3 ft are referred to as seepage beds. Given the appropriate soil conditions (sandy soils), a wide bed makes more efficient use of available land than a series of long, narrow trenches.

Common Modifications - Many different designs may be used in laying out a subsurface disposal field. In sloping areas, serial distribution can be employed with absorption trenches by arranging the system so that each trench is utilized to its capacity before liquid flows into the succeeding trench. A dosing tank can be used to obtain proper wastewater distribution throughout the disposal area and give the absorption bed a chance to rest or dry out between dosings. Providing two separate alternating beds is another method used to restore the infiltrative capacity of a system. Aerobic units may be substituted for septic tanks with no changes in soil absorption system requirements (see Fact Sheet 7.1.1).

Technology Status - Septic tank-soil absorption systems are the most widely used method of on-site domestic waste disposal. Almost one-third of the United States population depends on such systems.

Typical Equipment/No. of Mfrs. - Septic tanks and distribution piping are locally supplied.

Applications - Used primarily in rural and suburban areas where economics are favorable. Properly designed and installed systems require a minimum of maintenance and can operate in all climates.

Limitations - Dependent on soil and site conditions, the ability of the soil to absorb liquid, depth to groundwater, nature of and depth to bedrock, seasonal flooding, and distance to well or surface water. A percolation rate of 60 min/in is often used as the lower limit of permeability. The limiting value for seasonal high groundwater should be 2 ft below the bottom of the drainfield. When a soil system loses its capacity to absorb septic tank effluent, there is a potential for effluent surfacing, which often results in odors and, possibly, health hazards.

Performance - Performance is a function of the design of the system components, construction techniques employed, rate of hydraulic loading, areal geology and topography, physical and chemical composition of the soil mantle, and care given to periodic maintenance. Pollutants are removed from the effluent by natural adsorption and biological processes in the soil zone adjacent to the field. BOD, SS, bacteria, and viruses, along with heavy metals and complex organic compounds, are adsorbed by soil under proper conditions. However, chlorides and nitrates may readily penetrate coarser, aerated soils to groundwater.

Residuals Generated - The sludge and scum layers accumulated in a septic tank must be removed every 3 to 5 years. (See Fact Sheet 7.1.9)

Design Criteria (134) - Absorption area requirements for individual residences:

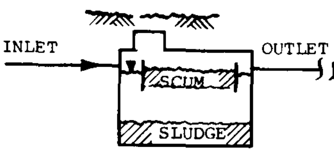
Percolation Rate (min/in)	Req. Area/Bedroom (ft^2)	Percolation Rate (min/in)	Req. Area/Bedroom (ft^2)
1 or less	70	15	190
3	100	30	250
5	125	45	300
10	165	60	330

Process Reliability - Properly designed, constructed, and operated septic tank systems have demonstrated an efficient and economical alternative to public sewer systems, particularly in rural and sparsely developed areas. System life for properly sited, designed, installed and maintained systems may equal or exceed 20 years.

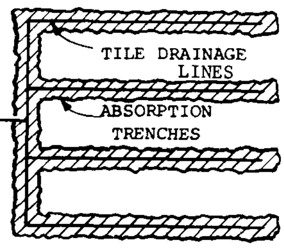
Environmental Impact - Leachate can contaminate groundwaters when pollutants are not effectively removed by the soil system. In many well aerated soils, significant densities of homes with septic tank - soil absorption systems have resulted in increasing nitrate content of the ground water. Soil clogging may result in surface ponding with potential aesthetic and public health problems.

References - 12, 14, 36, 134, 135

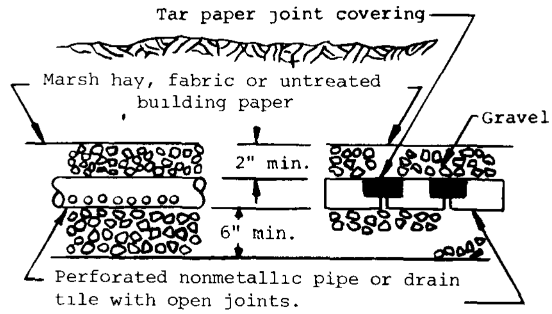
FLOW DIAGRAM - (typical)



SEPTIC TANK
(PROFILE)



ABSORPTION FIELD
(PLAN)



ABSORPTION TRENCH AND LATERAL
(CROSS SECTION)

ENERGY NOTES - System gravity fed. Head loss insignificant.

COSTS* - 1978 dollars; ENR Index = 2776. Site specific cost estimate for a conventional septic tank - soil absorption system for a typical three bedroom home (new) is as follows:

Construction cost:

Inspection and design	$ 250
Permit	75
Building sewer and septic tank (1000 gal) with 50 yr service life	350 to 500
Soil absorption system (375 to 1000 ft^2) with 20 to 30 yr service life ($1 to $2.10/$ft^2$)	375 to 2,100
Total	$1,000 to 3,000

Annual operation and maintenance cost:

Pumping septage from septic tank (every 3 to 5 years)	$ 5 to 20
Total	$ 5 to 20

Soil absorption system construction cost includes excavation, gravel, pipe, backfill, and miscellaneous labor. This cost can vary significantly, depending upon site and soil characteristics, size and type of bed, and local material and labor costs.

REFERENCE - 103

*To convert construction cost to capital cost see Table A-2.

SEPTIC TANK MOUND SYSTEMS FACT SHEET 7.1.7

Description - A septic tank and mound system is a method of on-site treatment and disposal of domestic wastewater that can be used as an alternative to the conventional septic tank-soil absorption system. (See Fact Sheet 7.1.6.) In areas where problem soil conditions preclude the use of subsurface trenches or seepage beds, mounds can be installed to raise the absorption field above ground, provide treatment, and distribute the wastewater to the underlying soil over a wide area in a uniform manner.

The three main elements of the system are the septic tank, dosing chamber, and the mound. The relative dimensions and location of the septic tank, the type of control structures, the size and loading of inspection ports, and the materials of construction are dictated by State and local codes. A pressure distribution network should be used for uniform application of clarified tank effluent to the mound. A subsurface chamber can be installed with a pump and high water alarm to dose the mound through a series of perforated pipes. Where sufficient head is available, a dosing siphon may be used.

The design of a mound is based on the expected daily wastewater volume it will receive and the natural soil characteristics. As with the conventional subsurface disposal system, pollutants are removed by natural adsorption and biological processes in the soil zone adjacent to the seepage bed. The mound must provide an adequate amount of unsaturated soil and spread septic tank effluent over a wide enough area so that distribution and purification can be effected before the water table is reached.

A clean, medium sand is normally used as fill in which gravel trenches or beds are excavated consisting of 1 to 1½ inch stones to surround distribution pipes. As in any seepage system, a clogging mat will develop at the gravel-sand interface. The equilibrium flow rate through this zone has been shown to be 1.25 gpd/ft^2. Sufficient interfacial area must therefore be available for the design flow. The total effective basal area of the mound must be sized to permit the effluent to percolate into the native soil. Infiltration rates into the natural soil are based on the hydraulic conductivity characteristics of the least permeable soil horizon below the proposed site.

Common Modifications - Different types and arrangements of seepage systems may be installed within a mound, depending upon the characteristics of the underlying soil. One or more trenches may be used above wet, slowly permeable subsoil to spread percolating liquid over a large area and to prevent ponding. When the permeability of the natural soil is not a limiting factor, rectangular seepage beds are usually more suitable than trenches. Although some mound designs do not employ dosing systems, these designs are not normally suitable for proper performance of a mound.

Technology Status - Septic tank mound systems have proven to be successful alternatives for difficult soil conditions. They have been in use for more than twenty years in various forms and for nearly ten years with the design described herein.

Typical Equipment/No. of Mfrs. - Pump chamber with controls/more than 50; Septic tank and piping/locally supplied.

Applications - Used as alternative to septic tank-soil absorption system in problem soil conditions. Spreads percolating liquid over wide area to slowly permeable (60-120 min/in percolation rate) subsoil. Increases amount of soil over shallow, permeable subsoil on creviced bedrock or high water table to provide sufficient contact time for purification before effluent reaches groundwater.

Limitations - Requires more space and periodic maintenance than conventional subsurface disposal system, along with higher construction costs. System cannot be installed on steep slopes, nor over highly (120 min/in.) impermeable subsurface. Seasonal high groundwater must be deeper than two feet to prevent surfacing at the edge of the mound. Pumping is usually required to distribute tank effluent throughout mound, necessitating O/M requirements.

Performance - As with other soil absorption systems, performance is a function of several factors, including design, construction, maintenance, waste characteristics, and soil conditions. BOD, SS, heavy metals, complex organic compounds, bacteria, and viruses are effectively removed by soil under proper conditions. However, nitrates are unaffected and often discharged to groundwaters.

Chemicals Required - None.

Residuals Generated - Septage is generated, requiring treatment and disposal. See Fact Sheet 7.1.9. Volume equal to septic tank capacity every 3 to 5 years.

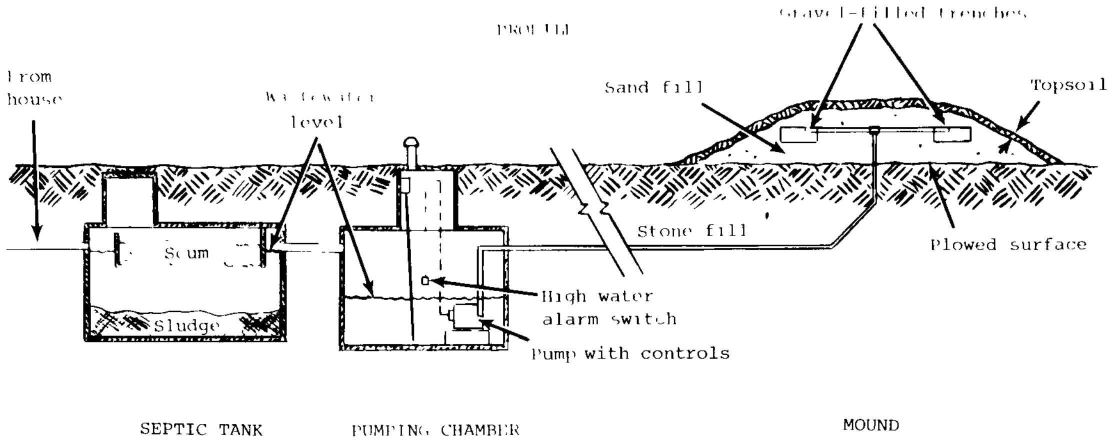
Design Criteria - Design flow basis: 75 gal/person/d; 150 gal/bedroom/d. Basal area based on percolation rates up to 120 min/in. Mound height at center approximately 3.5 to 5 ft. Pump (centrifugal) must accommodate approximately 30 gal/min at required TDH. Pump controls: level or timer.

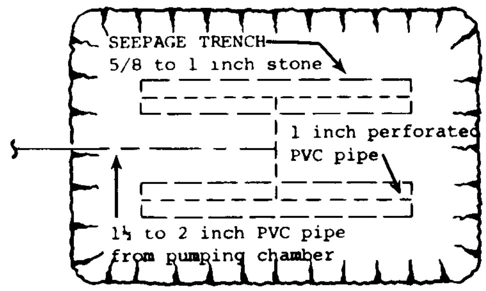
Process Reliability - Septic tank-mound systems that are properly designed and constructed are viable alternatives to centralized treatment facilities. Dosing equipment should be routinely maintained, and septic tanks must be periodically pumped out for systems to operate effectively. Long term service life data is not available as yet, but projections suggest mound life to be about the same as that of properly designed soil system.

Environmental Impact - Visual impact can raise major aesthetic issues, particularly in suburban areas, due to the shape, size and proximity of mound systems. Drainage patterns and land use flexibility may also be affected.

References - 14, 36, 134, 135

FLOW DIAGRAM (typical)





PLAN VIEW

ENERGY NOTES - Minimum power (50 to 250 kWh/yr) required to operate small sump pump for dosing mound.

COSTS* - 1978 dollars; ENR Index = 2776. The following site specific costs serve to illustrate the major components of a 300 gal/d household mound with two level trenches 3 x 41 ft, 65 x 42 ft basal area, and a peak mound height of 3.5 ft.

Construction Cost	
Building sewer and 1000 gal septic tank, design and permit	$ 700
Pumping chamber with 1/2 hp sump pump and controls ($600 to $1000)	800
Mound system	2,400
Total	$3,900

Annual Operating and Maintenance Cost	
Operation and maintenance of pumping chamber ($20 to $50 per year)	$ 30
Pumping septage from septic tank (every 3 to 5 years)	15
Total	$ 45

The construction cost for this mound system includes 12 tons gravel, 265 tons sand, 110 tons clay fill/topsoil, 48 ft of 2-in PVC pipe, 82 ft of 1-in perforated PVC pipe, hay to cover trenches, and labor. This cost can vary significantly depending upon site characteristics and local material and labor costs. Mound systems of this type are quoted to cost anywhere from $2,500 to $5,000. The range of mound costs has also been expressed as $0.75 to $3.00/ft^2 of basal area.

REFERENCES - 14, 103

*To convert construction cost to capital cost see Table A-2.

Description - Surface discharge of septic tank effluent is a method of on-site disposal of domestic wastewater that can be used as an alternative to the conventional soil absorption system (See Fact Sheet 7.1.6). Where permitted by code, surface discharge units can be employed in areas where subsurface disposal systems are not feasible. Since septic tank effluent quality is clearly unacceptable for direct discharge, additional processing is required which should be consistent with the principles of on-site treatment, i.e., simplicity and low O/M. Filtration, with its positive removal mechanisms, is particularly well suited for this purpose. Sand filter trenches are similar to absorption trenches, but contain an intermediate layer of sand as filtering material and underdrains for carrying off the filtered sewage. Buried sand filters, which require less area than trenches, are typically installed with underdrains in 1 ft of coarse gravel, covered with 2 ft of sand (0.4 to 0.6mm effective size with uniformity coefficient less than 4.0), followed by influent drain tile or perforated pipe in another foot of gravel, and covered with at least 6 in of topsoil. Intermittent slow sand filters are divided into two or more units, which are alternately loaded and rested. Wastewater is applied over a bed of sand (0.2 to 0.6 mm effective size with uniformity coefficient less than 4.0) 2 to 3 ft deep and the filtrate is collected by underdrains contained in a layer of gravel. The sand remains aerobic and serves as a biological filter, removing SS and dissolved organics. Because of smaller sand size and higher loading rates, these units require accessibility for periodic servicing. The recirculating filter system consists of a septic tank and a recirculation tank, containing a timer-controlled sump pump for dosing onto a sand filter. The filter bed contains 3 ft of coarse sand (0.6 to 1.5mm effective size with less than 2.5 uniformity coefficient) and 1 ft of gravel surrounding the underdrain system. A recirculation ratio of 4:1 (recycled filter effluent to forward flow) is recommended. If the tank effluent requires disinfection, alternatives that are likely with on-site systems include tablet chlorination, iodine crystals, and ultraviolet irradiation. (See Fact Sheet 7.1.3.)

Common Modifications - Buried sand filters should be constructed in two sections, which are dosed separately by a tank with alternating siphons. Above ground sand filters (intermittent or recirculating) can be installed in areas where subsurface construction is impossible. Dosing tanks and pumps feed these filters, which may be open or covered, but must be accessible for cleaning. Covering and insulation are recommended for intermittent and recirculating filters to minimize freezing in cold weather and potential health risks and nuisances in warm weather.

Technology Status - Sand filtration has traditionally been employed to treat septic tank effluent. The recirculating and sand filter is a relatively new type of on-site filter, but has enjoyed success in Illinois and Oregon.

Typical Equipment/No. of Mfrs. - Septic tank and distribution piping/locally supplied; dosing tank and pump/more than 5; dry chlorine feeder/approx. 10; iodination unit/more than 2; UV water purification unit/approx. 6.

Applications - Surface discharge systems are alternative designs to be used where site conditions, including geology, hydrology, and lot size, preclude the use of the soil as a treatment and disposal medium. Centralized management, rather than homeowners, are normally required for successful operation.

Limitations - Because of additional processing involved, these systems are more expensive than conventional on-site systems. Filter surfaces and disinfection equipment require periodic maintenance. Buried sand beds are inaccessible. Power is required for pumping and some disinfection units. State or Federal discharge permits along with sampling and monitoring are required.

Performance (14)- Effluent quality data from experimental septic tank-intermittent sand filter systems with 5 $gal/d/ft^2$ average loading rate, 0.45mm effective size, and 3.0 uniformity coefficient:

Parameter	Septic Tank Effluent	Sand Filter Effluent	Chlorinated Effluent
BOD, mg/l	123	9	3
TSS, mg/l	48	6	6
Total nitrogen (N), mg/l	23.9	24.5	19.9
Ammonia-nitrogen, mg/l	19.2	1.0	1.6
Nitrate-nitrogen, mg/l	.3	20.0	18.9
Total phosphorus (P), mg/l	10.2	9.0	8.4
Fecal coliforms (number per 100 ml)	5.9×10^5	1.3×10^3	2
Total coliforms (number per 100 ml)	9.0×10^5	6.5×10^3	3

Residuals Generated - See Fact Sheet 7.1.9 for septic tank residuals. Sand with putrescible organic matter must be removed from intermittent and recirculating filter surfaces when clogging occurs and may be buried on-site or require off-site disposal.

Design Criteria - Recommended loading rates in $gal/d/ft^2$: Buried sand filter 0.75 to 1.5, intermittent sand filter 5, recirculating sand filter 3 (based on forward flow alone).

Reliability - Sand filters perform well, unless overloaded. Periodic inspection is required to obtain proper functioning of chlorination, UV, and iodination units. (See Fact Sheet 7.1.3).

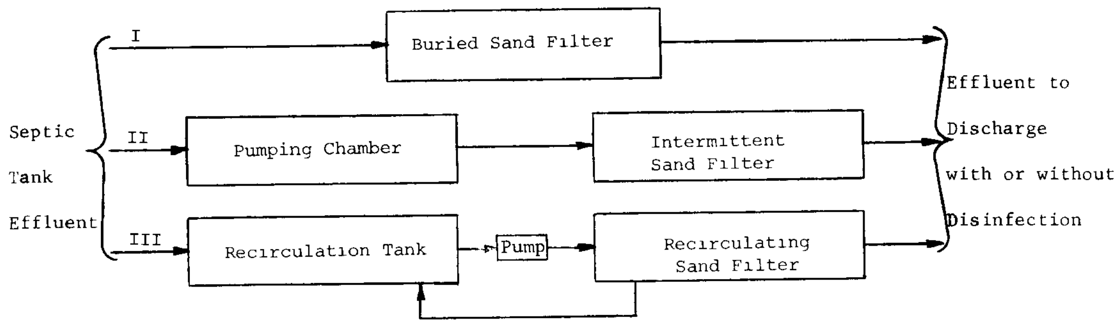
Environmental Impact - Treated effluents are discharged to surface waters. Processing and disposal of septage is required. Odors may emanate from open filters, and potential health risks increase without proper fencing or other access control.

References - 14, 36, 103, 134

SEPTIC TANK POLISHING, SURFACE DISCHARGE

FACT SHEET 7.1.8

FLOW DIAGRAM -



ENERGY NOTES - Minimum power (50 to 250 kWh/yr) required for operation of small sump pump for dosing intermittent slow sand filter and recirculating sand filter. Dosing siphons are often used with buried sand filters.

COSTS* - 1978 dollars; ENR Index = 2776. The following site specific costs serve to illustrate the major components of three types of filters normally employed to treat septic tank effluent for on-site, surface discharge.

I. Buried sand filter: 300 gal/d; 17 ft x 17 ft filter; vertical profile of 12 in. gravel, 2 ft sand and 12 in. gravel; 2 ft soil cover for depth necessary to operate dosing siphon; 25 ft from discharge.

Construction cost:

Excavation, backfill, hauling (160 yd^3)	$ 400
Sand (22 yd^3) and gravel (22 yd^3)	200
Filter pipe (100 ft) and ancillary pipe (25 ft)	100
Siphon	500
Supervision and labor	300
Total	$1,500

Annual operation and maintenance cost:
None

The construction cost for the buried sand filter above lies at the low end of a reported range of $1,500 to $3,000 for these units. However, dual systems are recommended because of their permanence and inaccessibility. cessibility.

II. Intermittent slow sand filter: 250 gal/d; two 50 ft^2 covered filters; vertical profile of 30 in. sand and 16 in. gravel; pump dosing system; 25 ft from discharge.

Construction cost:

Excavation (40 yd^3)	$ 30
Sand (10 yd^3) and gravel (5 yd^3)	70
Filter pipe (100 ft) and ancillary pipe (25 ft)	80
Two 1500 gal tanks for filter housing	600
Insulated covers, splash plates, etc.	220
Pump chamber with 1/2 hp sump pump and controls	800
Supervision and labor	200
Total	$2,000

Annual operation and maintenance cost:

Pumping chamber maintenance and restoration of filter capacity	$100-150

The construction cost of the above sand filter, without the pump chamber, is $12/$ft^2$, which is consistent with a reported range of $10 to $15/$ft^2$. In mild climates, it is possible that an excavated, plastic-lined housing could be substituted for the tanks included above.

III. Recirculating sand filter: 300 gal/d; 100 ft^2 open filter; vertical profile 3 ft sand and 1 ft gravel; 25 ft from discharge.

Construction cost:

Excavation (22 yd^3)	$ 20
Sand (12 yd^3) and gravel (4 yd^3)	80
Internal (100 ft) and external (25 ft) piping	100
Recirculation tank (1000 gal)	250
Filter housing	600
Pump, controls, fittings	450
Supervision and labor	200
Total	$1,700

Annual operation and maintenance cost:

Pump maintenance and restoration of filter capacity	$50 - $100

The construction cost for the above recirculating sand filter does not include the cost of covers and insulation, which will be required for cold weather application.

NOTE - See Fact Sheets 7.1.3 and 7.1.6 for disinfection and septic tank cost and energy data.

REFERENCES - 14, 103

*To convert construction cost to capital cost see Table A-2.

SEPTAGE TREATMENT AND DISPOSAL FACT SHEET 7.1.9

Description - Common methods of septage treatment and disposal include land application, disposal at wastewater treatment plants, and disposal at separate septage treatment facilities. Septage is a highly variable, high strength organic slurry characterized by an obnoxious odor, resistance to settling and dewatering, potential to foam, and often significant contents of grease, grit and hair. The concentration of metals is considerably lower than that of domestic sludge; consequently, heavy metals in septage do not constitute a serious problem. Significant numbers of indicator organisms and pathogens may be found in septage. Several parasites have also been identified in septage. Proper handling, treatment, and disposal of septage is necessary to eliminate a potential threat to public health.

Land Disposal - Septage is applied to land by the same methods used for disposal of municipal treatment plant sludge. Fact Sheets which are most applicable to land disposal of septage are: Land Application of Sludge (6.1.3) and Sludge Lagoons (6.1.11). Septage is also disposed of at landfills by a variety of techniques. However, the low solids content of septage often makes this practice undesirable.

Disposal at Sewage Treatment Plants - Septage treatment and disposal is achieved by addition to the plant liquid or sludge streams at various points in the process train. For plants with primary clarification, addition upstream of the clarifier is preferable, as it effectively achieves septage solids concentration and incorporation into the sludge stream without upsetting effluent quality. Other plant configurations may require direct addition to the biological treatment process or to sludge handling processes such as thickening, digestion, dewatering, etc. Addition of septage to the liquid stream of a wastewater treatment plant may cause upsets in plant performance due to temporary hydraulic or organic overloads, clogging or fouling of plant equipment, or by exceeding the solids handling capacity of the plant. For this reason, a septage receiving station may be added to allow easy and safe transfer of septage from the hauler truck, to provide some form of pretreatment (e.g., screening) to protect equipment, and to allow controlled addition from a holding tank into the desired process. Most wastewater treatment processes are able to treat septage; however, some are more effective than others. Conventional activated sludge, preceded by a buffering primary clarifier, can effectively treat septage. Extended aeration plants of sufficient capacity are able to handle septage relatively well. Trickling filter plants are potential acceptors of septage; however, odor generation, filter fly proliferation, and media clogging may be a problem at increased organic loading. Contact stabilization processes without primary clarification appear to be least amenable to septage treatment due to short contact time. Septage addition to the reaeration zone or digester would be the preferred approach for such plants. Addition of septage to the sludge stream of a wastewater treatment plant avoids possible problems with pumping, biological overloading, and greater sludge volumes for final disposal. Fact Sheets applicable to disposal of septage at wastewater treatment plants are: Clarifier, Primary, Circular with Pump (3.1.1); Clarifier, Primary, Rectangular with Pump (3.1.2); Activated Sludge, Conventional, Diffused Aeration (2.1.1); Activated Sludge, Conventional, Mechanical Aeration (2.1.2); Activated Sludge with Nitrification (2.1.6); Contact Stabilization, Diffused Aeration (2.1.8); Extended Aeration, Mechanical and Diffused Aeration (2.1.10); Lagoons, Aerated (2.1.11); Oxidation Ditch (2.1.15); Trickling Filter, Plastic Media (2.2.6); Trickling Filter, High Rate, Rock Media (2.2.7); Trickling Filter, Low Rate, Rock Media (2.2.8).

Disposal at Separate Facilities - In rural areas where land disposal is not feasible and no wastewater treatment plant is available, septage may be collected and treated at separate septage treatment facilities. Several conventional processes for treating sludge can be used to stabilize and dispose of septage. Supernatant from separation processes must be treated prior to disposal. Applicable processes and Fact Sheets are: Sludge Lagoons (6.1.11); Lime Stabilization (6.4.8); Composting (6.2.3, 6.2.4); Chemical Treatment (4.3.1); Dewatering (6.3.1, 6.3.2, 6.3.3, 6.3.4, 6.3.5, 6.3.9). In addition, chlorine oxidation for stabilization of septage has also been used.

Technology Status - Land disposal practice for septage is generally uncontrolled surface application on remote land with little or no stabilization. Land application of septage is by far the most widely used means of septage disposal. Estimates regarding fraction of septage disposed of on land range from 60-90 percent of total septage generated. Septage disposal at the treatment plant is limited to plants which have excess capacity to handle the additional solids and BOD_5 load due to septage. Disposal at treatment plants is estimated to account for up to 25 percent of the total septage slated for disposal. Septage treatment and disposal at separate facilities is practiced in areas where high densities of septic tank systems exist and large volumes of septage are handled. Chemical treatment, composting, and lagoons are in full-scale use. Some septage treatment methods have not gained economic acceptance. Septage has also been improperly disposed of by surreptitious disposal into sewers, receiving streams, or by dumping on land.

Limitations - Refer to individual fact sheets referenced above.

Design Criteria - Septage generation rates for a particular area may be estimated by several methods. Accurate records kept by septage haulers may provide reasonable estimates of annual septage production rate. Alternatively, assuming the number of dwellings using septic tanks is known, a tank volume (e.g., 1000 gal) and pumping frequency (e.g., every 4 years) can be assumed, allowing a simple calculation of generation rates (e.g., 500 homes x 1000 gal/4 years = 125,000 gal/yr). A crude estimate of septage generation rate may be made by assuming a per capita septage production of 60-80 gal/cap/year.

Typical characteristics of domestic septage are: TS - 3,600-106,000 mg/l; SS - 1,770-22,600 mg/l; BOD_5 - 1,460-18,600 mg/l; COD - 2,200-190,000 mg/l; TKN - 66-1,560 mg/l; NH_3-N 6-385 mg/l; Total P - 24-760 mg/l; Grease - 604-23,468 mg/l. As indicated, septage characteristics are highly variable.

Environmental Impact - Refer to individual fact sheets referenced above.

References - 12, 14, 135, 234, 235, 236-258

SEPTAGE TREATMENT AND DISPOSAL

FACT SHEET 7.1.9

FLOW DIAGRAMS - Refer to individual fact sheets referenced in text for flow diagrams of pertinent processes.

ENERGY NOTES - Refer to individual fact sheets referenced in text for energy requirements for various methods of septage treatment and disposal.

COSTS* (1st quarter 1978 dollars); ENR = 2681

Septage Treatment and/or Disposal Method	Cost per 1000 gal of Septage	Notes
Land Application		
Surface Spreading	$1.25-$17.00	Transportation costs incurred by septage hauler to and from the disposal site not included.
Subsurface Disposal	$20-$35	Transportation costs not included.
Trench Disposal	$20-$30	Transportation costs not included. Site life is assumed to be 10 years. Facility capacity varies from 100,000 gal/yr to 250,000 gal/yr.
Sanitary Landfill Disposal	$5-$10	Accurate cost data not available. Septage often not accepted at landfills due to low solids content.
Disposal at Wastewater Treatment Plants	$20-$30	Costs shown are total treatment costs, including amortization of capital expenditure for a receiving station.
Separate Septage Facilities		
Lagoon Disposal	$5-$20	Costs may vary considerably depending upon land costs and costs of solids removal from lagoon.
Lime Stabilization	$10-$20 $30-$35	Includes land spreading of limed liquid sludge. Includes sand drying bed dewatering.
Chlorine Oxidation	$30-$60	Process has high chlorine requirement and the operating costs are dependent on fluctuations in the price of chlorine.
Composting	$30-$60	Revenues from sale of compost product not included. Unit cost of bulking materials may be critical. Dewatering prior to composting may be desirable.
Chemical Treatment/ Dewatering	$30-$50	Includes costs of chemical clarification, solids conditioning/dewatering, and effluent polishing/disposal.

REFERENCE - 234

*To convert construction cost to capital cost see Table A-2.

IN-THE-HOME TREATMENT AND RECYCLE — FACT SHEET 7.2.1

Description - The waste stream from one or more household fixtures can be treated to provide the water supply for water uses, such as laundry, toilet, lawn sprinkling, car washing, etc. The primary purpose of the in-the-home-treatment and recycle system is to reduce the quantity of water used and/or wastewater generated. Numerous wastewater reuse options are available. Recycle systems are presently marketed which involve the treatment of various fractions of the waste stream to satisfy a variety of uses. One purports to have a complete recycle-closed loop process. However, little reliability and cost data are available. A system can be assembled from existing components.

Treatment methods for recycle include ion exchange, aeration, adsorption, clarification, filtration and disinfection. One of the major options involves the recycling of bathing and laundry water for flushing of water carriage toilets (BL/T). This system may consist of a holding tank, filtration device (paper cartridge, sand, diatomaceous earth, etc.), a disinfection process (chlorine or iodine), and a pump-pressure tank combination for supplying the treated water. Makeup water (tap water) is brought in as required when demand exceeds supply. In general, pressurized media filtration systems are of moderate hardware complexity and require maintenance performed by semi-skilled servicemen. Routine adjustment of filtration equipment generally is required two to four times per year. Unscheduled maintenance is required infrequently. Disinfection is necessary to control odors and bacterial growth. The most common type of disinfection feeder for small waste flows has been the stacked-solid tablet feeder employing $Ca(OCl)_2$. Dosage is controlled by flow control weirs or by diversion of a portion of the waste through the unit. See Fact sheet 7.1.3. Maintenance also includes cleaning of storage reservoirs, maintenance of mechanical equipment, including pumps and residual disposal.

Modifications - Numerous options for recycle and reuse are possible. Most systems which recycle to the toilet are dyed in some manner for aesthetic reasons.

Technology Status - Many complete systems are currently being tested. Most systems are assembled from existing components.

Typical Equipment/No. Mfrs. (23) - Filters/20; tanks/2; pumps/34; automatic feeders/4; controls/310; disinfection units/more than 15; ion exchange equipment/15.

Applications - A flow reduction measure, which is suitable for increasing the life or improving the performance of on-site soil disposal systems. It occasionally permits the use of subsurface disposal systems where available land area is very limited but soils have acceptable percolation characteristics or where land is available with a limited ability to accept wastewater. Involves semi-skilled to skilled labor, depending on system.

Limitations - Operation and maintenance requirements are substantial and should be performed by centralized management personnel to prevent potential health risks.

Performance - Variable levels of flow reduction and treatment are achieved depending upon system developed. Recycling bath and laundry wastes to toilet (BL/T) reduces flow about 30 to 35 percent. Analysis of bath and laundry wastewaters after filtration through three units is summarized below: (159)

Filter System	Average Effluent Turbidity, ppm	Average Effluent Suspended Solids, mg/l
Diatomite	23	21
Cartridge, Surface Type	60	31
Cartridge, Depth Type	62	43

Chemicals Required - Disinfectants; may require coagulants, polymers for solids and scale control.

Residuals Generated - Sludge, scum.

Design Criteria - The following reuse water quality objectives are suggested to determine the level of wastewater treatment necessary prior to on-site reuse. (152)

	Suggested Reuse Water Quality Criteria		
Grade	BOD (mg/l)	SS (mg/l)	Turbidity (TU)
Toilet Flushing	20	20	25
Utility (lawn watering, irrigation, car and house washing, toilet flushing)	15	15	20
Body Contact (laundry, shower, fire fighting, plus all of the above)	10	10	1

There should be no disagreeable colors, odors or visible oil and grease; pH 6.5-8.5; and caution should be used in lawn watering, irrigation, etc., owing to certain constituents, e.g., boron which adversely affects plant growth.

Process Reliability - Reliability data on recycle systems not available, but significant maintenance can be anticipated as a direct function of system complexity.

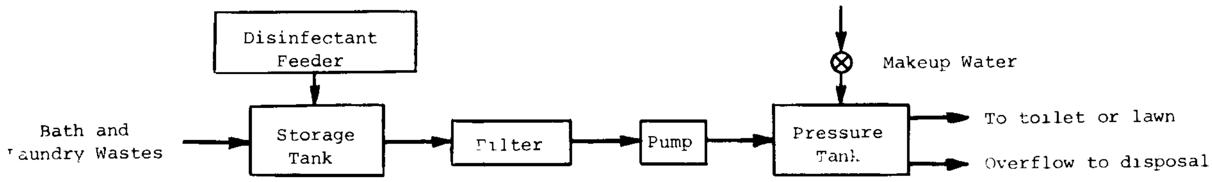
Environmental Impact - Odors may be generated and water quality may be aesthetically objectionable when systems malfunction or are overstressed. User acceptance may be difficult. Potential health risks exist but may be kept at an acceptable level by proper centralized arrangements.

References - 149, 152, 159

IN-THE-HOME TREATMENT AND RECYCLE

FACT SHEET 7.2.1

FLOW DIAGRAM
Numerous recycling options are possible. One example is given below:



ENERGY NOTES - Minimum power (60 to 600 kWh/yr) required for operation of small pump.

COSTS* - 1974 dollars; ENR = 2020.

	Prototype Recycle Systems		Projection for Mass Produced Recycle System
	Diatomite Filter	Cartridge Filter	Diatomite Filter
Installed Cost			
Storage system	$175	$175	$ 70
Filter	135	60	100
Pressurization system	115	115	85
Disinfectant feeder	20	20	20
Valves, pipe, fittings	95	80	75
Total Material Cost	540	450	350
Labor Cost	100	90	50
Total	$640	$540	$400

Costs of system housing and major retrofitting requirements are not included.

Annual Operating Cost			
Filter Media	3.50	38.80	3.50
Electric Power	12.00	1.20	7.00
Disinfectant	5.50	5.50	5.50
Total	$21.00	$45.50	$16.00

Electric Costs = $.02 kWh. Calculations based on a 16-h "on", 8-h "off" cycle for the recirculation pump.

Total Annual Cost			
Expected life, yrs	15	15	15
Total Cost/yr	$63.50	$81.50	$43.00

Installation of a recycle system for toilet flushwater can result in a cost saving in the installation of on-site disposal systems since there are reduced capacity requirements. Assuming a 1/3 reduction in flow, the following savings can be realized: (103)

Disposal Method	Costs without Recycling	minus Costs with Recycling	equals Savings
Septic Tank-Soil Adsorption System	$2275 (1000 ft^2)	$1775 (667 ft^2)	$ 500
Septic Tank-Evapotranspiration	5000 (5000 ft^2)	3600 (3333 ft^2)	1400
Septic Tank-Intermittent Sand Filter	2800 (100 ft^2)	2500 (67 ft^2)	300

Water costs would generally be reduced, but exact figures are site specific.

REFERENCES - 103, 149, 159

*To convert construction cost to capital cost see Table A-2.

NON-WATER CARRIAGE TOILETS FACT SHEET 7.2.2

Description - Non-water carriage toilets serve to eliminate the toilet contribution (black wastes) to the household wastewater. Methods include: thermal (incineration, evaporation-condensation), freezing, oil recirculating, composting (small, large), holding (packaging). Descriptions of those systems for which there is available on-site hardware and performance information follow:

Incinerating Toilets - Small self-contained units which utilize the process of incineration to volatilize the organic components of solid wastes and evaporate the liquid. Wastes are deposited into a combustion chamber and are incinerated upon a signal. The process is fueled by gas, fuel oil or electricity. Units are equipped with appropriate exhaust gas vent and blower. Ash residue should be removed using a vacuum cleaner or dustpan and brush once/wk. Routine cleaning of toilet bowl or replacement of toilet bowl liner is required.

Composting Toilets - Organic matter from feces, urine and sometimes garbage undergoes aerobic composting and is converted to humus which may be dispersed on the soil. Two basic varieties of toilet systems are available, those in which the point of use is removed from the decomposition chamber (separated) and those in which the point of use is directly attached to the chamber (non-separated). Separated units are generally larger and rely on low rate, generally aerobic biological action. The non-separated units are equipped with an electric heating element and a mechanical stirring mechanism. These smaller units depend upon both thermal dehydration and high rate aerobic biological activity. Operation and maintenance requirements: Separate units - removal of compost residue approximately once/yr; periodic addition of organic solids to prevent compost mass compaction may be required, and infrequent maintenance of mechanical parts. Non-separated units - removal of compost residue at least 4 times/yr; mixing of compost daily; periodic maintenance of mechanical parts including fan, heater and stirrers.

Oil Recirculating Toilets - Toilet wastes are carried by a recirculating petroleum base flushing liquid, separated, and stored for subsequent removal and disposal. System requirements include toilet bowl, waste separation and purification system, pump and controls. Removal and disposal of residuals is required annually. Maintenance includes the replacement of exhausted adsorbent, disinfection and filtration media and lost flushing oil. With all non-water carriage toilets, the remaining household wastewater (65 to 70 percent of combined volume) must be treated and disposed of in an environmentally acceptable manner.

Technology Status - Relatively new. Evaluation of performance in households is inadequate in United States.

Applications - Non-water carriage toilets, as part of total household wastewater alternative, may be economically viable in areas where water supplies are limited and other wastewater alternatives are environmentally limited.

Limitations - Incinerating toilets, gas and oil fired require more frequent maintenance than electric; electric have higher energy costs. Toilet capacity less than or equal to 3 uses/h. Composting - non-separated unit is subject to hydraulic overloads and has a unit capacity less than or equal to 3 persons. Larger, separated units have a capacity less than or equal to 5 persons. Continuous nature of both process types provides potential for short circuiting and contamination of stabilized compost by "fresh" waste materials. Oil recirculating - large space requirements. Incomplete separation of aqueous base liquids from flushing oil due to the formation of oil-water emulsions. Flushing oil deteriorates. Costs are quite high. All units are limited to toilet wastes (1/3 total waste flow), and graywater treatment and disposal must be provided. Also, user acceptance is an important factor. All systems require commitment of the user to sustain the process.

Typical Equipment/No. Mfrs. - Incinerating/more than 8; small composting/more than 12, large composting/more than 3, oil recirculating/more than 3.

Performance (14) - The effect of eliminating blackwater from household wastewater discharges (% reduction): Flow 30 to 35; BOD, 10 to 35; SS, 20 to 60; Total P, 15 to 40; TKN, 40 to 90; Pathogenic organisms, considerable.

Chemicals Required - Incinerating - none. Composting - peat "starters" are normally required to maintain good moisture distribution, prevent compaction and facilitate aeration; fibrous dry organic materials are added periodically with separated type. Oil recirculation - Makeup oil (up to 8 gal/yr) may be required; filter, coalescer, adsorbent and disinfectant cartridges.

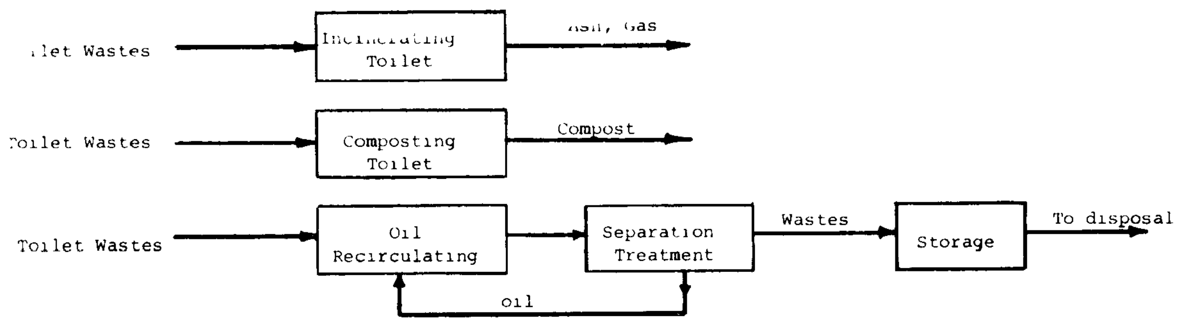
Residuals - Incinerating - an inert sterile ash; Composting - a humus suitable as a soil conditioner; Oil recirculating - oil coated residue, exhausted filtration media.

Design Criteria (149) - Typical toilet waste loadings (g/cap/d): BOD, 16.7; SS, 27; TKN, 8.7; Total P, 1.2; Incinerating - gas fired requires propane or natural gas, combustion/cooling cycle 20-25 minutes; electric unit requires 115 or 220 volts AC or 12 volts DC, combustion/cooling cycle 45 minutes; Composting - separated unit space requirement 30 to 70 ft^3; non-separated unit requires 2 to 5 ft^3; Oil recirculation - 53 ft^3 holding tank space requirement.

Environmental Impact - Commitment of water resources to toilet is eliminated; volume and pollutant loadings to on-site disposal systems are reduced. Incinerating - potential odor or air pollution problems, potential fire or explosion hazard, high energy use; Composting - nutrient elements in sewage are conserved, potential odor problems and health hazards due to vectors and incompletely composted residue contacts; Oil recirculating - potential odor and discoloration problems; disposal of residuals may be a problem due to their oily character.

References - 14, 149, 152

FLOW DIAGRAM



ENERGY NOTES (149) -

Incinerating Toilets - Gas (propane)	4,000 to 6,000 Btu/use	(17.5 to 26.2×10^6 Btu/yr)
Incinerating Toilets - Electricity	0.06 to 1.2 kWh/use	(262 to 5,250 kWh/yr)
Composting - Small	1-7 kWh/d	(365 to 2,555 kWh/yr)
Composting - Large	1-8 kWh/d	(365 to 2,920 kWh/yr)
Oil Recirculating Toilet	0.657 kWh/d	(240 kWh/yr)

COSTS*(103) (149) -

1. Labor rates @ $10/hr
2. Energy consumption estimates based on: Gas (propane) @ $\$8/10^6$ Btu; Oil @ $\$3.42/10^6$ Btu; Electricity @ $.02/kWh.
3. Cost estimates based on 1978 dollars; ENR Index ≈ 2776.

Installed Costs ($)

	Incinerating		Composting		Oil Recirculating
	Gas/Oil	Electric	Small	Large	
	800 to 1200	600 to 1000	700 to 1200	1500 to 3200	4500 to 6000

Operation and Maintenance ($/yr)

	Gas/Oil	Electric	Small	Large	Oil Recirculating
Maintenance	80	80	80	40	180
Energy	55 to 230	5 to 110	7 to 51	7 to 58	5
Total	135 to 310	85 to 190	87 to 131	47 to 98	185

REFERENCES - 103, 149, 152

*To convert construction cost to capital cost see Table A-2.

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APPENDIX B

LEGISLATION, REGULATIONS, AND PROGRAM GUIDANCE INFORMATION PERTAINING TO INNOVATIVE AND ALTERNATIVE TECHNOLOGY UNDER PL 95-217

APPENDIX B

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LEGISLATION

The following sections of the Clean Water Act Amendments of 1977 (PL 95-217) contain specific provisions relating to innovative and alternative technology. A one sentence synopsis as well as the complete text of the applicable sections of the law has been provided in this first section of the appendix. This is followed by all pertinent agency (EPA) regulations that have been promulgated as required by the law, along with additional program guidance information.

Section 201(d) Encourages revenue producing waste management facilities.

Section 201(g)(5) Requires all applicants to fully study innovative and alternative treatment options.

> The administrator shall not make grants from funds authorized for any fiscal year beginning after September 30, 1978, to any State, municipality, or intermunicipal or interstate agency for the erection, building, acquisition, alteration, remodeling, improvement or extension of treatment works unless the grant applicant has satisfactorily demonstrated to the Administrator that innovative and alternative wastewater treatment processes and techniques which provide for the reclaiming and reuse of water, otherwise eliminate the discharge of pollutants, and utilizing recycling techniques, land treatment, new or improved methods of waste treatment management for municipal and industrial waste (discharged into municipal systems) and the confined disposal of pollutants will not migrate to cause water or other environmental pollution, have been fully studied and evaluated by the applicant taking into account Section 201(d) of this Act and taking into account and allowing to the extent practicable the more efficient use of energy and resources.

Section 201(i) Encourages energy conservation.

> The Administrator shall encourage waste treatment management methods, processes, and techniques which will reduce total energy requirements.

Section 201(e) Requires EPA to encourage treatment techniques which will reduce total energy requirements.

> The Administrator shall encourage waste treatment management which results in integrating facilities for sewage treatment and recycling with facilities to treat, dispose of, or utilize other industrial and municipal wastes, including but not limited to solid waste and waste heat and thermal discharges. Such integrated facilities shall be designed and operated to produce revenues in excess of capital and operation and maintenance costs and such revenues shall be used by the designated regional management agency to aid financing other environmental improvement programs.

Section 201(j) Allows EPA to select the innovative and alternative process option if costs are as high as 115% of least costly option.

> The Administrator is authorized to make a grant for any treatment works utilizing processes and techniques meeting the guidelines promulgated under Section 304(d)(3) of this Act, if the Administrator determines it is in the public interest and if in the cost effectiveness study made of the construction grant application for the purpose of evaluating alternative treatment works, the life cycle cost of the treatment works for which the grant is to be made does not exceed the life cycle cost of the most effective alternative by more than 15 per centum.

Section 202(a)(2) Increases Federal grant to 85% for treatment works utilizing innovative or alternative processes.

> The amount of any grant made after September 30, 1978, and before October 1, 1981, for any eligible treatment works or significant portion thereof utilizing innovative or alternative wastewater treatment processes and techniques referred to in section 201(g)(5) shall be 85 per centum of the cost of construction thereof. No grant shall be made under this paragraph for construction of a treatment works in any State unless the proportion of the State contribution to the non-Federal share of construction costs for all treatment works in such State receiving a grant under this paragraph is the same as or greater than the proportion of the State contribution (if any) to the non-Federal share of construction costs for all treatment works receiving grants in such State under paragraph (1) of this subsection.

Section 202(a)(3) Authorizes EPA to pay 100% of all costs to replace innovative or alternative treatment facilities that failed.

> In addition to any grant made pursuant to paragraph (2) of subsection 202(a) the Administrator is authorized to make a grant to fund all of the costs of the modification or replacement of any facilities constructed with a grant made pursuant to paragraph (2) if the Administrator finds that such facilities have not met design performance specifications unless such failure is attributed to negligence on the part of any person and if such failure has significantly increased capital or operating and maintenance expenditures.

Section 202(a)(4) Limits the treatment works eligible for bonus grant increases for innovative and alternative processes to treatment plant-related works only.

> For the purposes of this section, the term "eligible treatment works" means those treatment works in each State which meet the requirements of section 201(g)(5) of this Act and which can be fully funded from funds available for such purpose in such State in

the fiscal years ending September 30, 1979, September 30, 1980, and September 30, 1981. Such term does not include collector sewers, interceptors, storm or sanitary sewers or the separation thereof, or major sewer rehabilitation.

Section 304(d)(3) Mandates that EPA promulgate guidelines for identifying and evaluating innovative and alternative processes during FY 1978.

The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall promulgate within one hundred and eighty days after the date of enactment of this subsection guidelines for identifying and evaluating innovative and alternative wastewater treatment processes and techniques referred to in section 201(g)(5) of this Act.

Section 205(i) Authorizes EPA to set aside a reserve of 2% for each allotment to use only to increase federal share of grants for innovative and alternative processes to 85%.

Not less than one-half of one per centum of funds allotted to a State for each of the fiscal years ending September 30, 1979. September 30, 1980, and September 30, 1981, under subsection (a) of this section shall be expended only for increasing the Federal share of grants for construction of treatment works utilizing innovative processes and techniques from 75 per centum to 85 per centum pursuant to section 202(a)(2) of this Act. Including the expenditures authorized by the preceding sentence, a total of two per centum of the funds alloted to a State for each of the fiscal years ending September 30, 1979, and September 30, 1980, and 3 per centum of the funds allotted to a State for the fiscal year ending September 30, 1981, under subsection (a) of this section shall be expended only for increasing grants for construction of treatment works from 75 per centum to 85 per centum pursuant to section 202(a)(2) of this Act.

REGULATIONS

The following regulations describe the Environmental Protection Agency's requirements for Innovative and Alternative Technolgoy. The basic Innovative Alternative Technology regulation is 35.908 and is presented in its entirety. Applicable portions of other regulations are presented.

35.908 Describes basic agency requirements and policy for funding, priority, and replacement costs for innovative and alternative technology.

(a) Policy. EPA's policy is to encourage, and, where possible, to assist in the development of innovative and alternative technologies for the construction of wastewater treatment works. Such technologies may be used in the construction of wastewater treatment works under this subpart as §35.915-1, §35.930-5, Appendix E, and this section provide. New technology or processes may also be developed or demonstrated with the assistance of EPA research or demonstration grants awarded under Title I of the Act (see Part 40 of this subchapter).

(b) <u>Funding for innovative and alternative technologies.</u>

(1) Projects or portions of projects which meet criteria for innovative or alternative technologies in Appendix E may receive 85 percent grants (see §35.930-5).

(i) Only funds from the reserve in §35.915-1(b) shall be used to increase these grants from 75 to 85 percent.

(ii) Funds for the grant increase shall be distributed according to the chronological approval of grants, unless the State and the Regional Administrator agree otherwise.

(iii) The project must be on the fundable portion of the State project priority list.

(iv) If the project is an alternative to conventional treatment works for a small community (a municipality with a population of 3,500 or less or highly dispersed section of a larger municipality, as defined by the Regional Administrator), funds from the reserve in §35.915(e) may be used for the 75 percent portion of the Federal grant.

(v) Only if sewer related costs qualify as alternatives to conventional treatment works for small communities are they entitled to the grant increase from 75 to 85 percent, either as part of the entire treatment of works or as components.

(2) A project or portions of a project may be designated innovative or alternative on the basis of a facilities plan or on the basis of plans and specifications. A project that has been designated innovative on the basis of the facilities plan may lose that designation if plans and specifications indicate that it does not meet the appropriate criteria stated in section 6 of Appendix E.

(3) Projects or portions of projects that receive Step 2, Step 3, or Step 2+3 grant awards after December 27, 1977, from funds allotted or reallotted in fiscal year 1978 may also receive the grant increase from funds allotted for fiscal year 1979 for eligible portions that meet the criteria for alternative technologies in Appendix E, if funds are available for such purposes under §35.915-1(b).

(c) Modification or replacement of innovative and alternative projects.

The Regional Administrator may award grant assistance to fund 100 percent of the eligible costs of the modification or replacement of any treatment works constructed with 85 percent grant assistance if:

(1) He determines that:

(i) The facilities have not met design performance specifications (unless such failure is due to any person's negligence); and

(ii) Correction of the failure requires significantly increased capital or operating and maintenance expenditures; and

(iii) Such failure has occurred within the two year period following final inspection; and

(2) The replacement or modification project is on the fundable portion of the State's priority list.

35.915(a)(1). Part of the State priority system and project priority list that permits raising priority of innovative alternative projects or innovative alternative 100% replacement grants.

....(iii) Step 2, Step 3 and Step 2+3 projects utilizing processes and techniques meeting the innovative and alternative guidelines in Appendix E of this part may receive higher priority. Also 100 percent grants for projects that modify or replace malfunctioning treatment works constructed with an 85 percent grant may receive a higher priority.

(iv) Other criteria, consistent with these, may be considered (including the special needs of small and rural communities); however, the State shall not consider the project area's development needs not related to pollution abatement, the geographical region within the State, or future population growth projections........

35.915(e). Submission and review of project priority list.

The State shall submit the priority list as part of the annual state program plan under Subpart G of this part. A summary of State agency response to public comment and hearing testimony shall be prepared and submitted with the priority list. The Regional Administrator will not consider a priority list to be final until the public participation requirements are met and all information required for each project has been received. The Regional Administrator will review the final priority list within thirty days to ensure compliance with the approved State priority system. No project may be funded until this review is complete.

35.917-1(d)(8)(9). Energy analysis content of Facilities plan prepared after September 30, 1978, for innovative technology.

(8) For facilities planning begun after September 30, 1978, whether or not prepared under a Step 1 grant, an analysis of innovative and alternative treatment processes and techniques that reclaim and reuse water, productively recycle wastewater constituents, eliminate the discharge of pollutants, recover energy or otherwise achieve the benefits described in Appendix E.........

(9) For facilities planning begun after September 30, 1978, whether or not prepared under a Step 1 grant, an analysis of the primary energy requirements (operational energy inputs) for each system considered. The alternative selected shall propose adoption of measures to reduce energy consumption or to increase recovery as long as such measures are cost-effective. Where processes or techniques are claimed to be innovative technology on the basis of energy reduction criterion contained in paragraph 6e(2) of Appendix E to this subpart, a detailed energy analysis shall be included to substantiate the claim to the satisfaction of the Regional Administrator.

35.915-1(b). Reserve funding for innovative alternative technology.

(b) Reserve for innovative and alternative technology project grant increase.

Each State shall set aside from its annual allotment a specific percentage in order to increase the Federal share of grant awards from 75 percent to 85 percent of the eligible cost of construction (under § 35.908(b)(1)) for construction projects which use innovative or alternative wastewater treatment processes and techniques. The set-aside amount shall be 2 percent of the State's allotment for each of the fiscal years 1979 and 1980, and 3 percent for fiscal year 1981. Of this amount not less than one-half of one percent of the State's allotment shall be set aside in order to increase the Federal grant share for projects utilizing innovative processes and techniques. Funds reserved under this section may be expended on projects for which facilities plans were initiated before fiscal year 1979. These funds shall be reallotted if not used for this purpose during the allotment period.

35.930-5(b). Federal and State funding of Step 2 or 3 grants and Step 2+3 increased (85%) grants.

(b) Innovative and alternative technology.

In accordance with § 35.908(b), the amount of any Step 2, Step 3, or Step 2+3 grant made from funds allotted for fiscal years 1979, 1980, and 1981 shall be 85 percent of the estimated cost of construction for those eligible treatment works or significant portions of them that the Regional Administrator determines meet the criteria for innovative or alternative technology in Appendix E. These grants depend on the availability of funds from the reserve under § 35.915-1(b). The proportional State contribution to the non-Federal share of construction costs for 85 percent grants must be the same as or greater than the proportional State contribution (if any) to the non-Federal share of eligible construction costs for all treatment works which receive 75 percent grants in the State.

(c) Modification and replacement of innovative and alternative projects.

In accordance with §35.908(c) and procedures published by EPA, the Regional Administrator may award grant assistance to fund 100 percent of the eligible costs of the modification or replacement of any treatment works constructed with grant assistance based upon a Federal share of 85 percent under paragraph (b) of this section.

35.935.20. Post award innovative grant requirements

If the grantee receives an 85 percent grant for innovative processes and techniques, the following conditions apply during the 5 year period following completion of construction:

(a) The grantee shall permit EPA personnel and EPA designated contractors to visit and inspect the treatment works at any reasonable time in order to review the operation of the innovative processes or techniques.

(b) If the Regional Administrator requests, the grantee will provide EPA with a brief written report on the construction, operation, and costs of operation of the innovative processes or techniques.

35.936-13. Application of nonrestrictive specifications to innovative alternative technology.

(1) No specification for bids or statement of work in connection with such work shall be written in such a manner as to contain proprietary, exclusionary, or discriminatory requirements other than those based upon performance, unless such requirements are necessary to test or demonstrate a specific thing or to provide for necessary interchangeability of parts and equipment, or at least two brand names or trade names of comparable quality or utility are listed and are followed by the words "or equal." The single base bid method of solicitation for equipment and parts for determination of a low, responsive bidder may not be utilized. With regard to materials, if a single material is specified, the grantee must be prepared to substantiate the basis for the selection of the material.

(2) Project specifications shall, to the extent practicable, provide for maximum use of structures, machines, products, materials, construction methods, and equipment which are readily available through competitive procurement, or through standard or proven production techniques, methods, and processes, except to the extent that innovative technologies may be used under §35.908 of this subpart.

(b) Sole source restriction.

A specification shall not require the use of structures, materials, equipment, or processes which are known to be available only from a sole source, unless the grantee's engineer has adequately justified in writing that the proposed use meets the particular project's minimum needs.

(c) Experience clause restriction.

The general use of experience clauses requiring equipment manufacturers to have a record of satisfactory operation for a specified period of time or of bonds or deposits to guarantee replacement in the event of failure is restricted to special cases where the grantee's engineer adequately justifies any such requirement in writing. Where such justification has been made, submission of a bond or deposit shall be permitted instead of a specified experience period. The period of time for which the bond or deposit is required should not exceed the experience period specified.

(d) Buy American.

(1) Definitions. As used in this subpart, the following definitions apply:

(i) "Construction material" means any article, material, or supply brought to the construction site for incorporation in the building or work.

(ii) "Component" means any article, material, or supply directly incorporated in construction material.

(iii) "Domestic construction material" means an unmanufactured construction material which has been mined or produced in the United States, or a manufactured construction material which has been manufactured in the United States if the cost of its components which are mined, produced, or manufactured in the United States exceeds 50 percent of the cost of all its components.

(iv) "Nondomestic construction material" means a construction material other than a domestic construction material.

(2) Domestic Preference. Domestic construction material may be used in preference to nondomestic materials if it is priced no more than 6 percent higher than the bid or

offered price of the nondomestic materials including all costs of delivery to the construction site, and any applicable duty, whether or not assessed. Computations will normally be based on costs on the date of opening of bids or proposals.

(3) Waiver. The Regional Administrator may waive the Buy American provision based upon those factors that he considers relevant, including:

(i) Such use is not in the public interest;

(ii) The cost is unreasonable;

(iii) The Agency's available resources are not sufficient to implement the provision, subject to the Deputy Administrator's concurrence;

(iv) The articles, materials or supplies of the class or kind to be used or the articles, materials, or supplies from which they are manufactured are not mined, producted, or manufactured in the United States in sufficient and reasonably available commercial quantities or satisfactory quality for the particular project; or

(v) Application of this provision is contrary to multilateral government procurement agreements, subject to the Deputy Administrator's concurrence.

NOV 1 5 1978

CONSTRUCTION GRANTS
PROGRAM REQUIREMENTS MEMORANDUM
PRM 79-3

SUBJECT: Revision of Agency Guidance for Evaluation of Land Treatment Alternatives Employing Surface Application

FROM: Thomas C. Jorling, Assistant Administrator
Water and Waste Management (WH-556)

TO: Regional Administrators (Regions I thru X)

I. PURPOSE

This memorandum consolidates and updates Agency policy and guidance for evaluation of land treatment alternatives using slow rate, rapid infiltration, or overland flow processes in the Construction Grants Program. It provides guidance on the extent and nature of material to be included in facility plans to ensure that these land treatment alternatives have been given thorough evaluation.

II. DISCUSSION

Evaluation of land treatment in facilities planning has been mandatory under PL 92-500 (the Act) since July 1, 1974. The EPA construction grants regulations as published in the Federal Register vol. 39, no. 29, February 11, 1974, provided for coverage of land application techniques in facility planning [35.917-1(d)(5)(iii)]. Three land application (land treatment) techniques were included in the description of alternative techniques for best practicable treatment published in October 1975. Many other technical information bulletins, PGM's, and PRM's have been issued as guidance for the evaluation of land treatment alternatives in the Construction Grants Program.

This approach was used to provide the latest information available to the Regional Offices with a minimum of delay. While the objective of timely distribution of technical information and guidance has been achieved, this piecemeal distribution has also resulted in some disparities in the interpretation and implementation of policy.

Distribution of the Process Design Manual for Land Treatment of Municipal Wastewater (EPA 625/1-77-008) consolidates most of the technical information on surface application approaches into a single reference source. This consolidation of technical information provides a sound basis from which to establish more consistent and effective implementation of Agency policy on land treatment alternatives using the slow rate, rapid infiltration, or overland flow processes.

In the process of coordinating with the Regions on specific projects involving land treatment, OWPO staff has had the opportunity to review a number of selected facility plans with respect to their handling of land treatment alternatives. In addition to providing information pertinent to the specific projects being evaluated, this review has been used to determine what, if any, changes in guidance are needed to achieve more consistent and complete evaluation of land treatment alternatives. Areas being considered include technical assistance and staff training as well as revision of guidance documents.

The results of this review to date show that land treatment technologies have had and continue to have inadequate assessment in many instances. In addition and for substantially more cases, detailed coverage of land treatment has missed the mark for a variety of reasons. Three of the frequently encountered reasons are: (1) overly conservative and, consequently, costly design of slow rate (irrigation) systems, (2) failure to consider rapid infiltration as a proven and implementable land treatment alternative, and (3) provision for a substantially higher and more costly level of preapplication treatment than is needed to protect public health and ensure design performance.

Such inadequate assessment of land treatment alternatives has led to rejection of land treatment in cases where it appears that a thorough assessment would identify less costly alternatives utilizing the recycling and reclamation advantages of land treatment. Consistent with the revised construction grants regulations resulting from enactment of PL 95-217, award of Step 1 grants and subsequent approval of facility plans must ensure that the selected alternative is cost-effective and emphasizes energy conservation and recycling of resources. This is important both to meet the statutory requirements of the law and to provide the maximum pollution control benefits attainable with the funds allocated to the Construction Grants Program.

The Administrator's memorandum of October 3, 1977, emphasizes that the Agency grants program will include thorough consideration of land treatment as compared to conventional treatment and discharge to surface waters.

This program requirements memorandum is designed to consolidate the existing base of guidance into a uniform but still flexible set of guidelines for slow rate, rapid infiltration, and overland flow systems. This should improve our capability to effectively and consistently implement the Agency policy on recycling and reclamation through land treatment alternatives.

III. POLICY

The Administrator's memorandum of October 3, 1977 (Attachment A) spells out three major points of policy emphasis on land treatment of municipal wastewater as follows:

1. The Agency will press vigorously for implementation of land treatment alternatives to reclaim and recycle municipal wastewaters.

2. Rejection of land treatment alternatives shall be supported by a complete justification (reason for rejection shall be well documented in the facilities plan).

3. If the Agency deems the level of preapplication treatment to be unnecessarily stringent, the costs of achieving the excessive level of preapplication treatment will not be considered as eligible for EPA cost sharing when determining the total cost of a project.

These points highlight the Agency's role in implementing the legislative mandates of PL 92-500 and PL 95-217. PL 92-500 required EPA to encourage waste treatment management that recycles nutrients through production of agriculture, silviculture, or aquaculture products. PL 95-217 re-emphasizes the intent to encourage innovative/alternative systems including land treatment with many tangible incentives including (1) the "115%" cost preference, (2) 85% Federal grants with the specific set asides, (3) the eligibility of land for storage, and (4) 100% grants for modification or replacement if project fails to meet design criteria. It is imperative that the Agency moves positively and uniformly to implement land treatment which is clearly identified as an innovative/alternative technology which recycles nutrients and conserves energy in conjunction with wastewater management.

IV. IMPLEMENTATION

The guidance detailed in this PRM will apply to all facility planning grants (Step 1) awarded 30 days after the date of this PRM. In addition it should be applied on a case-by-case basis to those unapproved facility plans for which it appears that further assessment of land treatment alternatives could result in: (1) the timely and effective implementation of a reclamation and recycling alternative; and (2) benefits to the applicant while making better use of EPA construction grant funds.

A. Action Required

Facility plans in which land treatment alternatives are eliminated with only cursory coverage will be rejected as not fulfilling Agency requirements. A facility plan should not be approved until the coverage of these land treatment alternatives satisfies the guidance detailed below. As a minimum, the coverage of these land treatment processes will include assessment of at least one slow rate (irrigation) alternative and one rapid infiltration alternative. Coverage of an overland flow alternative will be optional (case-by-case) until additional information which is presently being developed furnishes design information for routine construction grant implementation. The technical design basis of these land treatment alternatives will be in accordance with the "EPA Design Manual on Land Treatment" (EPA 625/1-77-008), and "Costs of Wastewater Treatment by Land Application" (EPA 430/9-75-003). To be adequate, coverage of these land treatment alternatives shall include enough detail to support development of costs, except in those cases where thorough screening for available sites shows no suitable sites within economic transport distances. Designs for slow rate systems and rapid infiltration systems will include preapplication treatment which is in accord with the discussion of preapplication in the Design Manual (pages 5-26 thru 5-30) and summarized in Attachment B.

A universal requirement to reduce biochemical oxygen demand and suspended solids to 30 mg/l and to disinfect to an average fecal coliform count of 200/100 ml will be considered as excessively stringent preapplication treatment if specified for all land treatment alternatives. States shall be requested to reconsider use of such universal and stringent preapplication treatment requirements when it is established that a lesser level of preapplication treatment will protect the public health, protect the quality of surface waters and groundwater, and will ensure achievement of design performance for the wastewater management system.

States should be encouraged to adopt standards which avoid the use of uniform treatment requirements for land treatment systems, including a minimum of secondary treatment prior to application to the land. The EPA guidance on land treatment systems specifies ranges of values and flexible criteria for evaluating factors such as preapplication treatment, wastewater application rates and buffer zones. For example, simple screening or comminution may be appropriate for overland flow systems in isolated areas with no public access, while extensive biochemical oxygen demand and suspended solids control with disinfection may be called for in the case of slow rate systems in public access areas such as parks or golf courses.

B. Specific Guidance

The scope of work for preparation of a facility plan will provide for thorough evaluation of land treatment alternatives. This evaluation of land treatment alternatives may be accomplished in a two-phase approach. Such a two-phase approach would provide flexibility for establishing general site suitability and cost competitiveness before requiring extensive on-site investigations. The first phase of the two-phase approach would include adequate detail to establish whether or not sites are available, wastewater quality is suitable, and land treatment is cost competitive. The second phase would include in-depth investigation of sites and the refinement of system design factors to complete all of the requirements for preparing a facility plan. Approval of a facility plan will ensure that the following details for evaluation of land treatment are clearly delineated in the plan.

1. Site Selection. A regional map shall be included to show the tracts of land evaluated as probable land treatment sites. The narrative discussion of site evaluation should detail the reasons for rejection of tracts as well as the availability of tracts used in the preliminary design for land treatment alternatives. Table 2-2 of the Design Manual (Attachment C) delineates general site characteristics for land treatment alternatives which the narrative should cover in detail.

Categorical elimination of land treatment for lack of a suitable site (during phase one of a two-phase evaluation) should be documented with support materials showing how the applicant made the determination. For example, elimination for lack of suitable soils should be documented with soils information from the area Soil Conservation Service representatives or other soil scientists who may be available. Any categorical elimination of land treatment should demonstrate that additional engineering necessary to overcome site constraints would make the alternative too costly to fund in accordance with the cost-effectiveness requirements of the law.

2. Loading Rates and Land Area. The values for these parameters evaluated in the facility plan should concur with the technically established ranges for application rates and land area needed for a system. The cost of land treatment is sensitive to these factors and overly conservative design unduly inflates the cost of technically sound alternatives. Designs in a facility plan should fall within the general ranges given in Table 2-1 and Figure 3-3 of the Design Manual. Designs falling outside of these ranges should do so only because of extenuating circumstances peculiar to the site. These extenuating circumstances should be discussed in detail. Table 2-1 (Attachment B) is recommended as a quick reference for determining that designs are reasonable.

3. Estimated Costs. The estimated costs of land treatment alternatives should be comparable to those obtained by using EPA 430/9-75-003 pages 59-127, updated using local construction cost indices. Cost estimates generated by using this source are being compared to actual costs for recently constructed facilities. If this comparison shows that the curves in EPA 430/9-75-003 need adjustment, corrected curves will be made available as necessary.

Elimination of land treatment in the cost-effective analysis because of land costs or transport costs should be documented by means of an actual evaluation for the cost of land or cost of transport. This evaluation should show clearly that the cost of land or the cost of transport does rule out land treatment using the approach shown in "Cost-Effective Comparison of Land Application and Advanced Wastewater Treatment" (EPA 430/9-75-016). Examples on pages 23-24 (Attachment D) of that source show how to make these comparisons.

4. Preapplication Treatment. The level of preapplication treatment prior to storage or actual application to the land should be in accordance with the guidance given for screening wastewaters to be applied to the land in the Design Manual. A universal minimum of secondary treatment for direct surface discharge as published in the August 17, 1973 Federal Register and later modified (Federal Register July 26, 1976 and October 7, 1977) will not be accepted because it is inconsistent with the basic concepts of land treatment. Imposition of a defined discharge criteria at an intermediate point in a treatment train is, in most instances, an unnecessarily stringent preapplication treatment requirement as stated in the Administrator's memorandum dated October 3, 1977. Criteria imposed at an intermediate point should be for the purpose of ensuring overall system performance in the same context that primary sedimentation precedes biological secondary treatment by trickling filter or activated sludge processes.

Assessment of the level of preapplication treatment proposed should be in accord with the discussion in Section 5.2 (pages 5-26 to 5-30) of the Design Manual. Guidelines for evaluating the level of preapplication for slow-rate, rapid infiltration, and overland flow systems in relation to existing state regulations, criteria and guidelines are included in Attachment E. Preapplication treatment criteria more restrictive than the ranges of treatment levels described in Appendix E will be considered unnecessarily stringent unless justified on a case-by-case basis. When the more stringent preapplication treatment criteria cannot be justified, the EPA will consider that portion of the project to meet EPA guidance as eligible for Agency funding. The costs of the additional preapplication increment needed to meet more stringent preapplication treatment requirements imposed at the state or local level would be ineligible for Agency funding and thus would be paid for from state or local funds.

5. Environmental Effects. Assessing the environmental effects of land treatment alternatives involves a somewhat different concept than for conventional treatment and discharge to surface waters. The assessment for land treatment should include emphasis on the quality and quantity of both surface and groundwater resources; on energy conservation as well as energy demands; on pollutant (resource) recycling as well as chemical needs, and on land use in the overall coverage of environmental effects.

The assessment should determine that the proposed land treatment system is in accord with Agency policy on groundwater protection. The Agency policy for groundwater resulting from land treatment systems is set forth in the criteria for Best Practicable Waste Treatment Technology (BPWTT). These criteria specify that the groundwater resulting from a land treatment system must meet different requirements depending on current use and quality of the existing groundwater. The basic thrust of these criteria is to protect groundwater for drinking water purposes by specifying adherence to the appropriate National Primary Drinking Water Standards. The BPWTT criteria further require land treament systems which are underdrained or otherwise designed to have a surface discharge to meet the standards applicable to any treatment and discharge alternative. The criteria are fully described in 41 FR 6190 (February 11, 1976) which is attached as Appendix F.

An overall Agency policy statement on groundwater protection is scheduled for issuance in the near future. The draft Agency groundwater policy is generally consistent with present criteria for land treatment systems. However, any revisions to the present guidance on site evaluation and system monitoring as a result of this statement will have to be accounted for as they are developed. In the meantime, existing guidance should be used to evaluate groundwater influences.

Attachments

V. REFERENCES

Process Design Manual for Land Treatment of Municipal Wastewater EPA 625/1-77-008 October, 1977.

October 3, 1977 memorandum from Administrator:"EPA Policy on Land Treatment of Municipal Wastewater".

"Cost of Wastewater Treatment by Land Application" Technical Report EPA-430/9-75-003 June, 1975.

"Cost-Effective Comparison of Land Application and Advanced Wastewater Treatment" Technical Report EPA-430/9-75-016, November, 1975.

Secondary Treatment Information Federal Register 38(129), August 17,, 1973, pgs 22298-22299.

Secondary Treatment Information Federal Register 41(1440, July 26, 1976, pp. 30786-30789.

Suspended Solids Limitations Federal Register 42(195), October 7, 1977, pp. 54664-54666.

Water Quality Criteria 1972 EPA-R3-73-033, March 1973, pp. 323-366.

Quality Criteria for Water, USEPA, July, 1976.

Alternative Waste Management Techniques for Best Practicable Waste Treatment EPA 430/9-75-013, October, 1975.

Final Construction Grants Regulations Federal Register 39, No. 29 February 11, 1974.

VI. ATTACHMENTS

Attachment A	Administrator's Oct. 3, 1977 memo "EPA Policy on Land Treatment of Municipal Wastewater"
Attachment B	Table 2-1 from Design Manual
Attachment C	Table 2-2 from Design Manual
Attachment D	Pages 23-24 from EPA 430/9-75-016
Attachment E	Guidance for assessing level of preapplication
Attachment F	Alternative Waste Management Techniques (BPWTT)

ATTACHMENT A

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OCT 3 1977

THE ADMINISTRATOR

SUBJECT: EPA Policy on Land Treatment of Municipal Wastewater

FROM: The Administrator

TO: Assistant Administrators and Regional Administrators (Regions I-X)

President Carter's recent Environmental Message to the Congress emphasized the design and construction of cost-effective publicly owned wastewater treatment facilities that encourage water conservation as well as adequately treat wastewater. This serves to strengthen the encouragement under the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) to consider wastewater reclamation and recycling by land treatment processes.

At the time P.L. 92-500 was enacted, it was the intent of Congress to encourage to the extent possible the development of wastewater management policies that are consistent with the fundamental ecological principle that all materials should be returned to the cycles from which they were generated. Particular attention should be given to wastewater treatment processes which renovate and reuse wastewater as well as recycle the organic matter and nutrients in a beneficial manner. Therefore, the Agency will press vigorously for publicly owned treatment works to utilize land treatment processes to reclaim and recycle municipal wastewater.

RATIONALE

Land treatment systems involve the use of plants and the soil to remove previously unwanted contaminants from wastewaters. Land treatment is capable of achieving removal levels comparable to the best available advanced wastewater treatment technologies while achieving additional benefits. The recovery and beneficial reuse of wastewater and its nutrient resources through crop production, as well as wastewater treatment and reclamation, allow land treatment systems to accomplish far more than most conventional treatment and discharge alternatives.

The application of wastewater on land is a practice that has been used for many decades; however, recycling and reclaiming wastewater that may involve the planned recovery of nutrient resources as part of a designed wastewater treatment facility is a relatively new technique. One of the first such projects was the large scale Muskegon, Michigan, land treatment demonstration project funded under the Federal Water Pollution Control Act Amendments of 1966 (P.L. 84-660), which began operations in May 1974.

Reliable wastewater treatment processes that utilize land treatment concepts to recycle resources through agriculture, silviculture and aquaculture practices are available. The technology for planning, designing, constructing and operating land treatment facilities is adequate to meet both 1983 and 1985 requirements and goals of P.L. 92-500.

Land treatment is also presently in extensive use for treatment of many industrial wastewaters, particularly those with easily degraded organics such as food processing. Adoption of suitable in-plant pretreatment for the removal of excessive metals and toxic substances would expand the potential for land treatment of industrial wastewater and further enhance the potential for utilization of municipal wastewater and sludges for agricultural purposes.

APPROACH

Because land treatment processes contribute to the reclamation and recycling requirements of P.L. 92-500, they should be preferentially considered as an alternative wastewater management technology. Such consideration is particularly critical for smaller communities. While it is recognized that acceptance is not universal, the utilization of land treatment systems has the potential for saving billions of dollars. This will benefit not only the nationwide water pollution control program, but will also provide an additional mechanism for the recovery and recycling of wastewater as a resource.

EPA currently requires each applicant for construction grant funds to make a conscientious analysis of wastewater management alternatives with the burden upon the applicant to examine all available alternative technologies. Therefore, if a method that encourages water conservation, wastewater reclamation and reuse is not recommended, the applicant should be required to provide complete justification for the rejection of land treatment.

Imposition of stringent wastewater treatment requirements prior to land application has quite often nullified the cost-effectiveness of land treatment processes in the past. We must ensure that appropriate Federal, State and local requirements and regulations are imposed at the proper point in the treatment system and are not used in a manner that may arbitrarily block land treatment projects. Whenever States insist upon placing unnecessarily stringent preapplication treatment requirements upon land treatment, such as requiring EPA secondary effluent quality in all cases prior to application on the land, the unnecessary wastewater treatment facilities will not be funded by EPA. This should encourage the States to re-examine and revise their criteria, and so reduce the cost burden, especially to small communities, for construction and operation of unnecessary or too costly facilities. The reduction of potentially toxic metals and organics in industrial discharges to municipal systems often is critical to the success of land treatment. The development and enforcement at the local level of pretreatment standards that are consistent with national pretreatment standards should be required as an integral part of any consideration or final selection of land treatment alternatives. In addition, land treatment alternatives must be fully coordinated with on-going areawide planning under section 208 of the Act. Section 208 agencies should be involved in the review and development of land treatment options.

Research will be continued to further improve criteria for preapplication treatment and other aspects of land treatment processes. This will add to our knowledge and reduce uncertainties about health and environmental factors. I am confident, however, that land treatment of municipal wastewaters can be accomplished without adverse effects on human health if proper consideration is given to design and management of the system.

INTER-OFFICE COORDINATION

The implementation of more recent mandates from the Safe Drinking Water Act (P.L. 93-532), the Toxic Substances Control Act (P.L. 94-469), and the Resource Conservation and Recovery Act of 1976 (P.L. 94-580) must be closely coordinated with the earlier mandate to recycle wastes and fully evaluate land treatment in P.L. 92-500. Agencywide coordination is especially important to the proper management of section 201 of P.L. 92-500, because the construction and operation of thousands of POTW's involve such a broad spectrum of environmental issues. A concerted effort must be made to avoid unilateral actions, or even the appearance of unilateral actions, which satisfy a particular mandate of one Act while inadvertently conflicting with a major Agency policy based upon another Act. The intention of P.L. 92-500, as it concerns land treatment, is compatible with the pertinent aspects of more recent environmental legislation.

ACTION REQUIRED

Each of you must exert maximum effort to ensure that the actions of your staffs reflect clearly visible encouragement of wastewater reclamation and recycling of pollutants through land treatment processes in order to move toward the national goals of conserving water and eliminating the discharge of pollutants in navigable waters by 1985.

This policy will apply to all future municipal construction grant activities, as well as all current grant applications in the Step 1 category that have not been approved as of this date. Detailed information and guidance for implementation of this policy is under preparation and will be issued in the near future.

TABLE 2-1

COMPARISON OF DESIGN FEATURES FOR LAND TREATMENT PROCESSES

Feature	Principal processes			Other processes	
	Slow rate	Rapid infiltration	Overland flow	Wetlands	Subsurface
Application techniques	Sprinkler or surface[a]	Usually surface	Sprinkler or surface	Sprinkler or surface	Subsurface piping
Annual application rate, ft	2 to 20	20 to 560	10 to 70	4 to 100	8 to 87
Field area required, acres[b]	56 to 560	2 to 56	16 to 110	11 to 280	13 to 140
Typical weekly application rate, in.	0.5 to 4	4 to 120	2.5 to 6[c] 6 to 16[d]	1 to 25	2 to 20
Minimum preapplication treatment provided in United States	Primary sedimentation[e]	Primary sedimentation	Screening and grit removal	Primary sedimentation	Primary sedimentation
Disposition of applied wastewater	Evapotranspiration and percolation	Mainly percolation	Surface runoff and evapotranspiration with some percolation	Evapotranspiration, percolation, and runoff	Percolation with some evapotranspiration
Need for vegetation	Required	Optional	Required	Required	Optional

a. Includes ridge-and-furrow and border strip.

b. Field area in acres not including buffer area, roads, or ditches for 1 Mgal/d (43.8 l/s) flow.

c. Range for application of screened wastewater.

d. Range for application of lagoon and secondary effluent.

e. Depends on the use of the effluent and the type of crop.

1 in = 2.54 cm
1 ft = 0.305 m
1 acre = 0.405 ha

TABLE 2-2

COMPARISON OF SITE CHARACTERISTICS FOR LAND TREATMENT PROCESSES

	Principal processes			Other processes	
Characteristics	Slow rate	Rapid infiltration	Overland flow	Wetlands	Subsurface
Slope	Less than 20% on cultivated land, less than 40% on noncultivated land	Not critical; excessive slopes require much earthwork	Finish slopes 2 to 8%	Usually less than 5%	Not critical
Soil permeability	Moderately slow to moderately rapid	Rapid (sands, loamy sands)	Slow (clays, silts, and soils with impermeable barriers)	Slow to moderate	Slow to rapid
Depth to groundwater	2 to 3 ft (minimum)	10 ft (lesser depths are acceptable where underdrainage is provided)	Not critical	Not critical	Not critical
Climatic restrictions	Storage often needed for cold weather and precipitation	None (possibly modify operation in cold weather)	Storage often needed for cold weather	Storage may be needed for cold weather	None

1 ft = 0.305 m

Example No. 2

Requirements. An existing 20-mgd activated sludge plant is required to upgrade its effluent quality to meet the following criteria:

BOD - 10 mg/l

SS - 10 mg/l

N - 3 mg/l

P - 0.5 mg/l

Alternatives. It is evident from a review of Table 2 that the only methods of treatment capable of providing the necessary degree of treatment are AWT-4 and irrigation. In this example, the cost of AWT-4 is compared with that of irrigation under varying conditions of conveyance distance (Case A) and land costs (Case B). Since secondary treatment is existing, activated sludge or aerated lagoon will not be necessary.

Case A - Consider a moderately favorable site for irrigation, a distance of 5 miles away from the existing treatment plant site. How much can be paid for land and have the irrigation system competitive with the AWT-4 system?

Table 12. COST COMPARISON FOR CASE A

Treatment method	Cost component	Cost ¢/1,000 gal.	Source
AWT-4	AWT-4	44.0	Figure 1
	Existing activated sludge adjustment	-(16.0)	Figure 1
	Total	28.0	
Irrigation	Irrigation system	24.0	Figure 1
	Aerated lagoon adjustment	-(4.3)	Figure 1
	Land cost	-(6.7)	Table 7
	Subtotal	13.0	
	Amount available for land = (28.0-13.0)	15.0	
	Total area, acres	4,300	Table 7
	Allowable cost/acre $= \frac{20 \text{ mgd } (15¢/1,000 \text{ gal.})(10^3)}{(0.0154)\ (4,300 \text{ acres})}$	4,500	

Conclusions. Under the assumed site conditions for the irrigation system, as much as $4,500 per acre could be paid for land and have the irrigation system competitive with AWT-4.

Case B - Consider a moderately favorable irrigation site at a cost of $2,000 per acre. How far away from the existing treatment plant could the site be and have the irrigation system competitive with AWT-4?

Table 13. COST COMPARISON FOR CASE B

Treatment method	Cost component	Cost ¢/1,000 gal.	Source
AWT-4	From Case A	28.0	Figure 1
Irrigation	Irrigation system	24.0	Figure 1
	Aerated lagoon adjustment	-(4.3)	Figure 1
	Conveyance cost	-(1.7)	Table 7
	Subtotal	18.0	
	Amount available for conveyance = (28.0 - 18.0)	10.0	--
	Allowable distance, miles	33	Table 4

Conclusions. Under the assumed site conditions for the irrigation system, wastewater could be conveyed as far as 33 miles and have irrigation be competitive with AWT-4. Special conditions such as river or highway crossings and easements may add substantial costs and reduce this distanc somewhat.

Guidance for Assessing Level of Preapplication Treatment

I. Slow-rate Systems (reference sources include Water Quality Criteria 1972, EPA-R3-73-003, Water Quality Criteria EPA 1976, and various state guidelines).

A. Primary treatment - acceptable for isolated locations with restricted public access and when limited to crops not for direct human consumption.

B. Biological treatment by lagoons or inplant processes plus control of fecal coliform count to less than 1,000 MPN/100 ml acceptable for controlled agricultural irrigation except for human food crops to be eaten raw.

C. Biological treatment by lagoons or inplant processes with additional BOD or SS control as needed for aesthetics plus disinfection to log mean of 200/100 ml (EPA fecal coliform criteria for bathing waters) - acceptable for application in public access areas such as parks and golf courses.

II. Rapid-infiltration Systems

A. Primary treatment - acceptable for isolated locations with restricted public access.

B. Biological treatment by lagoons or inplant processes - acceptable for urban lcoations with controlled public access.

III. Overland-flow Systems

A. Screening or comminution - acceptable for isolated sites with no public access.

B. Screening or comminution plus aeration to control odors during storage or application - acceptable for urban locations with no public access.

ENVIRONMENTAL PROTECTION AGENCY

[FRL 482-6]

ALTERNATIVE WASTE MANAGEMENT TECHNIQUES FOR BEST PRACTICABLE WASTE TREATMENT

Supplement

Pursuant to Section 304(d)(2) of the Federal Water Pollution Control Act Amendments of 1972 (Pub. L. 92-500), the Environmental Protection Agency (EPA), gave notice on October 23, 1975 (40 FR 49598) that Alternative Waste Management Techniques for Best Practicable Waste Treatment has been published in final form. The final report contains the criteria for best practicable waste treatment technology and information on alternative waste management techniques.

The criteria for Best Practicable Waste Treatment for Alternatives employing land application techniques and land utilization practices required that the ground water resulting from land application of wastewater meet the standards for chemical quality [inorganic chemicals] and pesticides [organic chemicals] specified in the EPA Manual for Evaluating Public Drinking Water Supplies in the case of groundwater which potentially can be used for drinking water supply. In addition to the standards for chemical quality and pesticides, the bacteriological standards [microbiological contaminants] specified in the EPA Manual for Evaluating Drinking Water Supplies were required in the case of groundwater which is presently being used as a drinking water supply. The pertinent section of the EPA Manual for Evaluating Public Drinking Water Supplies was included as Appendix D of the Alternative Waste Management Techniques for Best Practicable Waste Treatment report.

Also specified in the Criteria for Best Practicable Waste Treatment is that "any chemical, pesticides, or bacteriological standards for drinking water supply sources hereafter issued by EPA shall automatically apply in lieu of the standards in the EPA Manual for Evaluating Public Drinking Water Supplies. The National Interim Primary Drinking Water Regulations were published in final form on December 24, 1975.

In consideration of the foregoing, Chapter II and Appendix D of Alternative Waste Management Techniques for Best Practicable Waste Treatment shall read as follows.

Dated: February 4, 1976.

RUSSELL E. TRAIN,
Administrator.

CHAPTER II

CRITERIA FOR BEST PRACTICABLE WASTE TREATMENT

Applicants for construction grant funds authorized by Section 201 of the Act must have evaluated alternative waste treatment management techniques and selected the technique which will provide for the application of best practicable waste treatment technology. Alternatives must be considered in three broad categories: treatment and discharge into navigable waters, land application and utilization practices, and reuse of treated wastewater. An alternative is "best practicable" if it is determined to be cost-effective in accordance with the procedures set forth in 40 CFR Part 35 (Appendix B to this document) and if it will meet the criteria set forth below.

(A) Alternatives Employing Treatment and Discharge into Navigable Waters. Publicly-owned treatment works employing treatment and discharge into navigable waters shall, as a minimum, achieve the degree of treatment attainable by the application of secondary treatment as defined in 40 CFR 133 (Appendix C). Requirements for additional treatment, or alternate management techniques, will depend on several factors, including availability of cost-effective technology, cost and the specific characteristics of the affected receiving water body.

(B) Alternatives Employing Land Application Techniques and Land Utilization Practices. Publicly-owned treatment works employing land application techniques and land utilization practices which result in a discharge to navigable waters shall meet the criteria for treatment and discharge under Paragraph (A) above.

The ground water resulting from the land application of wastewater, including the affected native ground water, shall meet the following criteria:

Case I: The ground water can potentially be used for drinking water supply.

(1) The maximum contaminant levels for inorganic chemicals and organic chemicals specified in the National Interim Primary Drinking Water Regulations (40 CFR 141) (Appendix D) for drinking water supply systems should not be exceeded except as indicated below (see Note 1).

(2) If the existing concentration of a parameter exceeds the maximum contaminant levels for inorganic chemicals or organic chemicals, there should not be an increase in the concentration of that parameter due to land application of wastewater.

Case II: The ground water is used for drinking water supply.

(1) The criteria for Case I should be met.

(2) The maximum microbiological contaminant levels for drinking water supply systems specified in the National Interim Primary Drinking Water Regulations (40 CFR 141) (Appendix D) should not be exceeded in cases where the ground water is used without disinfection (see Note 1).

Case III: Uses other than drinking water supply.

(1) Ground water criteria should be established by the Regional Administrator based on the present or potential use of the ground water.

The Regional Administrator in conjunction with the appropriate State officials and the grantee shall determine on a site-by-site basis the areas in the vicinity of a specific land application site where the criteria in Case I, II, and III shall apply. Specifically determined shall be the monitoring requirements appropriate for the project site. This determination shall be made with the objective of protecting the ground water for use as a drinking water supply and/or other designated uses as appropriate and preventing irrevocable damage to ground water. Requirements shall include provisions for monitoring the effect on the native ground water.

(C) Alternatives Employing Reuse. The total quantity of any pollutant in the effluent from a reuse project which is directly attributable to the effluent from a publicly-owned treatment works shall not exceed that which would have been allowed under Paragraphs (A) and (B) above.

NOTE 1.—Any amendments of the National Interim Primary Drinking Water Regulations and any National Revised Primary Drinking Water Regulations hereafter issued by EPA prescribing standards for public water system relating to inorganic chemicals, organic chemicals or microbiological contamination shall automatically apply in the same manner as the National Interim Primary Drinking Water Regulations.

APPENDIX D

GROUND WATER REQUIREMENTS

The following maximum contaminant levels contained in the National Interim Primary Drinking Water Regulations (40 CFR 141) are reprinted for convenience and clarity. The National Interim Primary Drinking Water Regulations were published in final form in the FEDERAL REGISTER on December 24, 1975. In accordance with the criteria for best practicable waste treatment, 40 CFR 141 should be consulted in its entirety when applying the standards contained therein to wastewater treatment systems employing land appplication techniques and land utilization practices.

Maximum contaminant levels for inorganic chemicals. The following are the maximum levels of inorganic chemicals other than fluoride:

Contaminant:	Level (*milligrams per liter*)
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10.
Selenium	0.01
Silver	0.05

The maximum contaminant levels for fluoride are:

Temperature degrees Fahrenheit [1]	Degrees Celsius	Level (milligrams per liter)
53.7 and below	12 and below	2.4
53.8 to 58.3	12.1 to 14.6	2.2
58.4 to 63.8	14.7 to 17.6	2.0
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

[1] Annual average of the maximum daily air temperature.

Maximum contaminant levels for organic chemicals. The following are the maximum contaminant levels for organic chemicals:

	Level (*milligram per liter*)
(a) Chlorinated hydrocarbons:	
Endrin (1,2,3,4,10,10-Hexachloro-6,7 - epoxy - 1,4,4a,5,6,7,8,8a-octahydro-1,4-endo,endo - 5,8-dimethano naphthalene)	0.0002
Lindane (1,2,3,4,5,6 - Hexachlorocyclohexane, gamma isomer)	0.004
Methoxychlor (1,1,1-Trichloro-2, 2-bis [p-methoxyphenyl] ethane)	0.1
Toxaphene ($C_{10}H_{10}Cl_8$ - Technical chlorinated camphene, 67 to 69 percent chlorine)	0.005
(b) Chlorophenoxys:	
2,4-D (2,4-Dichlorophenoxyacetic acid)	0.1
2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid)	0.01

Maximum microbiological contaminant levels. The maximum contaminant levels for coliform bacteria, applicable to community water systems and non-community water systems, are as follows:

(a) When the membrane filter technique pursuant to § 141.21(a) is used, the number of coliform bacteria shall not exceed any of the following:

(1) One per 100 milliliters as the arithmetic mean of all samples examined per month pursuant to § 141.21 (b) or (c);

(2) Four per 100 milliliters in more than one sample when less than 20 are examined per month; or

(3) Four per 100 milliliters in more than five percent of the samples when 20 or more are examined per month.

(b) (1) When the fermentation tube method and 10 milliliter standard portions pursuant to § 141.21(a) are used, coliform bacteria shall not be present in any of the following:

(i) More than 10 percent of the portions in any month pursuant to § 141.21 (b) or (c);

(ii) Three or more portions in more than one sample when less than 20 samples are examined per month; or

(iii) Three or more portions in more than five percent of the samples when 20 or more samples are examined per month.

(2) When the fermentation tube method and 100 milliliter standard portions pursuant to § 141.21(a) are used, coliform bacteria shall not be present in any of the following:

(i) More than 60 percent of the portions in any month pursuant to § 141.21 (b) or (c);

(ii) Five portions in more than one sample when less than five samples are examined per month; or

(iii) Five portions in more than 20 percent of the samples when five or more samples are examined per month.

(c) For community or non-community systems that are required to sample at a rate of less than 4 per month, compliance with Paragraphs (a), (b) (1), or (2) shall be based upon sampling during a 3 month period, except that, at the discretion of the State, compliance may be based upon sampling during a one-month period.

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OFFICE OF WATER AND
HAZARDOUS MATERIALS
PROGRAM REQUIREMENTS MEMORANDUM
PRM# 79-8

SUBJECT: Small Wastewater Systems

FROM: John T. Rhett, Deputy Assistant Administrator for Water Program Operations (WH-546) *John T. Rhett*

TO: Regional Administrators
Regions I-X

I. Purpose

This memorandum clarifies EPA policy on the funding of privately and publicly owned small alternative wastewater systems, provides guidelines for identifying expensive projects and implements the new Federal interagency agreement for rural wastewater projects.

II. Discussion

During the facility planning stage, alternatives for providing wastewater treatment systems are explored to determine the most cost-effective method of treatment. Review of a sample of approved systems indicates that on-site or small-flow wastewater treatment systems often have not been considered carefully even when such systems are likely to be more cost-effective than collection and interceptor networks. Section 201(g)(5) of the Clean Water Act of 1977, (P.L. 95-217), requires all grant applicants to study fully innovative and alternative treatment options.

Both privately owned and publicly owned small alternative wastewater systems are grant eligible under the Act with specific restrictions and conditions applicable. Key terms are defined as follows:

Small alternative wastewater systems are wastewater conveyance and/or treatment systems other than conventional systems. Alternatives include, but are not limited to: septic tanks and subsurface disposal systems; other on-site systems including dual systems; small systems serving clusters each consisting of a small number of households or commercial users, each user with average annual (seasonal for facility in use for portion of year) dry weather flows of under 25,000 gallons per day; six-inch and smaller gravity sewers carrying partially or fully treated wastewater or carrying raw wastewater as a part of limited conveyance systems serving clusters of households and small commercial establishments and pressure and vacuum sewers. These alternative sewers are specifically exempted from the collection sewer-interceptor designations when planned for small communities and are not subject to the collection system policy. These systems also include other treatment works which employ alternative technologies listed in Appendix E, 40 CFR 35, and serve communities of 3,500 population or less or the sparsely populated areas of larger communities.

A conventional system is a collection and treatment system consisting of minimum-size (6 or 8 inches) or larger gravity collector sewers, normally with manholes, force mains, pumping and lift stations and interceptors leading to a central treatment plant employing conventional concepts of treatment as defined in Section 5, Appendix E, 40 CFR 35.

Small alternative wastewater systems may be publicly or privately owned. Privately owned systems (called "individual systems" in the Act and 40 CFR 35) may serve only one or more principal residences or small commercial establishments. Publicly owned systems may serve one or more users. Perpetual or life-of-project easements or other binding convenant running with the land affording complete access to and control of wastewater treatment works on private property are tantamount to ownership of such works.

High wastewater user costs exceeding $200, $300, and even $500 annually for households in some communities under 10,000 in population have resulted from debt retirement costs for new collection systems or from high operation and maintenance costs of new sophisticated plants. Extremely high cost projects have culminated in political upheaval, refusal to connect into or to pay after connecting into central sewers, violence at public meetings, requests for injunctions, and filing suits against several parties, including EPA. In most cases, all of the feasible alternatives were not considered in the cost-effectiveness analysis and some systems were overdesigned by using inflated population projections and excessive water usage data. In the past, it has been difficult during facility plan review to pinpoint those projects that have severe financial impacts.

Previous policy and facility planning guidance have called for verification by the grantee that that community is able to raise the local share. PRM 76-3 requires the estimated operation and maintenance and debt retirement costs to each user to be presented in clear, understandable terms at the facility planning public meeting. In his letter of December 30, 1976, the Administrator asked the Regional Administrators to pay careful attention to facility plans where average local debt retirement costs per household exceed 1 percent of annual median income and for which local debt retirement costs plus operation and maintenance costs exceed 2 percent.

Guidelines modifying the 1 percent to 2 percent guide have been included below to assist in identification of expensive projects for further analysis. We are preparing a format with instructions for municipal officials and State and Federal reviewers to use to determine the size of project the municipality can afford using readily available local financial data.

Loan and grant programs of several Federal agencies for construction of wastewater treatment works in the past usually have been handled individually with little coordination among the agencies. This has resulted in unnecessary paperwork, duplication, federally imposed administrative burdens, construction of inappropriate or too sophisticated, costly facilities, fostering of development on rural land, and poor structuring of local share debt financing.

Under the Interagency Agreement for Rural Water and Sewer Projects, Environmental Protection Agency (EPA), Farmers Home Administration (FmHA), Economic Development Administration (EDA), Housing and Urban Development (HUD), and Community Services Administration (CSA) will coordinate their efforts to improve the delivery of Federal water and sewer programs to rural and semi-rural communities. Major features include:

°Emphasis on alternatives that may have lower per capita capital and operating costs and require less sophisticated technology and skill to operate than conventional collection and treatment facilities;

°A regular exchange of information among the agencies involved in funding the project, including meeting periodically and using the Federal Regional Councils;

°The facilitating of application and disbursement of funds for rural water and sewer projects and informing communities of the range of funding and other assistance available to them;

°The establishment of a universal data base for national wastewater disposal and treatment needs;

°The more efficient use of the A-95 process of review by clearinghouse agencies;

°Use of the same criteria to evaluate the financial impact of the proposed system upon the community;

°Coordination of the review of facility plans between EPA and FmHA and use of the plans by FmHA as their feasibility report to the extent possible;

°The demonstration of compliance with Federal requirements under specific statutes only once when communities are using funds from more than one program with identical compliance requirements. Where agency regulations differ in compliance requirements, agencies will work together to ensure individual or coordinated review as appropriate.

Facility planning in some small communities with unusual or inconsistent geologic features or other unusual conditions may require house-to-house investigations to provide basic information vital to an accurate cost-effectiveness analysis for each particular problem area. One uniform solution to all the water pollution problems in a planning area is not likely and may not be desirable. This extensive and time-consuming engineering work will normally result in higher planning costs which are expected to be justified by the considerable construction and operation and maintenance cost savings of small systems over conventional collection and treatment works.'

Though house-to-house visits are necessary in some areas, sufficient augmenting information may be available from the local sanitarian, geologist, Soil Conservation Service representative or other source to permit preparation of the cost-effective analysis. Other sources include aerial photography and boat-carried leachate-sensing equipment which can be helpful in locating failing systems. Detailed engineering investigation, including soil profile examination, percolation tests, etc., on each and every occupied lot should rarely be necessary during facility planning.

III. Policy

A. Funding of Publicly and Privately Owned Small Alternative Wastewater Systems

1. Minimum Standards and Conditions

The Clean Water Act and the regulations implementing the Act impose no restrictions on types of sewage treatment systems. These alternative systems are eligible for funding for State approved certified projects when the following minimum standards and conditions are met:

a. For both publicly and privately owned systems, the public body must meet the requirements of 40 CFR 35.918-1 (b), (c), (e) through (j); 35.918-2 and 35.918-3.

A comprehensive program for regulation and inspection of these systems must be established prior to EPA approval of the plans and specifications. Planning for this comprehensive program shall be completed as part of the facility plan. The program shall include, at a minimum, the physical inspection of all on-site systems in the facility planning area every three years with pumpouts and systems renovation or replacement as required. The program shall also include, at a minimum, testing of selected existing potable water wells on an annual basis. Where a substantial number of on-site systems exist, if necessary, appropriate additional monitoring of the aquifer(s) in the facility planning area shall be provided.

For privately owned systems the applicant must demonstrate in the facility plan that the solution chosen is cost-effective and selected in accordance with the cost-effectiveness guidelines for the Construction Program, (Appendix A, 40 CFR Part 35). These systems are not eligible for a 15 percent cost preference for the alternative and innovative processes and techniques in the cost-effectiveness analysis. Publicly owned systems, however, are eligible for the 15 percent cost preference.

b. In addition to the conditions in paragraph A.1, privately owned systems must meet the requirements of 40 CFR 35.918-1(a) and (d) and the following:

(1) Provide facilities only for principal residences, (see 40 CFR 35.918(a)(2)) and small commercial establishments (i.e., those with annual or seasonal, if not operated throughout the year, dry weather flows of less than 25,000 gpd and more than one user equivalent per day; e.g. 300 gpd). Not included are second homes, vacation or recreation residences;

(2) Require commercial users to pay back the Federal share of the cost of construction with no moratorium during the industrial cost recovery study. The 25,000 gpd exemption does not apply for those commercial establishments;

(3) Treat nonprofit and non-governmental institutional entities such as churches, schools, hospitals and charitable organizations, for purposes of this special authority, generally the same as small commercial establishments.

2. Other Eligible and Ineligible Costs

In addition to the costs identified in the Construction Grants Regulations, 40 CFR 35.918-2, the following costs are also grant eligible:

(a) Vehicles and associated capital equipment required for servicing of the systems such as septage pumping trucks and/or dewatered residue haul vehicles.

(1) Vehicles purchased under the grant must have as their sole purpose, the transportation of liquid or dewatered wastes from the collection point (e.g., holding tanks, sludge-drying beds) to the treatment or disposal facility. (Other mobile equipment is allowable for grant participation as provided for on pages VII-12 and 13, "Handbook of Procedures, Construction Grants Program for Municipal Wastewater Treatment Works.")

(2) If vehicles or equipment are purchased the grantee must maintain property accountability in accordance with OMB Circular A-102 and 40 CFR 30.810.

(b) Septage treatment plants (eligible for 85 percent grant funding as part of an alternative system).

(c) Planning for establishment of small alternative wastewater systems management districts, including public hearings to discuss district formation. The "mechanics" of establishing the districts such as legal and other costs for drafting of ordinances and regulations, elections, etc., are a normal function of government and are not grant eligible, (Construction Grants Program Handbook of Procedures, VII-6).

(d) Rehabilitation, repair or replacement of small alternative wastewater systems as provided for by 40 CFR 35.908(c).

3. Grant Funding of Small Alternative Wastewater Systems

Small alternative wastewater systems are eligible for 85 percent grants; 75 percent of the Federal grant may be funded from the 4 percent set-aside. The 10 percent grant increase must be funded from the 2 percent set-aside (3 percent in FY 1981). The 10 percent grant increase can also be applied to small alternative wastewater systems where 4 percent set-aside funds are not available (i.e., in States where there is no 4 percent set aside or States where 4 percent set-aside funds have been depleted).

4. Use of Prefabricated or Preconstructed Treatment Components

The use of prefabricated or preconstructed treatment components such as septic tanks, grinder pump/tank units, etc., normally is more economical than construction in place and should be carefully considered. In the case of very small systems, prefabricated or preconstructed units should in most instances be the most cost-effective. For somewhat larger systems of standard design, prefabricated or preconstructed units may also be cost-effective and should be carefully considered in the facility plan.

5. Useful Life of Small Alternative Wastewater Systems

Whenever conditions permit, these alternative treatment works including soil absorption systems, shall be designed to ensure a minimum useful life of twenty years.

6. Comparison of Small Alternative Wastewater Systems with Collection Systems in Cost-Effective Analysis

The present worth of small alternative wastewater systems for future development permitted by the cost-effectiveness guidelines, (40 CFR 35, Appendix A) may be compared with the costs of alternative and conventional collection systems for the same planning area. In each instance both eligible and ineligible costs shall be considered including service line costs from residence to collector, connection fees and service to the on-site units.

IV. Determination of the Economic Impact of the Project

When total user charges for wastewater treatment services, including debt service and operation and maintenance, for the average user in the service area, exceed the following percentages of annual household median incomes:

- -- 1.50 percent when the median income is under $6,000;
- -- 2.00 percent when the median income is between $6,000-$10,000;
- -- 2.50 percent when the median income is over $10,000.

the projects shall be considered expensive and shall receive further intensive review to determine, at a minimum:

1. the adequacy and accuracy of the cost-effective analysis, particularly noting whether all the feasible alternatives have been considered and if the cost estimates are reasonable;

2. the soundness of financing of the local share, and

3. whether the grant applicant has sought out all the sources of supplemental funding.

(Costs of an expensive project can sometimes be reduced by additional facility planning effort, including reduction in scope.)

A format, instructions and criteria for determination of the financial capability of the public body to carry the debt load of a new project are being prepared and will be promulgated at an early date. This process will be tailored for the use of municipal authorities and State and EPA reviewing officials.

V. Interagency Coordination and Streamlining the Review and Approval of Grants or Loans for Construction of Wastewater Treatment Works in Sparsely Populated Communities

A. Coordination with Farmers Home Administration (FmHA)

Communities should be encouraged to contact FmHA during the development of their facility plans to receive informal comments before the plans are finalized and submitted for review.

Upon receipt of State certified facility plans for communities under 10,000 population, the Region shall send a copy of each plan to State FmHA officials for their review concurrently with regional review. FmHA will provide comments normally within 30 days to the Region on the financial capability of the community to carry the project, the structuring of the local share debt, the viability of the selected alternative and other matters in which FmHA is interested. The comments are for each Regional Administrator's information and appropriate action, if received within the 30-day period. They are not FmHA's official comments to the community on its plan. Close cooperation between FmHA and regional reviewers is encouraged. For States which are delegated final facility plan review, the above coordination shall be between the State and State FmHA officials.

B. Exchange of Information Among FmHA, HUD, EDA, CSA and EPA Through Joint Meetings

The agencies shall meet periodically during the year using the Federal Regional Councils. Meetings shall be initiated by any of these organizations and one of these meetings will take place at least 120 days before the beginning of each new fiscal year. These meetings may include:

1. Review of status of projects being jointly or concurrently funded;

2. Discussion of future projects in common;

3. Exchange of information on current and new administrative or substantive procedures or requirements; and

4. Review of action items such as:

   a. One year priority or project lists to identify combined funding possibilities;

   b. Existing project lists to identify overlapping projects or funding; and

   c. Construction and inspection schedules to identify areas of coordination.

Regular meetings between respective state-level agencies are encouraged for similar purposes of coordination.

C. Encouragement of Alternatives to Conventional Collection and Treatment of Wastewater

Alternatives to conventional wastewater collection and treatment facilities that may have lower per capita capital, operating and maintenance costs and require less sophisticated technology and skill to operate shall be encouraged.

D. Provision of Funding and Other Assistance Information to Small Communities

Regional offices and other sources will provide, on request, information on the range of funding and other assistance for rural sewer projects. Technical information may be obtained from the Environmental Research Information Center (ERIC), Cincinnati, Ohio 45268, telephone number (513) 684-7394, or the Small Wastewater Flows Clearinghouse, West Virginia University, Morgantown, West Virginia 26506, telephone number (800) 624-8301.

E. <u>Establishment of a Universal Data Base for National Wastewater Disposal and Treatment Needs</u>

The EPA biennial Needs Survey will be used as the initial data base for all agencies involved in funding rural facilities.

F. <u>More Efficient Use of the A-95 Process of Review</u>

Notification of intent to apply for grant funds submitted to A-95 clearinghouses should indicate the intention to apply for joint or combined funding and identify the prospective assisting agencies.

The A-95 agency needs to conduct only one review of the actual project for each plan of study and Step 1 grant (except for special circumstances) which will meet the requirements for all agencies involved.

The use of the A-95 process and Water Quality Management Planning process under section 208 to identify projects that may be eligible for funding should be promoted.

Regions should encourage the clearinghouses to use the A-95 process to evaluate the rural and urban impact of jointly funded projects.

G. <u>Acceptance of One-Time Demonstration or Assurance of Compliance with Federal Requirements for Jointly Funded Projects</u>

The Regions and States where responsibility has been delegated should accept evidence of compliance with requirements of the following when they apply in an identical manner to the programs of each agency:

1. Uniform Relocation and Real Property Acquisition Policies Act of 1970;

2. Civil Rights Act of 1964; Civil Rights Act of 1968; Executive Order No. 11246;

3. Davis-Bacon Fair Labor Standards Act;

4. The Contract Work Hours Standards Act;

5. The Copeland (Anti-Kickback) Act;

6. The Hatch Act;

7. The Coastal Zone Management Act of 1972;

8. The Archaeological and Historic Preservation Act of 1974;

9. The National Flood Insurance Act of 1968, as amended by the Flood Disaster Protection Act of 1973, and regulations and guidelines issued thereunder;

10. The Wild and Scenic Rivers Act of 1968;

11. The Endangered Species Act of 1973;

12. The Clean Air Act;

13. Executive Order No. 11988 on floodplains management;

14. Executive Order No. 11990 on wetlands protection;

15. The National Historic Preservation Act of 1966, and Executive Order No. 11593;

16. The Safe Drinking Water Act of 1974.

Further guidance in this area will be issued after detailed review and discussion by all agencies of regulations and requirements implementing each of the above statutes.

VI. Implementation

This policy should be emphasized through Step 1 preapplication conferences, contacts through municipalities and the States and reviews of Steps 1 and 2 grant applications. This PRM is effective for facility plans started after May 31, 1979, except as follows:

a. The determination of economic impact is applicable to facility plans review commencing 90 days after issuance of this guidance.

b. Review of facility plans by FmHA should commence on facility plans received for review 60 days after issuance of this guidance.

c. Joint meetings to exchange information using the Federal Regional Councils should commence prior to May 31, 1979. At least one of the future meetings should take place at least 120 days before the beginning of each new fiscal year that follows.

d. The more efficient use of the A-95 review above shall commence as soon as practicable, but not later than May 31, 1979.

APPENDIX C

COST INDEXING

C.1 General

Cost data for construction and operation and maintenance (O&M) have originated from a variety of reference sources and reflect differing time periods and geographic locations. Values presented in this manual have been converted to a September, 1976 (constant dollar) base except where noted.

C.2 Indexes

Among the indexes commonly used are the EPA Sewage Treatment PLant Construction Cost Indexes and the EPA Operation and Maintenance Cost Index. The Construction Cost Index for a 1 mgd trickling filter plant (originally designated the PHS-STP index and later designated as the WPC-STP index for treatment plant construction costs) was developed through an analysis of 733 contract awards during the period 1956 through 1962. The econometric model for a hypothetical 1 mgd trickling filter plant is based on grouping of input costs and weighted averages of detailed labor and material costs from each of 20 cities' commercial marketing areas throughout the country. For construction materials and equipment, area prices for common brick, concrete, crushed stone, sand, foundry pig iron, structural steel, cast iron, reinforcing bars, and exterior plyforms are incorporated by weightings developed for construction conditions of 1957-1962. The input to labor for construction includes wage rates for electrical workers, hoisting engineers, structural workers, bricklayers, carpenters, and common labor. Table C-1 shows the EPA Sewage Treatment Plant Construction Cost Index for a 1 mgd plant for the period 1957 through September, 1979.

The EPA Municipal Wastewater Treatment Plant Operation and Maintenance (O&M) Cost Index was developed to overcome the shortcomings of applying a single Wholesale Price Index (WPI) to escalate operation and maintenance costs. The O&M Cost Index was developed through regression analyses of actual 1967 O&M cost data for a composite 5 mgd conventional activated sludge plant.

The average index is comprised of six sub-indexes which are averaged to form the single O&M Index. The six sub-indexes are Labor, Chemicals, Power, Maintenance, Other Costs, and a "quality-added factor" called Added Input. Each of these categories is escalated individually on a quarterly basis (annually before 1974) by using commodity group indexes, productivity data indexes, chemical prices, and a specialized maintenance index. Table C-2 gives the parameters that represent each cost category, the weight of each parameter within the category, and the source of the escalating factors.

Table C-3 summarizes the average O&M Index and the sub-indexes for the years 1967 through the third quarter of 1979. A breakdown of the Chemical Cost sub-index into component chemicals is shown in Table C-4, and details of the Other Costs sub-index are shown in Table C-5.

In addition to adjusting to a constant dollar base, cost indexes, such as those previously described, are used to perform economic analyses, adjust to current dollars, and make cost comparisons. However, such indexes, when applied to the several components of construction or operation and maintenance costs, will only adjust the data on a national average basis.

In order to arrive at a more accurate cost figure than one which results from the use of the national average indexes alone, Locality Factors can be applied to an estimated cost or cost index. The use of Locality Factors, which have been calculated from generally available statistics, permit the localizing of national average cost data for construction labor, construction materials, total construction cost, operation and maintenance labor costs, and power costs. The factors for labor and materials are given in Table C-6 and those for power costs are given in Table C-7.

In order to obtain current cost and price indexes, contact Robert L. Michel, Priority Needs and Assessment Branch (WH-595), Office of Program Operations, U.S. Environmental Protection Agency, Washington, D.C. 20460 (202) 426-4443.

TABLE C-1

EPA SEWAGE TREATMENT PLANT CONSTRUCTION COST INDEX
U.S. CITY AVERAGE (1957-1959 = 100) (1)(2)

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Avg.
1957													98.0
1958													101.5
1959													103.7
1960													105.0
1961													105.9
1962									107.2	107.2	107.0	106.8	107.0
1963	106.8	107.1	107.1	107.1	107.2	107.8	108.1	108.5	108.6	109.5	109.5	109.6	108.5
1964	109.6	109.5	109.5	109.6	109.7	110.0	110.2	110.5	110.6	110.7	110.7	110.7	110.1
1965	110.8	111.0	111.1	111.1	111.2	111.8	112.3	112.6	112.7	112.8	112.9	113.1	112.0
1966	114.1	114.6	114.8	115.1	115.3	116.1	116.8	116.9	117.1	117.5	117.5	117.5	116.1
1967	117.8	118.1	118.1	118.2	118.3	119.1	119.6	120.3	120.6	120.9	120.9	121.0	119.4
1968	121.1	121.2	121.2	121.6	121.7	122.5	123.4	123.7	124.5	126.8	127.2	127.7	123.6
1969	128.7	129.5	129.8	130.0	130.0	131.1	132.4	135.3	135.5	135.9	136.6	136.9	132.7
1970	137.6	137.9	138.2	138.5	141.2	143.0	146.3	146.7	147.5	148.1	149.3	149.6	143.6
1971	150.6	150.9	153.3	155.4	157.3	158.6	160.6	165.1	166.3	166.3	166.4	167.2	159.8
1972	167.7	168.7	169.2	169.9	171.4	172.2	172.3	173.1	173.8	174.5	175.5	175.7	172.0
1973	176.1	177.5	180.7	181.6	182.6	182.9	183.7	183.9	184.5	185.0	185.8	187.5	182.6
1974	188.1	190.2	191.0	196.1	197.8	208.9			230.1			238.8	217.2
1975			247.4			245.9			251.3			255.4	250.0
1976			256.7			259.6			262.5			270.3	262.2
1977			270.9			273.8			281.0			287.6	278.3
1978			290.1			303.1			311.0			314.1	304.6
1979			322.0			334.1			337.8				

(1) Based on 1.0 MGD high rate trickling filter with aeration.
(2) Note: The input to the two indexes include wage rates (for each of 20 cities) for electrical workers, hoisting engineers, structural workers, bricklayers, carpenters, and common labor. For materials and equipment, area prices for common brick, concrete, crushed stone, sand, foundry pig iron, structural steel, cast iron, reinforcing bars, and exterior plyform are incorporated by weightings developed for construction conditions of 1957-1962.

TABLE C-2

PARAMETERS USED TO ESCALATE O&M COST CATEGORIES (1)

CATEGORY	PARAMETER	% WEIGHT 1/	SERIES	SOURCE
Salaries and Wages	Average Hourly Earnings Water, Steam and Sanitary Systems	100	SIC 4947	2/
Electricity	Industrial Power, 500 Kw Demand, Price Index	100	PPI 0543	3/
Chemicals	Chlorine Liquid	70	PPI 0613 0101	3/
	Lime	10	PPI 0613 0213	3/
	Methanol	5	$/gal FOB Gulf Coast	4/
	Ferric Chloride	5	$/100 lb. Sewage Gr.	4/
	Chemical Freight	5	Code 28 - Railroad Freight	3/
	Alum	5	$/Bulk Ton	4/
Maintenance	Factory Maintenance	60	1968 Base Year	5/
	Transformers and Power Regulators Index	10	PPI 1174	3/
	Valves & Fittings	10	PPI 114901	3/
	Pumps, Compressors and Equipment	10	PPI 1141	3/
	Centrifugal Blowers	10	PPI 11470101	3/
Other	Insurance	20	-----------	7/
	Gasoline	30	PPI 0571	3/
	Private Non-Farm, Unit Non-Labor Payments	50	-----------	6/

1/ Percent of Base Year (1967) Category Cost

2/ Employment and Earnings, BLS DOL

3/ Producer Price Indexes, BLS DOL

4/ Chemical Marketing Reporter

5/ Factory Vol. 8, No. 11, November 1975

6/ Monthly Labor Review, May 1976

7/ EPA Sewage Treatment Plant Cost Index with MD Rate Adjustments

(1) Reference: Development of a Cost Index for Operation and Maintenance of Municipal Wastewater Treatment Plants, Robert L. Michel, July 1976.

TABLE C-3

EPA MUNICIPAL WASTEWATER TREATMENT OPERATION AND MAINTENANCE COST INDEX (1)(2)(3)

Year	Qtr	Labor Index	Chemical Cost Index	Power Index	Main-tenance Index	Other Cost Index	Added Input Index	Average O&M Index
1967	A	1.00	1.00	1.000	1.000	1.00	1.00	1.00
1968	A	1.06	1.03	1.009	1.037	1.01	1.04	1.03
1969	A	1.14	1.08	1.022	1.081	1.03	1.11	1.09
1970	A	1.24	1.10	1.066	1.133	1.06	1.21	1.16
1971	A	1.32	1.12	1.155	1.189	1.14	1.31	1.23
1972	A	1.41	1.13	1.239	1.218	1.19	1.40	1.30
1973	A	1.48	1.18	1.326	1.321	1.27	1.52	1.38
1974	1	1.54	1.34	1.543	1.408	1.46	1.68	1.50
1974	2	1.57	1.54	1.741	1.550	1.60	1.80	1.60
1974	3	1.63	1.83	1.852	1.660	1.68	1.92	1.69
1974	4	1.67	2.05	1.951	1.718	1.67	1.99	1.76
1975	1	1.70	2.37	2.080	1.746	1.73	2.08	1.83
1975	2	1.72	2.39	2.060	1.767	1.80	2.11	1.85
1975	3	1.76	2.39	2.137	1.790	1.92	2.17	1.90
1975	4	1.79	2.39	2.152	1.812	1.93	2.19	1.93
1976	1	1.84	2.50	2.207	1.835	1.92	2.29	1.97
1976	2	1.86	2.49	2.255	1.865	1.96	2.32	2.00
1976	3	1.91	2.55	2.341	1.896	2.03	2.39	2.06
1976	4	1.96	2.58	2.327	1.919	2.05	2.43	2.09
1977	1	1.96	2.54	2.486	1.953	2.08	2.47	2.12
1977	2	1.97	2.56	2.562	1.986	2.13	2.53	2.15
1977	3	2.04	2.58	2.662	2.041	2.16	2.63	2.22
1977	4	2.09	2.54	2.627	2.071	2.19	2.65	2.24
1978	1	2.13	2.54	2.797	2.112	2.19	2.73	2.30
1978	2	2.15	2.52	2.869	2.182	2.25	2.82	2.33
1978	3	2.24	2.51	2.800	2.229	2.35	2.88	2.38
1978	4	2.24	2.58	2.830	2.289	2.41	2.91	2.40
1979	1	2.29	2.57	2.921	2.334	2.50	2.98	2.46
1979	2	2.35	2.63	3.024	2.411	2.66	3.10	2.54
1979	3	2.37	2.75	3.144	2.478	2.91	3.23	2.62

(1) 1967 = 1.000
(2) Based on 5 MGD conventional activated sludge
(3) Reference: EPA Operations and Maintenance Cost Index, September 1979, Robert L. Michel, EPA, Washington, D.C.

TABLE C-4

EPA MUNICIPAL WASTEWATER TREATMENT PLANT
OPERATION AND MAINTENANCE COST INDEX
CHEMICAL COST COMPONENT (1)(2)(3)

Yr	QTR	Chlorine Index	Alum Index	Ferric Chloride Index	Methanol Index	Lime Index	R.R. Index Chemical Freight	Overall Chemical Index
67	A	1.000	1.00	1.00	1.00	1.000	1.000	1.00
68	A	1.037	1.08	1.00	1.00	1.000	1.031	1.03
69	A	1.089	1.08	1.00	1.11	1.013	1.061	1.08
70	A	1.111	1.16	1.00	1.11	1.045	1.146	1.10
71	A	1.111	1.16	1.14	1.11	1.113	1.292	1.12
72	A	1.111	1.26	1.14	1.11	1.137	1.324	1.13
73	A	1.111	1.26	1.14	1.55	1.174	1.350	1.18
74	1	1.201	1.26	1.28	2.22	1.482	1.501	1.34
74	2	1.338	1.60	1.28	3.00	1.483	1.519	1.54
74	3	1.645	1.60	1.28	3.55	1.619	1.656	1.83
74	4	1.843	1.60	1.42	4.33	1.705	1.663	2.05
75	1	2.228	1.98	1.42	4.33	1.964	1.663	2.37
75	2	2.265	1.98	1.42	4.33	1.919	1.763	2.39
75	3	2.256	2.22	1.42	4.22	1.932	1.857	2.39
75	4	2.241	2.22	1.42	4.22	1.963	1.905	2.39
76	1	2.347	2.22	1.42	4.44	2.133	1.907	2.50
76	2	2.316	2.22	1.42	4.44	2.207	1.949	2.49
76	3	2.328	2.42	1.42	4.77	2.249	1.950	2.55
76	4	2.370	2.42	1.42	4.77	2.273	2.003	2.58
77	1	2.382	2.42	1.42	4.22	2.313	2.083	2.54
77	2	2.338	2.59	1.42	4.66	2.311	2.083	2.56
77	3	2.334	2.59	1.42	4.88	2.317	2.085	2.58
77	4	2.258	2.59	1.57	4.88	2.371	2.181	2.54
78	1	2.220	2.75	1.57	4.88	2.531	2.170	2.54
78	2	2.201	2.75	1.57	4.88	2.550	2.163	2.52
78	3	2.173	2.75	1.57	4.88	2.604	2.237	2.51
78	4	2.256	2.75	1.57	4.88	2.629	2.394	2.58
79	1	2.214	2.93	1.67	4.88	2.711	2.397	2.57
79	2	2.195	2.93	1.69	5.55	2.762	2.430	2.63
79	3	2.245	2.95	1.69	6.22	2.847	2.518	2.75

(1) 1967 = 1.000

(2) Chlorine estimated at 70% of 1967 plant chemical cost.
Lime 10%, others 5% each.

(3) Reference: EPA Operation and Maintenance Cost Index, September 1979, Robert L. Michel, EPA, Washington, D.C.

TABLE C-5

EPA MUNICIPAL WASTEWATER TREATMENT PLANT
OPERATION AND MAINTENANCE COST INDEX
OTHER COST COMPONENTS (1)(2)(3)

Year	Quarter	Insurance Index	Administration Index	Fuel Index	Overall Other Index
1967	A	1.000	1.000	1.000	1.00
1968	A	1.035	1.032	.959	1.01
1969	A	1.111	1.040	.978	1.03
1970	A	1.202	1.069	.961	1.06
1971	A	1.338	1.148	1.013	1.14
1972	A	1.440	1.190	1.040	1.19
1973	A	1.529	1.208	1.220	1.27
1974	1	1.599	1.229	1.775	1.46
1974	2	1.749	1.269	2.059	1.60
1974	3	1.927	1.303	2.158	1.68
1974	4	2.000	1.336	2.032	1.67
1975	1	2.072	1.384	2.094	1.73
1975	2	2.059	1.427	2.258	1.80
1975	3	2.104	1.493	2.541	1.92
1975	4	2.139	1.520	2.499	1.93
1976	1	2.151	1.550	2.413	1.92
1976	2	2.174	1.573	2.487	1.96
1976	3	2.198	1.590	2.658	2.03
1976	4	2.263	1.629	2.631	2.05
1977	1	2.268	1.668	2.674	2.08
1977	2	2.293	1.658	2.821	2.13
1977	3	2.353	1.697	2.828	2.16
1977	4	2.408	1.750	2.795	2.19
1978	1	2.429	1.769	2.759	2.19
1978	2	2.538	1.775	2.854	2.25
1978	3	2.604	1.857	3.011	2.35
1978	4	2.630	1.907	3.103	2.41
1979	1	2.696	1.957	3.290	2.50
1979	2	2.798	1.920	3.817	2.66
1979	3	2.829	1.943	4.598	2.91

(1) 1967 = 1.000
(2) Insurance Index combines rate changes and property valuation increases.
(3) Reference: EPA Operation and Maintenance Cost Index, September 1979; Robert L. Michel; EPA, Washington, D.C.

TABLE C-6

COST LOCALITY FACTORS

	Construction (1)			O&M (2)
	Labor	Materials	Total	Labor
Atlanta	0.66	1.03	0.79	0.77
Baltimore	0.90	0.95	0.92	0.79
Birmingham	0.66	1.02	0.79	0.79
Boston	1.12	0.90	1.04	0.97
Chicago	1.25	1.10	1.20	1.02
Cincinnati	1.10	1.05	1.08	0.98
Cleveland	1.19	1.01	1.13	1.05
Dallas	0.63	0.83	0.70	0.92
Denver	0.76	1.07	0.87	1.00
Detroit	1.17	0.98	1.10	1.32
Kansas City	0.97	1.25	1.07	0.88
Los Angeles	1.17	1.16	1.17	1.32
Minneapolis	0.93	1.03	0.97	1.21
New Orleans	0.88	1.05	0.94	0.66
New York	1.43	0.91	1.24	1.14
Philadelphia	1.23	1.00	1.15	1.05
Pittsburgh	1.05	0.96	1.02	0.87
St. Louis	1.29	0.99	1.18	0.83
San Francisco	1.23	0.96	1.13	1.13
Seattle	1.16	0.91	1.07	1.21
NATIONAL INDEX VALUES	1.00	1.00	1.00	1.00

(1) Calculated from EPA Sewage Treatment Plant and Sewer Construction Cost Index Third Quarter 1979.

(2) Reference: U.S. Department of Commerce Bureau of Census, City Employment in 1976, GE76 No. 2 July 1977. Based on average earnings by city of non-education employees.

TABLE C-7

POWER COST LOCALITY FACTOR (1)(2)

New England	1.31
Mid-Atlantic	1.18
East North Central	1.10
West North Central	0.98
South Atlantic	0.94
East South Central	0.98
West South Central	0.87
Mountain	0.79
Pacific	0.86
U.S. Average	1.00

(1) Basis: BLS, September, 1979 Producers Price Index

(2) Source: "Construction Cost Indexes," EPA, Municipal Construction Division; R.L. Michel; September, 1979

APPENDIX D - LIST OF TABLES

APPENDIX D - LIST OF FIGURES

APPENDIX D

ENERGY UTILIZATION CURVES AND CONVERSION FACTORS

D.1 General

The information in this appendix supplements the energy utilization data presented in Appendix A for the individual municipal treatment unit processes. Emphasis here is placed on the presentation of energy utilization curves for the more energy intensive municipal treatment processes of pumping and aeration along with the specifically identified alternative technology processes of anaerobic digestion, incineration, and dewatering. Also included are commonly used energy conversion tables, conversion factors, and a table of fuel and energy equivalents.

D.2 Energy Intensive Processes

In conventional municipal wastewater treatment plants, about 60% of the electrical energy is consumed in aeration, and about 20% in pumping. Thus, about 80% of the total electrical energy consumption is associated with these two processes which offer the greatest potential for electrical energy conservation. The major energy requirement for many land treatment systems is also for aeration (prior to application to the land) and pumping (when applying the effluent to the land for treatment). For this reason, the following principles can be readily applied to those systems.

D.2.1 Aeration

The two basic methods of aeration of suspended growth systems are mechanical aeration and air bubble diffusion. Turbine spargers which are a combination of the above two devices have also been used.

The oxygen transfer effiencies and energy requirements of selected aeration devices are shown in Table D-1. Aeration systems are rated in terms of their aeration efficiencies as pounds of O_2 per horsepower-hour (hp-hr) at standard conditions. Standard conditions exist when the temperature is 20°C, pressure is 760mm Hg, the D.O. is 0.0 mg/l and the test liquid is clean water. These ideal efficiencies and transfer rates vary from those found for wastewater under field conditions. Efficiency claims should be accepted only when supported by actual test data for the actual model and size of aerator under consideration; and for design purposes, the standard performance data must be adjusted to reflect anticipated field conditions. This is accomplished by converting lb O_2/hp-hr transferred under standard conditions to lb O_2/hp-hr transferred under field conditions. This can be done by using the following formula:

$$N = N_o \left[\alpha \left(\frac{\beta C^*_{walt} - C_L}{C^*_{st}} \right) \theta^{(T_c - 20)} \right]$$

N	=	**Aeration efficiency** at field operating conditions (lb O_2/**hp-hr**)
N_o	=	Standardized N in clean water at stated conditions of temperature, pressure, dissolved oxygen, depth mixing, geometry, etc., usually aken at 20°C, 760mm Hg, and zero dissolved oxygen (lb O_2/hp-hr)
C^*_{st}	=	Dissolved oxygen equilibrium saturation concentration in clean water at stated standard conditions (mg/l)
C^*_{walt}	=	Dissolved oxygen equilibrium saturation concentration in clean water as corrected for design temperature and altitude field operating conditions (mg/l)
C_L	=	Desired design dissolved oxygen concentration in wastewater under field operating conditions (mg/l)
T_c	=	Design operating temperature of wastewater under field conditions, in degrees centigrade
θ	=	Temperature correction factor **normally** equals 1.024 (dimensionless)
α	=	Ratio of mass transfer coefficient in wastewater to that in clean water at equivalent conditions of temperature, etc. (dimensionless)
β	=	Ratio of dissolved oxygen saturation concentration in wastewater to that in clean water at equivalent conditions of temperature and partial pressure (dimensionless)

The value of C^*_{walt} is determined by adjusting for altitude the value of dissolved oxygen solubility from available tables such as the one below. Dissolved oxygen solubility in fresh water (zero chlorides) exposed to dry air containing 20.90% oxygen under a total pressure of 760 mm Hg (sea level) varies with temperature as follows:

Temperature (°C)	D.O. (mg/l)
0	14.62
5	12.80
10	11.33
15	10.15
20	9.17
25	8.38
30	7.63

This value must be adjusted for the altitude of the field condition by multiplying times a correction factor, which varies linearly with elevation and which can be interpolated directly from the following:

Elevation (Feet)	Correction Factor, F
Sea Level	1.00
2,000	0.93
4,000	0.87
6,000	0.80
8,000	0.73

Since aeration devices may operate under submerged conditions, and exposure to more than atmospheric pressure at the point of oxygen transfer, a further adjustment to C^*_{walt} may be needed. Also, if a value of C^*_{st} is given at a condition of atmospheric pressure, adjustment to this value may also be needed. These further adjustments are beyond the scope of this manual, but can be obtained from the equipment manufacturer. As an example, at a ten-foot depth, these saturation values may increase as much as 9% according to one manufacturer.

The value for α can vary widely according to wastewater characteristics, type of equipment, geometry of the basin, etc. In fact, the outside range for α is reported to be from 0.3 to 1.2 whereas a more normal range for α is reported from 0.5 to 1.0. Since α is part of the numerator, this means that resultant field O_2 transfer efficiencies can be affected as much as two times (normal range) to four times (outside range). Therefore, it is critical that the value for α is selected carefully. The following example is provided to demonstrate use of the conversion equation.

Standard test conditions are 20°C, 760mm Hg, 0.0 mg/l D.O. and the N_o is given as 3.0 lb O_2/hp-hr for a surface aerator. α is 0.75, β is 0.9. The field conditions are to be a 30°C average temperature at 2,000 feet elevation and design D.O. concentration is 2.0 mg/l.

C^*_{walt} = 9.17 x 0.93 = 8.53 (no change for depth required)

C^*_{st} = 9.17

C_L = 2.0 mg/l

T_c = 30°C

By applying the aforementioned equation, the conversion factor becomes 0.59, and the efficiency of the aerator under field conditions (N) becomes 0.59 x 3.0 = 1.77 or 1.8 lb O_2/hp-hr.

This conversion to actual operating conditions can significantly affect energy usage in a system. Therefore, it is important to realize that comparison of two kinds of aeration devices can be made under standard conditions but when calculating actual energy use, actual anticipated field conditions must be used.

The oxygen transfer efficiencies and energy requirements of selected aeration devices are shown in Table D-1. The values given are for standard conditions rather than field conditions. In the fact sheets (Appendix A) values for efficiencies for aeration devices in terms of lb O_2/hp-hr are given <u>which do reflect anticipated field conditions</u>. The energy and power cost curves in the fact sheets are based on these field values; and if another value is to be used, the curves would have to be modified accordingly by the user.

Example Calculations:

A 1.0 mgd wastewater flow with a BOD of 200 mg/l is to be treated in an aeration basin equipped with low speed mechanical aerators. Calculate the electrical energy required.

Assume 1.0 lb O_2/lb BOD required

$$1{,}000{,}000 \ \frac{gal}{day} \times 200 \ \frac{mg}{l} \times \frac{1}{1{,}000{,}000} \ \frac{1}{mg} \times 8.34 \ \frac{lb}{gal}$$

$= 1{,}668$ lb O_2/day

$$1{,}668 \ \frac{lb}{day} \times 0.26 \ \frac{KwH}{lb} = 433.68 \text{ KwH/day}$$

D.2.2 Pumping

Pumping devices commonly used in municipal wastewater application include centrifugal, axial-flow, mixed flow, reciprocating, air lift pumps, and pneumatic ejectors. The radial, or so-called "non-clog" centrifugal pumps with specially designed impellers are widely used in raw wastewater pumping. The axial-flow pumps, such as screw pumps, are applicable to well settled sewage only, and are used for recirculation or effluent pumping. The mixed-flow pumps which are intermediate between centrifugal and axial-flow pumps are suitable for moderate head pumping. Reciprocating pumps such as diaphragm pumps have their greatest use in pumping sludges. Air lift pumps are generally used in smaller treatment plants and are also useful as sludge pumps. Pneumatic ejectors are suitable for pumping wastewater of small flows from an isolated area to a main sewer line or treatment facility.

Since centrifugal pumps are the most widely used pumping equipment, their hydraulic efficiencies and electrical energy requirements are shown in Figures D-1 and D-2, respectively. Calculations of energy requirements are illustrated in the following example.

Example Calculations:

A 1 mgd flow is to be pumped against a total dynamic head of 30 ft. The pump motor is 95% efficient and the efficiency of the pump is 75%. Calculate the electrical energy required.

$$\frac{1 \text{ mgd}^6 \times 10^6 \times 8.34 \text{ lb/gal}}{1440 \text{ min/day} \times 60 \text{ sec/min}} \times 30 \text{ ft.} = 2896 \text{ ft lb/sec}$$

$$2896 \text{ ft lb/sec} \times \frac{1 \text{ HP}}{550 \text{ ft lb/sec}} = 5.27 \text{ HP}$$

$$\frac{5.27 \times 0.7457 \times 24 \text{ hours/day}}{0.95 \times 0.75} = 132.4 \text{ KwH/day}$$

If the wire to water efficiency is not given, it can be estimated from Figure D-1. For the above example, the overall efficiency given in the figure is approximately 63%. Using this estimate, the required power in the above example is:

$$\frac{5.27 \times 0.7457 \times 24}{0.63} = 149.7 \text{ KwH/day}$$

Estimates of the annual power requirements for raw sewage pumping against different values of the total dynamic head are provided in Figure D-2.

D.3 Alternative Sludge Handling Processes

The specifically identified energy recovery technology in the Innovative and Alternative Guidelines includes co-disposal of sludge and refuse, anaerobic digestion with more than 90% methane recovery, and self-sustaining incineration. The energy utilization for anaerobic digestion and incineration is presented in the following discussion.

D.3.1 Anaerobic Digestion

Heat energy is required to raise the temperature of the influent sludge solids and associated water and to compensate for heat losses through the digester walls, bottom, and cover. Electrical energy is required for mixed digesters to operate the mixing equipment and to pump the digester contents through the heat exchangers. The digester gas can be collected and burned to provide needed energy. The influent heat requirement per ton of suspended solids fed to the digester can be determined from Figure D-3. The temperature difference is that between the influent sludge stream and the digester operating temperature. Heat losses per ton of solids fed to the digester are shown in Figure D-4 for varying reactor detention times and solids feed concentrations. Figure D-5 shows the heating value of the digester gas per ton of solids fed to the digester as a function of volatile solids destruction for different volatile solids percentages in the feed sludge. The following example illustrates the use of Figures D-3 thru D-5 to calculate heat balances around a digester.

Example Calculations:

Example No. 1

A sludge stream at 3% solids which are 70% volatile is fed to an anaerobic digester in the northern U.S. The digester detention time is 20 days and the volatile solids destruction is 60%. The digester operates at 95°F and the average annual influent sludge temperature is 55°F. The heating equipment has an efficiency of 75%.

From Figure D-3 — 2.67×10^6 BTU/ton required for 3% solids and Δ Temp of 40°F.

Correct for heating equipment efficiency:
$2.67 \times 10^6/0.75 = 3.56 \times 10^6$ BTU/ton input to heater needed.

From Figure D-4 — 1.33×10^6 BTU/ton required.
Correct for heating equipment efficiency:
$1.33 \times 10^6/0.75 = 1.77 \times 10^6$ BTU/ton input to heater needed.

From Figure D-5 — 7.55×10^6 BTU/ton generated.

Overall Net Heat Generation Potential:

$7.55 \times 10^6 - 3.56 \times 10^6 - 1.77 \times 10^6 = 2.22 \times 10^6$ BTU/ton solids fed.

Example No. 2

A sludge stream at 5% solids which are 75% volatile is fed to an anaerobic digester in the southern U.S. The digester detention time is 15 days and the volatile solids destruction is 50%. The digester operates at 95°F and the influent sludge feed averages 70°F. The heating equipment has an efficiency of 75%.

From Figure D-3 — 1.0×10^6 BTU/ton required for 5% solids and Δ Temp of 25°F.

Correct for heating equipment efficiency:
$1.0 \times 10^6/0.75 = 1.33 \times 10^6$ BTU/ton input to heater needed.

From Figure D-4 — 0.6×10^6 BTU/ton required in northern U.S.
$0.6 \times 10^6 \times 0.3 = 0.18 \times 10^6$ needed for southern U.S.

Correct for heating equipment efficiency:
$0.18 \times 10^6/0.75 = 0.24 \times 10^6$ BTU/ton input to heater needed.

From Figure D-5 — 6.75×10^6 BTU/ton generated.

Overall Net Heat Generation Potential:
$6.75 \times 10^6 - 1.33 \times 10^6 - 0.24 \times 10^6 = 5.18 \times 10^6$ BTU/ton solids fed.

Electrical Energy

The electrical energy requirement in KwH/yr to mix the digester(s) can be estimated from Figure D-6. The required digester total volume in ft^3 is given by the following equation as:

$$\frac{\text{Sludge Flow, gpd} \times \text{Digester Detention Time, days}}{7.48 \text{ gal/ft}^3}$$

The electrical energy required in KwH/yr to pump the sludge through the heat exchangers can be estimated by finding the sum of the heating requirement from Figures D-3 and D-4 in million of BTU's per dry ton of solids and multiplying this value by the tons per day of solids fed to the digester. This computed value in million BTU/day can be used in Figure D-7 to estimate the electrical energy requirements for pumping the sludge through the digester. The total heat requirements of anaerobic digestion can also be estimated by using Figures D-7(a) and D-7(b). These heat requirements are based on a digestion temperature of 95°F. Typical loading in lb VS/day/cu ft is 0.05 for standard rate, and 0.15 for high rate digestion. Typical detention time is 30 days for standard rate, and 15 to 20 days for high rate digestion.

The amount of sludge produced in a wastewater treatment plant, and the VS content of the sludge varies with the influent suspended solids concentration, the BOD, and type and efficiency of the biological treatment process. The following sludge quantities are representative of typical primary and activated sludge plants:

Sludge Type		Sludge Solids (lb/mil gal) Total	Volatile
Primary		1,151	690 (60%)
Waste Activated		945	756 (80%)
	TOTAL	2,096	1,446

Generally, about 50% of the volatile solids are destroyed by anaerobic digestion and the gas produced has a heat value of about 600 BTU/scf. These criteria give the following estimates for gas and heat available from anaerobic digestion:

	Primary Sludge	Waste Activated Sludge	Total
Gas Produced, scf/mil/gal	5,175	5,670	10,845
Heat Available, BTU/mil/gal	3,105,000	3,402,000	6,507,000

For planning purposes, and in the absence of more specific information, it may be assumed that about 6.5 mil BTU are available from gas produced by anaerobic digestion of primary and conventional activated sludge treatment of one million gallons of wastewater.

D.3.2 Incineration

Energy requirements for incineration and the potential for energy recovery have been described by Smith (1). When the sludge is 70% volatile, the minimum solid concentrations needed to operate a self-sustaining incineration without auxiliary fuel at different flue gas temperatures were calculated to be 25.9% at 800°F, 30% at 1,000°F, 34.7% at 1,200°F, and 40.4% at 1,400°F. The attached figures provide a brief summary of some of the design parameters. Further details are available in the above reference.

Figure D-8: This figure shows the pounds of water (W_s) per lb of dry volatile solids (DVS) as a function of the solids content of the sludge (F_s) for different volatile solids fractions. For example, a sludge containing 25% solids which are 70% volatile, has 4.29 lb of water per lb of DVS.

Figure D-9: This figure shows the flue gas temperature (T_s) attained with 50% excess air and 100% excess air for various values of W_s. For example, if W_s is 3.0, the flue gas temperature will be 1100°F with 50% excess air and 920°F with 100% excess air. If one desires a flue gas temperature of 1000°F, W_s would have to be less than 3.35 to avoid using supplemental fuel.

Figure D-10: The gallons of fuel oil per ton of DVS (R_f) that must be used to incinerate sludge with different values of W_s using 50% excess air are shown in Figure D-10. For example, to achieve a 1000°F flue gas temperature with $W_s = 6$, the supplemental fuel requirement is 77.5 gal/ton DVS. This fuel requirement does not include an estimate for start-up requirements.

Figure D-11: The gallons of fuel oil per ton of DVS (R_f) that must be used to incinerate sludge with different values of W_s using 100% excess air are shown in Figure D-11.

Figure D-12: When the sludge is sufficiently dry to sustain combustion, the excess air requirement varies to hold the desired flue gas temperature. the excess air requirement (E_x) for different values of W_s is shown as a function of flue gas temperature in Figure D-12.

Figure D-13: The heat that can be recovered across a waste heat boiler operated with an exit temperature of 500°F is shown for different inlet gas temperatures and values of W_s in Figure D-13. For a sludge with a value of W_s of 2.0 and the excess air controlled to provide a flue gas temperature of 1200°F, the heat recovered across the boiler would be 3920 BTU/lb DVS.

When supplemental fuel is burned in the sludge incineration process, the total heat that can be recovered from a waste heat boiler is given by:

$$\text{BTU/lb DVS} = (0.505 \times W_s + 2.55 + 2.09 \times E_x + 0.0152 \times R_f) \times \Delta T$$

where ΔT is the temperature drop across the waste heat boiler. For $E_x = 0.5$ or 1.0 the values of R_f are presented in Figures D-10 and D-11 respectively. This information can be used in conjunction with Figure D-8 to calculate the recoverable heat.

For example, consider a sludge with W_s = 6.0 combusted with 50% excess air at a flue gas temperature of 1200°F and a waste heat boiler operating with a boiler exit temperature of 500°F. Here R_f = 116 gal/ton DVS (From Figure D-10) and the heat recovered is:

$$(0.505 \times 6. + 2.55 + 2.09 \times 0.5 + 0.0152 \times 116) \times (1200 - 500) = 5872 \text{ BTU/lb DVS}$$

D.4 Dewatering Processes

As previously mentioned, self-sustaining incineration can be achieved if the sludge is adequately dewatered. The energy requirements for the three commonly used sludge dewatering processes, i.e., vacuum filtration, filter press, and centrifuge, are presented as follows to assist the overall evaluations of the energy utilization.

D.4.1 Vacuum Filtration

The electrical energy requirement in KwH/yr to continuously operate a vacuum filter of various sizes is given in Figure D-14.

Variables which affect the performance of the vacuum filter include feed sludge type, feed sludge concentration, feed sludge loading, type and amount of conditioning chemicals, type and operation of filter, etc. Alternative sludge types, typical loading rates, and the corresponding cake solids are presented in Table D-2.

Example Calculations

A 100,000 gpd sludge stream at 5% solids (after addition of conditioning chemicals) will be fed at 4 lb/ft²/hr for 16 hrs/day. Solids capture is 96% and cake solids are 25%.

$$100{,}000 \frac{\text{gal}}{\text{day}} \times 8.34 \frac{\text{lb}}{\text{gal}} \times 0.05 = 41{,}700 \frac{\text{lb solids fed}}{\text{day}}$$

$$\frac{41{,}700 \text{ lb/day}}{16 \frac{\text{hrs}}{\text{day}} \times 4 \frac{\text{lb/ft}^2}{\text{hr}}} = 651 \text{ ft}^2 \text{ required}$$

From Figure D-14:

651 ft^2: 490,000 KwH/yr

$$\frac{490{,}000 \times (16/24)}{365 \text{ days/yr}} = 895 \text{ KwH/day}$$

$$\frac{895 \text{ KwH/day} \times 2000 \text{ lb/ton}}{41{,}700 \times 0.96} = 44.7 \frac{\text{KwH}}{\text{ton DS captured}}$$

Water Remaining in Cake:

$$41{,}700 \times 0.96 \times \frac{1.0 - 0.25}{0.25} = 120{,}096 \text{ lb}$$

D.4.2 Filter Press

The electrical power requirement in KwH/yr to continuously operate a filter press of various volumes is given in Figure D-15. Typical conditioning requirements, cycle times and cake solids for various sludge types are presented in Table D-3.

Example Calculations:

A 100,000 gpd sludge stream at 5% solids (after addition of conditioning chemicals) will be fed to a filter press with a two hour cycle time. Solids capture is 96% and cake solids are 45%. Operation is 16 hrs/day.

$$\frac{100{,}000 \text{ gal/day}}{7.48 \text{ gal/ft}^3} = 13{,}369 \text{ ft}^3\text{/day}$$

$$\frac{13{,}369 \text{ ft}^3\text{/day}}{8 \text{ cycles/day}} = 1{,}670 \text{ ft}^3 \text{ required}$$

From Attached Figure (For 835 ft^3 Press)

$$2 \times 600{,}000 = 1{,}200{,}000 \text{ KwH/yr}$$

$$100{,}000 \frac{\text{gal}}{\text{day}} \times 8.34 \frac{\text{lb}}{\text{gal}} \times 0.05 = 41{,}700 \frac{\text{lb solids fed}}{\text{day}}$$

$$\frac{2{,}192 \text{ KwH/day} \times 2{,}000 \text{ lb/ton}}{41{,}700 \times 0.96} = 109.5 \frac{\text{KwH}}{\text{ton DS captured}}$$

Water Remaining in Cake:

$$41{,}700 \times 0.96 \times \frac{1.0 - 0.45}{0.45} = 48{,}928 \text{ lb}$$

D.4.3 Centrifuge

The electrical energy requirement in KwH/yr to continuously operate a centrifuge at various flow rates can be estimated from Figure D-16.

Example Calculations:

A 100,000 gpd sludge stream at 5% solids (after addition of conditioning chemicals) will be fed to a centrifuge for 16 hrs/day. Solids capture is 90% and cake solids are 25%.

$$\frac{100{,}000 \text{ gal/day}}{60 \times 16} = 104 \text{ gpm to centrifuge}$$

From Figure D-16:

104 gpm: 220,000 KwH/yr

$$\frac{220{,}000 \times (16/24)}{365 \text{ days/yr}} = 402 \text{ KwH/day}$$

$$100{,}000 \frac{\text{gal}}{\text{day}} \times 8.34 \frac{\text{lb}}{\text{gal}} \times 0.05 = 41{,}700 \frac{\text{lb solids fed}}{\text{day}}$$

$$\frac{402 \text{ KwH/day} \times 2{,}000 \text{ lb/ton}}{41{,}700 \times 0.90} = 21.4 \frac{\text{KwH}}{\text{ton DS captured}}$$

Water Remaining in Cake:

$$41{,}700 \times 0.90 \times \frac{1 - 0.25}{.25} = 112{,}590 \text{ lb}$$

D.5 Energy Conversion Methods

Whenever various forms of energy are interconverted there will be some loss due to inefficiencies. For example, whenever electrical energy is converted to mechanical energy, some of the energy is lost as heat energy in the motor. Similarly, if an engine operating on a Carnot cycle has a source temperature of 1100°F (1560°R) and a receiver temperature of 500°F (960°R) the efficiency is only (1.0 - 960/1560) or 38.5%. Since no heat engine can be more efficient than a Carnot engine, it is clear that this is the maximum possible efficiency for these source and receiver temperatures.

The efficiency of pumps and blowers is usually in the range of 70-80% so that mechanical energy can be converted to hydraulic energy with no more than about 30% loss. Similarly, mechanical and electrical energy can be converted from one form to the other with a loss of less than 10%. On the other hand, the conversion of heat energy to mechanical energy necessitates the wasting of roughly 2/3 of the heat energy. For example, if electrical energy is converted to heat energy, one KwH will generate about 3,413 BTU of heat. However, if heat energy is used to generate electrical energy in a modern coal fired power plant, about 10,500 BTU of heat energy is needed to generate one KwH; this is a conversion efficiency of only 32.5%.

D.6 Present-Worth Methodology

The purpose of this methodology is to determine the present-worth cost of an alternative. The costs identified include construction cost, constant and variable operation and maintenance (O&M) costs, existing facility phase out costs, facility replacement costs, and facility salvage value. This procedure converts these costs over the project life into an equivalent cost that represents the current investment that would be required to satisfy all of the identified project costs for the planning period. For a more detailed discussion, the user may consult any standard engineering economy text.

The construction costs incurred by the project represent single-payment costs that occur at certain times throughout the planning period. The single-payment present-worth factor (sppwf) is used to determine the present-worth cost, and is determined by the following formula and shown in the first column of Table D-6:

$$\text{sppwf} = \frac{1}{(1 + i)^n}$$

where: i is the interest
n is the number of interest periods

The operation and maintenance (O&M) cost includes both constant and variable costs. The constant O&M cost is based on the flow rate at the beginning of the planning period. The variable O&M cost represents the difference between the O&M cost at the flow rate in the final year of the planning period and the constant O&M cost identified by the flow rate at the beginning of the planning period. The uniform-series present-worth factor (uspwf) is used to convert the constant annual O&M cost to a present-worth cost by the following formula and shown in the second column of Table D-6.

$$\text{uspwf} = \frac{(1 + i)^n - 1}{i\,(1 + i)^n}$$

where: i is the interest rate
n is the number of interest periods

For cases where the constant payment is for a period that does not start at the beginning of the planning period (Phase 2 constant O&M costs), the uniform-series factor must be adjusted by multiplying it by the single-payment present-worth factor for the number of years from the beginning of the planning period to the time that the constant payment begins, as in the following:

$$(\text{uspwf}^{t1}) \times (\text{sppwf}^{t2})$$

where: t1 is the number of years that the constant payment will be made
t2 is the number of years from the beginning of the planning period to the time that the constant payment begins

The variable operation and maintenance costs are assumed to vary linearly through the planning period and are multiplied by the gradient series present-worth factor for the same number of years that the corresponding constant operation and maintenance is paid. This value is computed as:

$$\text{gspwf} = \frac{\dfrac{(1 + i)^{n}-1}{i\,(1 + i)^n} - n\,\dfrac{1}{(1 + i)^n}}{(i)}$$

where: i is the interest rate
n is the number of interest periods that the series is in effect

Gradient series present-worth factors are shown in the third column of Table D-6. When using this term for computing the present worth of a variable O&M cost, care must be exercised to insure that the gradient O&M is used (i.e., the annual average increase in O&M costs during the phase).

If the gradient series does not start at the beginning of the planning period, it must be adjusted by multiplying it by the single payment present-worth factor as follows:

$$(gspwf^{t1}) \times (sppwf^{t2})$$

where: t1 is the period in which the gradient series is in effect
t2 is the number of years from the beginning of the planning period to the time the variable payment is started

The new cost effectiveness guidelines require that natural gas prices be escalated at a compound rate of 4% annually over the planning period unless the regional administrator determines that a lesser or greater rate can be used based on regional differentials between historical natural gas price escalation and construction cost escalation. The inflation factor results in a geometric increase in the value of natural gas and the geometric series present-worth factor (gespwf) can be calculated by the following formula:

$$gespwf = \frac{1}{(1 + i)} \left[\frac{1 - \left(\frac{1 + a}{1 + i}\right)^n}{1 - \left(\frac{1 + a}{1 + i}\right)} \right]$$

where: i is the interest rate
n is the number of interest periods that the series is in effect
a is the appreciation factor

The formula contains three variables. For an appreciation factor of 4% for natural gas, the present-worth factor for varying interest rates (6 1/4-8%) and time periods (1-20 years) can be found from column four of Table D-6. The factor in the table is multiplied by the initial first-year value of the natural gas. For example, to determine the present worth of natural gas used over 20 years and which is worth $1,000 at the beginning of the first year, at an interest rate of 6 1/4% per annum; multiply 15.47730 times $1,000 to get $15,477.30. At this time, the only energy cost which is appreciated is for natural gas and any present worth analysis which does so must break out the cost of the natural gas from the rest of the O&M costs. If the geometric series does not start at the beginning of a planning period, it must be adjusted by multiplying it by the single payment present-worth factor as follows:

$$(gespwf^{t1}) \times (sppwf^{t2})$$

where: t1 is the period in which the geometric series is in effect
t2 is the number of years from the beginning of the planning period to the time the variable payment is started

The facility replacement cost identifies the cost required to extend the useful life of equipment to the end of the planning period. This is computed when a capital item has a service life of less than the remaining years in the planning period, and is computed by:

$$\text{Replacement Cost} = \frac{\text{Planning Period - Remaining Service Life}}{\text{Service Life}} \times \text{Capital Value}$$

where: Capital Value represents the capital that would be required today to completely replace the facility. This is a single-payment cost, with present worth computed using the factor sppwf.

Finally, the salvage value represents the value remaining for all capital at the end of the planning period, and is computed by:

$$\text{Salvage Value} = \frac{\text{Service Life - Years to Planning End}}{\text{Service Life}} \times \text{Capital}$$

where: Capital (or Capital Value) represents the initial investment (or cost to replace today). This is a negative cost, with the present-worth value computed using the factor sppwf.

D.7 References

1. Smith, R., Total Energy Consumption for Municipal Wastewater Treatment, EPA-600/2-78-149, August 1978

2. Wesner, G.M.; Culp, G.L.; Lineck, T.S.; and Hinrichs, D.J.; Energy Conservation in Municipal Wastewater Treatment, EPA 430/9-77-011, MCD-32, March 1978

TABLE D-1

COMPARATIVE CLEAN WATER OXYGEN TRANSFER INFORMATION FOR AIR AERATION SYSTEMS UNDER STANDARD CONDITIONS (1)

Type of Aeration Device	Range of Clean Water O_2 Transfer (%)	Range of Clean Water Efficiencies $\#O_2$/wire HP-Hr	Energy Requirement KwH/$\#O_2$
Mechanical Aerator			
Low Speed Surface	----	2.5 - 3.5	0.21 - 0.30
High Speed Surface	----	2.0 - 3.0	0.25 - 0.37
Turbine Sparger (2)	14 - 18	2.0 - 3.0	0.25 - 0.37
Fine Bubble Aerators (3)			
Fine Bubble Diffuser			
(a) Total Floor Coverage	20 - 32	5.0 - 7.5	0.10 - 0.15
(b) Side Wall Mounted	15 - 20	3.0 - 5.5	0.14 - 0.25
Jet Aerator (2)	15 - 26	2.7 - 3.8	0.20 - 0.28
Coarse Bubble Diffuser (3)			
Static Aerator	10 - 16	2.3 - 3.2	0.23 - 0.32
Coarse Bubble Dual Aeration	10 - 13	2.3 - 2.7	0.28 - 0.32
Coarse Bubble Single Side Aeration	8 - 10	2.0 - 2.5	0.30 - 0.32

(1) Compiled using a combination of manufacturers' company bulletins, technical reports, and historically accepted data ranges. See text on aeration, Section D.2.1, starting on Page D-1 for proper use of table
(2) Includes energy requirements for two prime movers
(3) Based on clean water test at 15' water depth; submergence varies depending on device.

TABLE D-2

DESIGN CRITERIA FOR VACUUM FILTRATION

Sludge Type	Design Assumptions	Percent Solids To VF	Typical Loading Rates, (psf/hr)	Percent Solids VF Cake
Primary	Thickened to 10% solids polymer conditioned	10	8-10	25-38
Primary + $FeCl_3$	85 mg/l $FeCl_3$ dose Lime conditioning Thickening to 2.5% solids	2.5	1.0-2.0	15-20
Primary + Low Lime	300 mg/l lime dose Polymer conditioned Thickened to 15% solids	15	6	32-35
Primary + High Lime	600 mg/l lime dose Polymer conditioned Thickened to 15% solids	15	10	28-32
Primary + WAS	Thickened to 8% solids Polymer conditioned	8	4-5	16-25
Primary + (WAS + $FeCl_3$)	Thickened to 8% solids $FeCl_3$ & lime conditioned	8	3	20
(Primary + $FeCl_3$) + WAS	Thickened primary sludge to 2.5% Flotation thickened WAS to 5% Dewater blended sludges	3.5	1.5	15-20
Waste Activated Sludge (WAS)	Thickened to 5% solids Polymer conditioned	5	2.5-3.5	15
WAS + $FeCl_3$	Thickened to 5% solids Lime + $FeCl_3$ conditioned	5	1.5-2.0	15
Digested Primary	Thickened to 8-10% solids Polymer conditioned	8-10	7-8	25-38
Digested Primary + WAS	Thickened to 6-8% solids Polymer conditioned	6-8	3.5-6	14-22
Digested Primary + (WAS + $FeCl_3$)	Thickened to 6-8% solids $FeCl_3$ + lime conditoned	6-8	2.5-3	16-18
Tertiary Alum	Diatomaceous earth precoat	0.6-0.8	0.4	15-20

Source: Wesner, G.M., et al, Energy Conservation in Municipal Wastewater, MCD-32, EPA-430/9-77-011, March 1978.

TABLE D-3

DESIGN CRITERIA FOR FILTER PRESSING

Sludge Type	Conditioning	Percent Solids To Pressure Filter	Typical Cycle Length	Percent Solids Filter Cake
Primary	5% $FeCl_3$, 10% Lime	5	2 hours	45
Primary + $FeCl_3$	10% Lime	4*	4	40
Primary + 2 stage high lime	None	7.5	1.5	50
Primary + WAS	5% $FeCl_3$, 10% Lime	8*	2.5	45
Primary + (WAS + $FeCl_3$)	5% $FeCl_3$, 10% Lime	8*	3	45
(Primary + $FeCl_3$) + WAS	10% Lime	3.5*	4	40
WAS	7.5% $FeCl_3$, 15% Lime	5*	2.5	45
WAS + $FeCl_3$	5% $FeCl_3$, 10% Lime	5*	3.5	45
Digested Primary	5% $FeCl_3$, 10% Lime	8	2	45
Digested Primary + WAS	7.5% $FeCl_3$, 15% Lime	6-8*	2.5	45
Digested Primary + (WAS + $FeCl_3$)	5% $FeCl_3$, 10% Lime	6-8*	3	40
Tertiary Alum	10% Lime	4*	6	35
Tertiary Low Lime	None	8*	1.5	55

*Thickening used to achieve this solids concentration

Source: Wesner, G.M., et al, Energy Conservation in Municipal Wastewater, MCD-32, EPA-430/9-77-011, March 1978.

TABLE D-4

ENERGY CONVERSION* AND
REPRESENTATIVE HEAT VALUES

ENERGY CONVERSION

Type of Conversion	Efficiency (%)
Heat to Mechanical	$\lessapprox$ 38.5
Heat to Electrical	$\lessapprox$ 32.5
Mechanical to Electrical	> 90
Mechanical to Hydraulic	70-80
Electrical to Mechanical	> 90
Electrical to Heat	$\approx$ 100
Electric to Hydraulic	65-80

REPRESENTATIVE HEAT VALUES OF COMMON FUELS

Anthracite Coal	14,200 BTU/# Coal
Digester Gas	600 BTU/ft^3
Fuel Oil	140,000 BTU/gal
Lignite Coal	7,400 BTU/# Coal
Liquified Natural Gas (LNG)	86,000 BTU/gal
Municipal Refuse (25% Moisture)	4,200 BTU/lb
Natural Gas	1,000 BTU/ft^3
Propane Gas	2,500 BTU/ft^3
Waste Paper (10% Moisture)	7,600 BTU/lb
Wastewater Sludge	10,000 BTU/lb dry VS

*Refer to References 1 and 2 for further information on energy conversion in municipal wastewater treatment.

TABLE D-5

CONVERSION FACTORS

Multiply	By	To Obtain
Acres	43,560	ft^2
Atmospheres	29.92	in of mercury
Atmospheres	33.90	ft of water
Atmospheres	14.70	psi
BTU	1.055	KJ
BTU	777.5	ft-lb
BTU	3.927×10^{-4}	hp-hr
BTU	2.928×10^{-4}	Kw-hr
BTU/lb	2.326	KJ/kg
cu ft	28.32	l
cu ft	0.03704	cu yd
cu ft	7.481	gal
cu ft/second	0.6463	mgd
cu ft/second	448.8	gpm
cu yd	0.765	m^3
^oF	$0.555\ (^oF - 32)$	^oC
ft	0.3048	m
gal	3.785	l
gal, water	8.345	lb, water
gpd/sp ft	0.04074	$m^3/m^2 \cdot d$
gpm	0.06308	l/s
gpm/sq ft	0.06790	$l/m^2 \cdot s$
hp	0.7457	Kw
hp	42.44	BTU/min
hp	33.00	ft-lb/min
hp-hr	2.685	MJ
in	25.4	mm
lb (mass)	0.4536	kg
mil gal	3,785	m^3
mgd	3,785	m^3/d
ppm (by weight)	1.000	mg/l
psi	6.895	KN/m^2
sq ft	0.0929	m^2
tons (short)	907.2	kg

Notes: Energy conversion in practice should take into account the efficiences shown in Table D-4, e.g. to produce an electrical power of 1 Kwh from heat energy, the BTU required is $1/(2.928 \times 10^{-4})(0.325) = 10{,}508$, but not $1/(2.928 \times 10^{-4}) = 3.415$ which does not include the actual heat to electrical energy conversion efficiency.

TABLE D-6

PRESENT WORTH FACTORS

6 1/4 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.94118	0.94118	0.00000	0.94118
2	0.88581	1.82699	0.88581	1.86242
3	0.83371	2.66070	2.55322	2.76416
4	0.78466	3.44536	4.90722	3.64680
5	0.73851	4.18387	7.86126	4.51075
6	0.69507	4.87894	11.33659	5.35640
7	0.65418	5.53312	15.26167	6.18415
8	0.61570	6.14881	19.57156	6.99436
9	0.57948	6.72830	24.20741	7.78743
10	0.54539	7.27369	29.11596	8.56369
11	0.51331	7.78700	34.24908	9.32352
12	0.48312	8.27012	39.56338	10.06725
13	0.45470	8.72482	45.01975	10.79524
14	0.42795	9.15277	50.58315	11.50781
15	0.40278	9.55555	56.22204	12.20529
16	0.37909	9.93463	61.90830	12.88800
17	0.35679	10.29142	67.61689	13.55625
18	0.33580	10.62722	73.32546	14.21035
19	0.31605	10.94327	79.01430	14.85061
20	0.29745	11.24072	84.66594	15.47730

6 3/8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.94007	0.94007	0.00000	0.94007
2	0.88373	1.82380	0.88375	1.85915
3	0.83077	2.65458	2.54530	2.75771
4	0.78098	3.43556	4.88825	3.63621
5	0.73418	4.16974	7.82498	4.49510
6	0.69018	4.85992	11.27589	5.33481
7	0.64882	5.50874	15.16879	6.15577
8	0.60993	6.11867	19.43834	6.95840
9	0.57338	6.69205	24.02541	7.74312
10	0.53902	7.23107	28.87659	8.51031
11	0.50672	7.73779	33.94374	9.26037
12	0.47635	8.21414	39.18358	9.99369
13	0.44780	8.66194	44.55721	10.71063
14	0.42096	9.08290	50.02976	11.41157
15	0.39574	9.47864	55.57008	12.09686
16	0.37202	9.85066	61.15038	12.76685
17	0.34973	10.20039	66.74599	13.42187
18	0.32877	10.52915	72.33503	14.06228
19	0.30906	10.83822	77.89819	14.68838
20	0.29054	11.12876	83.41846	15.30051

6 1/2 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93897	0.93897	0.00000	0.93897
2	0.88166	1.82063	0.88169	1.85589
3	0.82785	2.64848	2.53741	2.75129
4	0.77732	3.42580	4.86937	3.62568
5	0.72988	4.15568	7.78892	4.47953
6	0.68533	4.84102	11.21560	5.31335
7	0.64351	5.48452	15.07664	6.12759
8	0.60423	6.08875	19.30626	6.92271
9	0.56735	6.65611	23.84509	7.69917
10	0.53273	7.18883	28.63964	8.45741
11	0.50021	7.68905	33.64178	9.19784
12	0.46968	8.15873	38.80829	9.92090
13	0.44102	8.59975	44.10050	10.62698
14	0.41410	9.01385	49.48382	11.31649
15	0.38883	9.40267	54.92739	11.98981
16	0.36510	9.76777	60.40382	12.64732
17	0.34281	10.11058	65.88882	13.28940
18	0.32189	10.43247	71.36095	13.91641
19	0.30224	10.73472	76.80136	14.52870
20	0.28380	11.01851	82.19347	15.12662

6 5/8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93787	0.93787	0.00000	0.93787
2	0.87959	1.81746	0.87958	1.85264
3	0.82494	2.64240	2.52944	2.74490
4	0.77368	3.41608	4.85051	3.61519
5	0.72561	4.14170	7.75295	4.46405
6	0.68053	4.82222	11.15557	5.29202
7	0.63824	5.46047	14.98503	6.09960
8	0.59859	6.05905	19.17515	6.88730
9	0.56140	6.62045	23.66630	7.65561
10	0.52651	7.14696	28.40491	8.40500
11	0.49380	7.64076	33.34291	9.13594
12	0.46312	8.10388	38.43719	9.84889
13	0.43434	8.53822	43.64930	10.54429
14	0.40736	8.94558	48.94492	11.22257
15	0.38205	9.32762	54.29354	11.88414
16	0.35831	9.68593	59.66814	12.52944
17	0.33604	10.02197	65.04485	13.15884
18	0.31516	10.33714	70.40265	13.77275
19	0.29558	10.63272	75.72314	14.37154
20	0.27722	10.90994	80.99026	14.95560

6 3/4 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93677	0.93677	0.00000	0.93677
2	0.87753	1.81430	0.87754	1.84940
3	0.82205	2.63635	2.52163	2.73853
4	0.77007	3.40642	4.83184	3.60475
5	0.72137	4.12779	7.71733	4.44866
6	0.67576	4.80355	11.09613	5.27082
7	0.63303	5.43658	14.89432	6.07181
8	0.59300	6.02958	19.04535	6.85216
9	0.55551	6.58509	23.48941	7.61241
10	0.52038	7.10547	28.17282	8.35307
11	0.48748	7.59295	33.04758	9.07465
12	0.45665	8.04960	38.07076	9.77765
13	0.42778	8.47738	43.20408	10.46253
14	0.40073	8.87811	48.41355	11.12977
15	0.37539	9.25349	53.66900	11.77983
16	0.35165	9.60515	58.94379	12.41313
17	0.32942	9.93456	64.21445	13.03013
18	0.30859	10.24315	69.46043	13.63122
19	0.28907	10.53223	74.66379	14.21684
20	0.27080	10.80302	79.80891	14.78736

6 7/8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93567	0.93567	0.00000	0.93567
2	0.87548	1.81116	0.87549	1.84617
3	0.81917	2.63032	2.51381	2.73218
4	0.76647	3.39679	4.81323	3.59436
5	0.71717	4.11396	7.68189	4.43334
6	0.67103	4.78499	11.03704	5.24975
7	0.62787	5.41286	14.80424	6.04420
8	0.58748	6.00033	18.91660	6.81728
9	0.54969	6.55002	23.31408	7.56957
10	0.51433	7.06434	27.94302	8.30161
11	0.48124	7.54559	32.75544	9.01397
12	0.45028	7.99587	37.70856	9.70716
13	0.42132	8.41719	42.76437	10.38170
14	0.39422	8.81140	47.88918	11.03810
15	0.36886	9.18026	53.05318	11.67684
16	0.34513	9.52539	58.23012	12.29840
17	0.32293	9.84832	63.39697	12.90323
18	0.30215	10.15047	68.53360	13.49180
19	0.28272	10.43319	73.62253	14.06454
20	0.26453	10.69772	78.64863	14.62186

7 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93458	0.93458	0.00000	0.93458
2	0.87344	1.80802	0.87345	1.84295
3	0.81630	2.62432	2.50606	2.72586
4	0.76290	3.38721	4.79476	3.58401
5	0.71299	4.10020	7.64671	4.41811
6	0.66634	4.76654	10.97843	5.22881
7	0.62275	5.38929	14.71494	6.01679
8	0.58201	5.97130	18.78901	6.78267
9	0.54393	6.51524	23.14049	7.52708
10	0.50835	7.02358	27.71562	8.25062
11	0.47509	7.49868	32.46658	8.95387
12	0.44401	7.94269	37.35071	9.63741
13	0.41496	8.35765	42.33029	10.30178
14	0.38782	8.74547	47.37190	10.94752
15	0.36245	9.10792	52.44617	11.57516
16	0.33873	9.44665	57.52719	12.18520
17	0.31657	9.76323	62.59238	12.77813
18	0.29586	10.05909	67.62207	13.35445
19	0.27651	10.33560	72.59923	13.91460
20	0.25842	10.59402	77.50919	14.45905

7 1/8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93349	0.93349	0.00000	0.93349
2	0.87140	1.80489	0.87138	1.83975
3	0.81344	2.61833	2.49827	2.71957
4	0.75934	3.37767	4.77628	3.57372
5	0.70884	4.08651	7.61161	4.40296
6	0.66169	4.74820	10.92006	5.20801
7	0.61768	5.36588	14.62614	5.98957
8	0.57660	5.94248	18.66232	6.74834
9	0.53825	6.48073	22.96830	7.48497
10	0.50245	6.98317	27.49032	8.20011
11	0.46903	7.45220	32.18063	8.89439
12	0.43783	7.89004	36.99680	9.56841
13	0.40871	8.29875	41.90136	10.22278
14	0.38153	8.68028	46.86125	10.85805
15	0.35615	9.03644	51.84739	11.47480
16	0.33247	9.36890	56.83438	12.07355
17	0.31035	9.67925	61.80002	12.65483
18	0.28971	9.96897	66.72511	13.21916
19	0.27044	10.23941	71.59306	13.76703
20	0.25245	10.49186	76.38969	14.29891

7 1/4 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93240	0.93240	0.00000	0.93240
2	0.86937	1.80177	0.86938	1.83655
3	0.81060	2.61238	2.49058	2.71330
4	0.75581	3.36818	4.75800	3.56348
5	0.70471	4.07290	7.57687	4.38789
6	0.65708	4.72997	10.86225	5.18733
7	0.61266	5.34263	14.53820	5.96254
8	0.57124	5.91388	18.53691	6.71425
9	0.53263	6.44651	22.79795	7.44319
10	0.49662	6.94313	27.26755	8.15004
11	0.46305	7.40618	31.89807	8.83547
12	0.43175	7.83793	36.64732	9.50013
13	0.40256	8.24050	41.47811	10.14465
14	0.37535	8.61585	46.35766	10.76964
15	0.34998	8.96582	51.25735	11.37569
16	0.32632	9.29214	56.15215	11.96337
17	0.30426	9.59640	61.02031	12.53324
18	0.28369	9.88010	65.84309	13.08585
19	0.26452	10.14461	70.60438	13.62171
20	0.24663	10.39125	75.29044	14.14133

7 3/8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93132	0.93132	0.00000	0.93132
2	0.86735	1.79866	0.86735	1.83336
3	0.80778	2.60644	2.48290	2.70705
4	0.75229	3.35873	4.73979	3.55328
5	0.70062	4.05936	7.54229	4.37290
6	0.65250	4.71186	10.80479	5.16677
7	0.60768	5.31954	14.45090	5.93568
8	0.56595	5.88549	18.41252	6.68043
9	0.52707	6.41256	22.62910	7.40177
10	0.49087	6.90343	27.04696	8.10043
11	0.45716	7.36059	31.61852	8.77713
12	0.42576	7.78635	36.30186	9.43257
13	0.39651	8.18286	41.06002	10.06740
14	0.36928	8.55214	45.86065	10.68228
15	0.34392	8.89606	50.67550	11.27783
16	0.32029	9.21635	55.47991	11.85466
17	0.29829	9.51465	60.25264	12.41336
18	0.27781	9.79245	64.97534	12.95450
19	0.25873	10.05118	69.63240	13.47863
20	0.24096	10.29213	74.21057	13.98628

7 1/2 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.93023	0.93023	0.00000	0.93023
2	0.86533	1.79557	0.86535	1.83018
3	0.80496	2.60053	2.47528	2.70082
4	0.74880	3.34933	4.72168	3.54312
5	0.69656	4.04589	7.50792	4.35800
6	0.64796	4.69385	10.74774	5.14634
7	0.60275	5.29660	14.36427	5.90902
8	0.56070	5.85731	18.28918	6.64687
9	0.52158	6.37889	22.46185	7.36069
10	0.48519	6.86408	26.82860	8.05127
11	0.45134	7.31543	31.34205	8.71937
12	0.41985	7.73528	35.96044	9.36571
13	0.39056	8.12584	40.64718	9.99102
14	0.36331	8.48916	45.37028	10.59596
15	0.33797	8.82712	50.10181	11.18121
16	0.31439	9.14151	54.81760	11.74740
17	0.29245	9.43396	59.49685	12.29516
18	0.27205	9.70601	64.12168	12.82508
19	0.25307	9.95908	68.67695	13.33775
20	0.23541	10.19449	73.14979	13.83373

7 5/8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.92915	0.92915	0.00000	0.92915
2	0.86332	1.79247	0.86331	1.82701
3	0.80216	2.59463	2.46763	2.69462
4	0.74533	3.33996	4.70360	3.53302
5	0.69252	4.03248	7.47368	4.34317
6	0.64346	4.67594	10.69098	5.12604
7	0.59787	5.27381	14.27821	5.88254
8	0.55551	5.82933	18.16678	6.61355
9	0.51616	6.34548	22.29603	7.31995
10	0.47959	6.82507	26.61232	8.00255
11	0.44561	7.27068	31.06842	8.66217
12	0.41404	7.68472	35.62286	9.29956
13	0.38471	8.06943	40.23932	9.91549
14	0.35745	8.42688	44.88617	10.51067
15	0.33213	8.75900	49.53593	11.08580
16	0.30860	9.06760	54.16485	11.64157
17	0.28673	9.35433	58.75256	12.17861
18	0.26642	9.62075	63.28167	12.69757
19	0.24754	9.86829	67.73743	13.19904
20	0.23000	10.09830	72.10752	13.68363

7 3/4 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.92807	0.92807	0.00000	0.92807
2	0.86132	1.78940	0.86132	1.82385
3	0.79937	2.58877	2.46006	2.68845
4	0.74188	3.33064	4.68568	3.52296
5	0.68852	4.01916	7.43974	4.32842
6	0.63899	4.65815	10.63470	5.10586
7	0.59303	5.25118	14.19290	5.85623
8	0.55038	5.80156	18.04555	6.58049
9	0.51079	6.31235	22.13188	7.27955
10	0.47405	6.78641	26.39838	7.95427
11	0.43996	7.22636	30.79794	8.60552
12	0.40831	7.63468	35.28938	9.23410
13	0.37894	8.01362	39.83670	9.84080
14	0.35169	8.36531	44.40865	10.42638
15	0.32639	8.69170	48.97816	10.99159
16	0.30292	8.99462	53.52191	11.53713
17	0.28113	9.27575	58.01997	12.06368
18	0.26091	9.53666	62.45543	12.57190
19	0.24214	9.77880	66.81399	13.06244
20	0.22473	10.00353	71.08381	13.53591

7 7/8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.92700	0.92700	0.00000	0.92700
2	0.85933	1.78633	0.85932	1.82070
3	0.79659	2.58292	2.45252	2.68230
4	0.73844	3.32136	4.66784	3.51294
5	0.68454	4.00590	7.40598	4.31375
6	0.63456	4.64046	10.57879	5.08580
7	0.58824	5.22870	14.10825	5.83011
8	0.54530	5.77400	17.92533	6.54768
9	0.50549	6.27949	21.96925	7.23948
10	0.46859	6.74808	26.18654	7.90643
11	0.43438	7.18246	30.53036	8.54942
12	0.40267	7.58513	34.95974	9.16931
13	0.37328	7.95841	39.43904	9.76694
14	0.34603	8.30443	43.93739	10.34309
15	0.32077	8.62520	48.42811	10.89855
16	0.29735	8.92255	52.88836	11.43406
17	0.27564	9.19819	57.29864	11.95034
18	0.25552	9.45371	61.64248	12.44806
19	0.23687	9.69058	65.90608	12.92791
20	0.21958	9.91015	70.07800	13.39052

8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

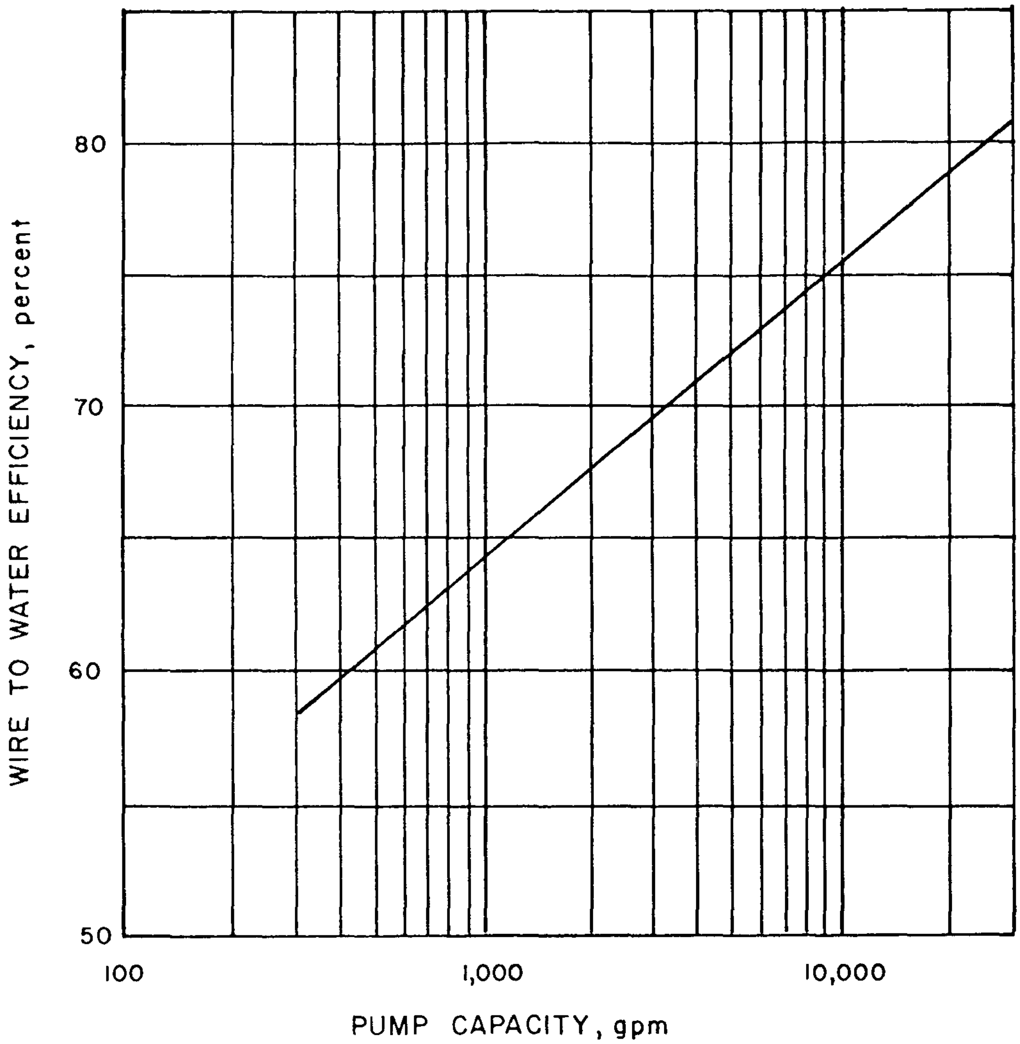
N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.92593	0.92593	0.00000	0.92593
2	0.85734	1.78327	0.85735	1.81756
3	0.79383	2.57710	2.44502	2.67617
4	0.73503	3.31213	4.65011	3.50297
5	0.68058	3.99271	7.37245	4.29916
6	0.63017	4.62288	10.52330	5.06586
7	0.58349	5.20637	14.02425	5.80416
8	0.54027	5.74664	17.80614	6.51512
9	0.50025	6.24689	21.80813	7.19974
10	0.46319	6.71008	25.97688	7.85901
11	0.42888	7.13897	30.26571	8.49386
12	0.39711	7.53608	34.63395	9.10520
13	0.36770	7.90378	39.04633	9.69389
14	0.34046	8.24424	43.47233	10.26078
15	0.31524	8.55948	47.88572	10.80668
16	0.29189	8.85137	52.26407	11.33236
17	0.27027	9.12164	56.58838	11.83857
18	0.25025	9.37189	60.84262	12.32603
19	0.23171	9.60360	65.01342	12.79543
20	0.21455	9.81815	69.08986	13.24745

8 1/8 PERCENT COMPOUND INTEREST - PRESENT WORTH FACTORS

N	SINGLE PAYMENT	UNIFORM SERIES	GRADIENT SERIES	GEOMETRIC SERIES 4%
1	0.92486	0.92486	0.00000	0.92486
2	0.85536	1.78021	0.85535	1.81443
3	0.79108	2.57129	2.43750	2.67006
4	0.73164	3.30293	4.63241	3.49305
5	0.67666	3.97959	7.33904	4.28465
6	0.62581	4.60540	10.46810	5.04604
7	0.57879	5.18418	13.94079	5.77839
8	0.53529	5.71948	17.68785	6.48280
9	0.49507	6.21455	21.64838	7.16033
10	0.45787	6.67241	25.76918	7.81202
11	0.42346	7.09587	30.00378	8.43885
12	0.39164	7.48751	34.31183	9.04176
13	0.36221	7.84972	38.65834	9.62167
14	0.33499	8.18471	43.01323	10.17945
15	0.30982	8.49453	47.35068	10.71596
16	0.28654	8.78107	51.64877	11.23200
17	0.26501	9.04608	55.88887	11.72835
18	0.24509	9.29117	60.05543	12.20576
19	0.22668	9.51784	64.13557	12.66497
20	0.20964	9.72749	68.11878	13.10665

FIGURE D-1

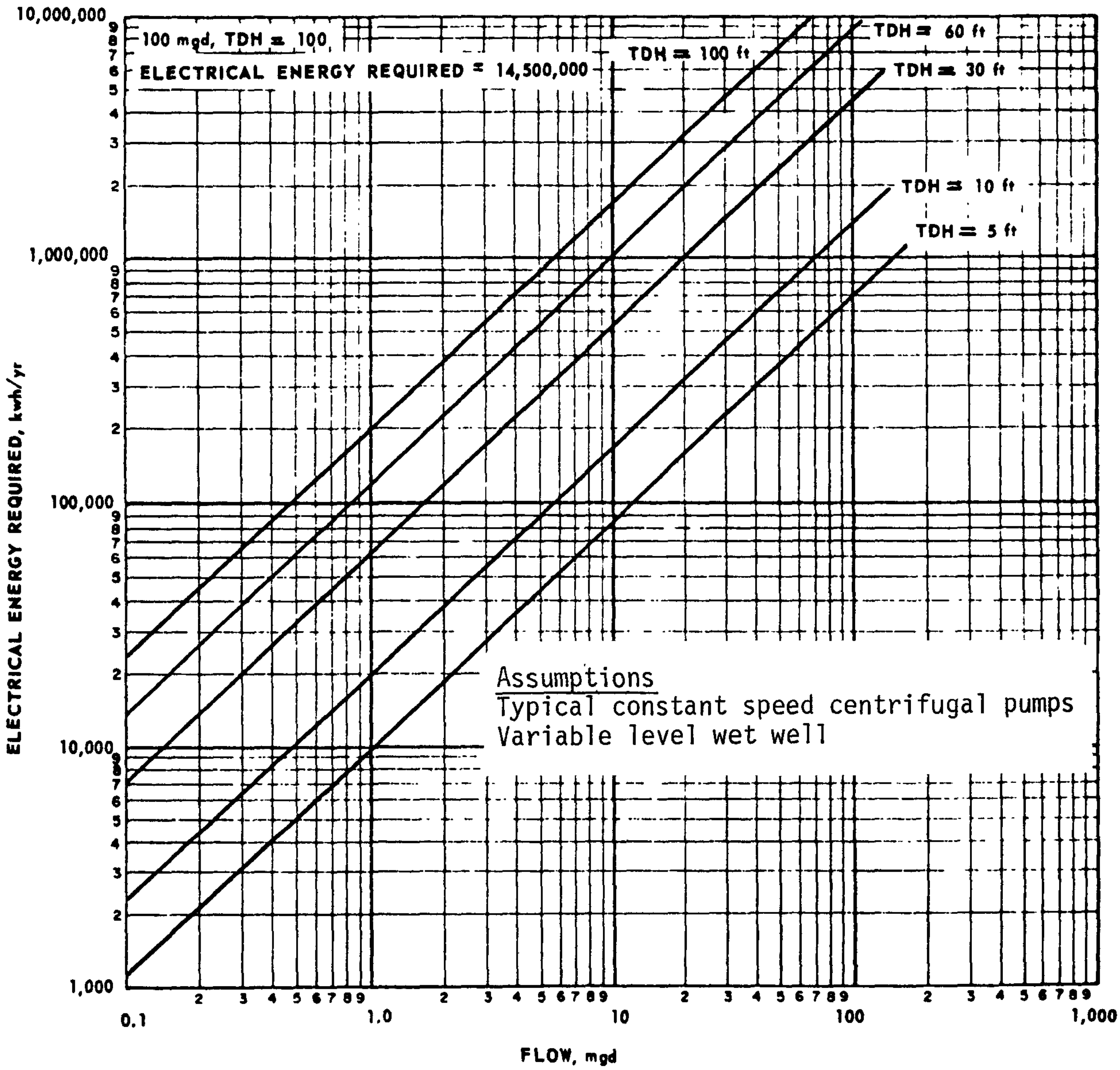
HYDRAULIC EFFICIENCY OF CENTRIFUGAL PUMPS



Source: Wesner, G.M., Energy Requirements for Municipal Pollution Control Facilities, EPA-600/2-77-214, November 1977

FIGURE D-2

POWER REQUIREMENTS FOR RAW SEWAGE PUMPING



RAW SEWAGE PUMPING (CONSTANT SPEED)

Source: Wesner, G.M., et al, Energy Conservation in Municipal Wastewater, MCD-32, EPA-430/9-77-011, March 1978

FIGURE D-3

ANAEROBIC DIGESTER HEATING REQUIREMENTS

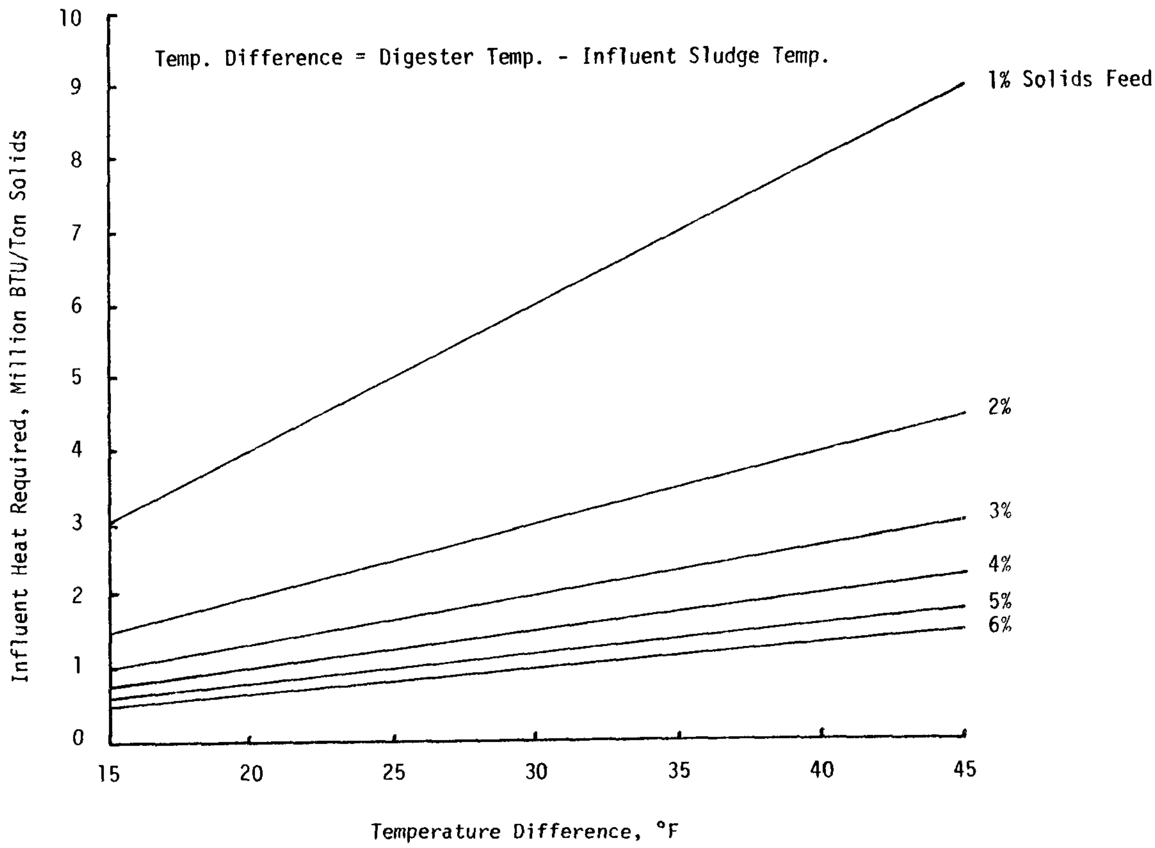


FIGURE D-4

ANAEROBIC DIGESTER HEAT LOSS

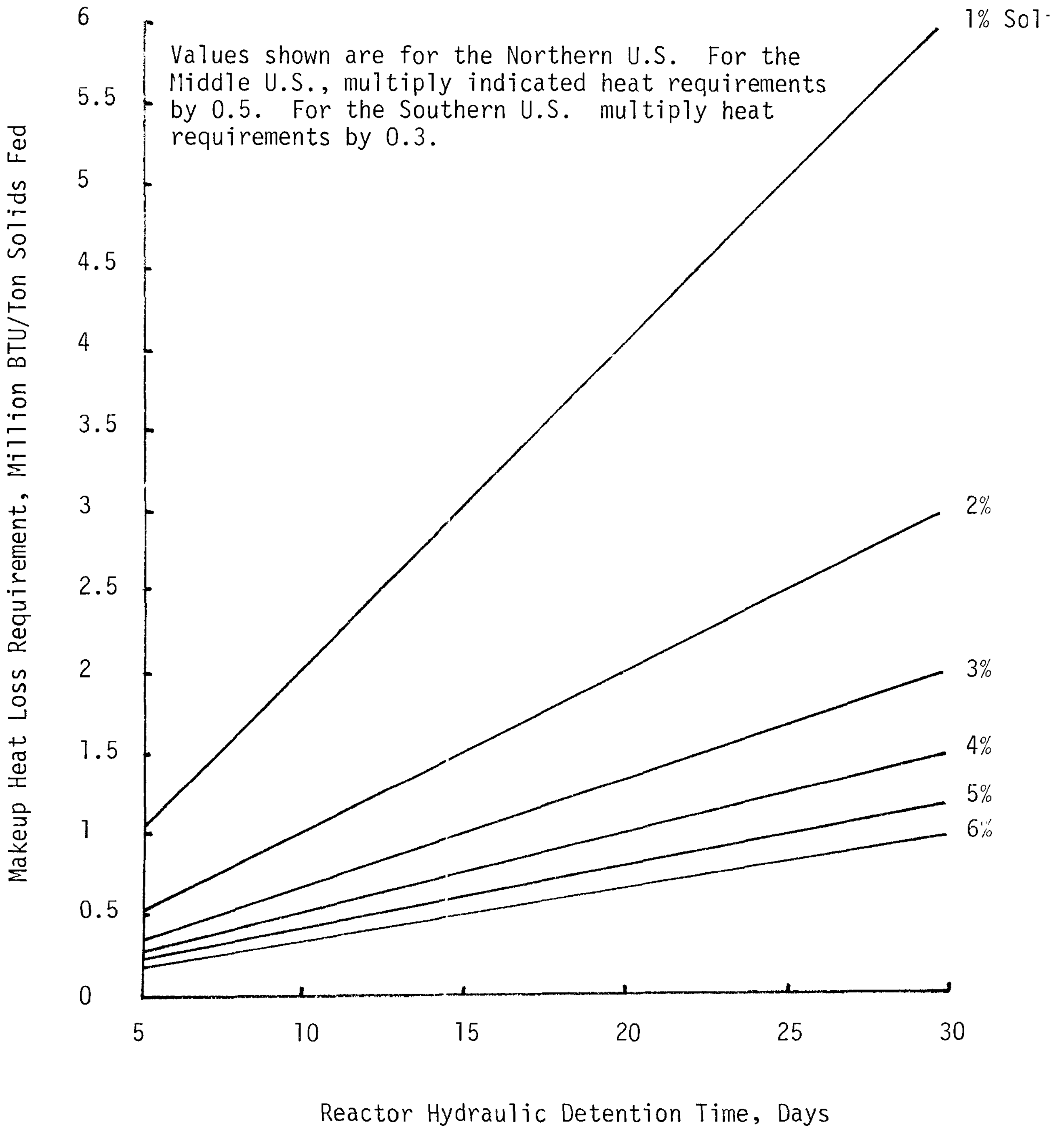


FIGURE D-5

ANAEROBIC DIGESTER HEAT PRODUCTION

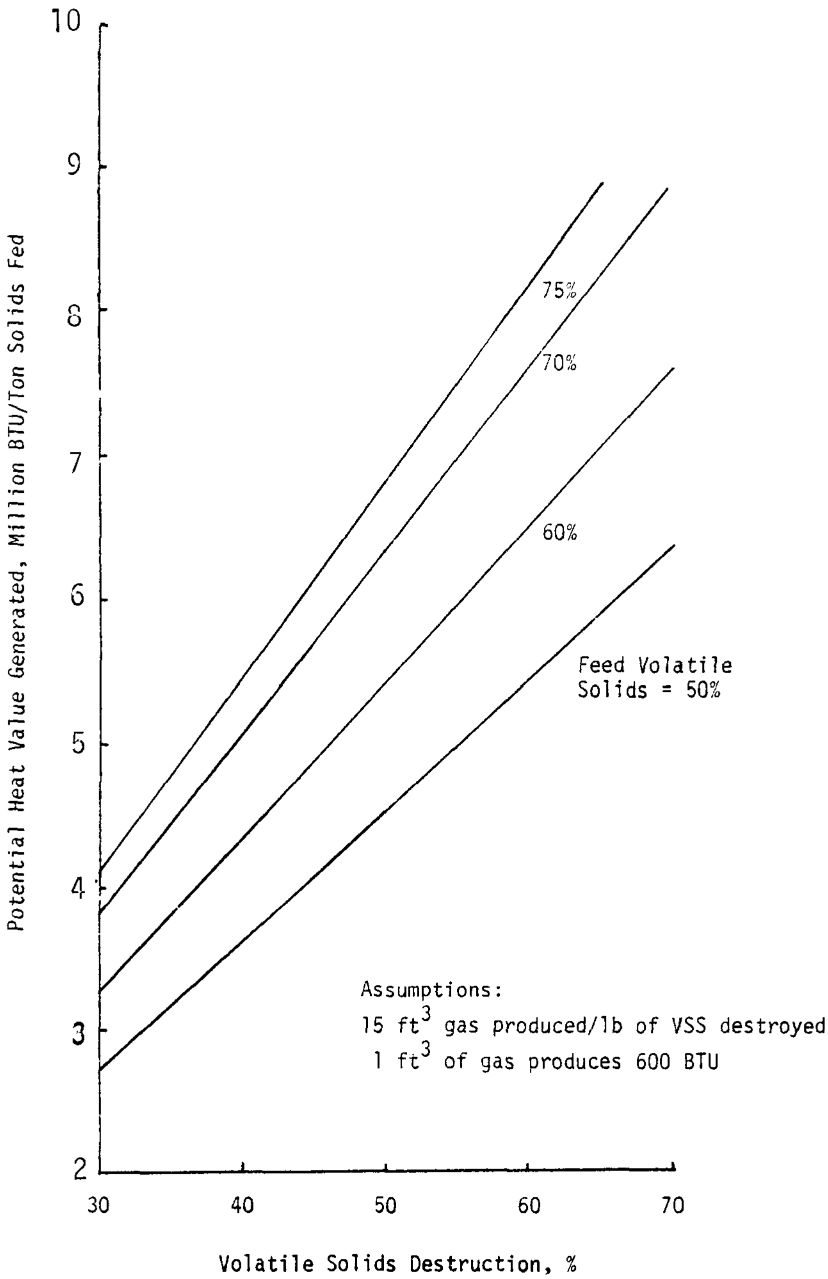


FIGURE D-6

HIGH RATE ANAEROBIC DIGESTER MIXING REQUIREMENTS

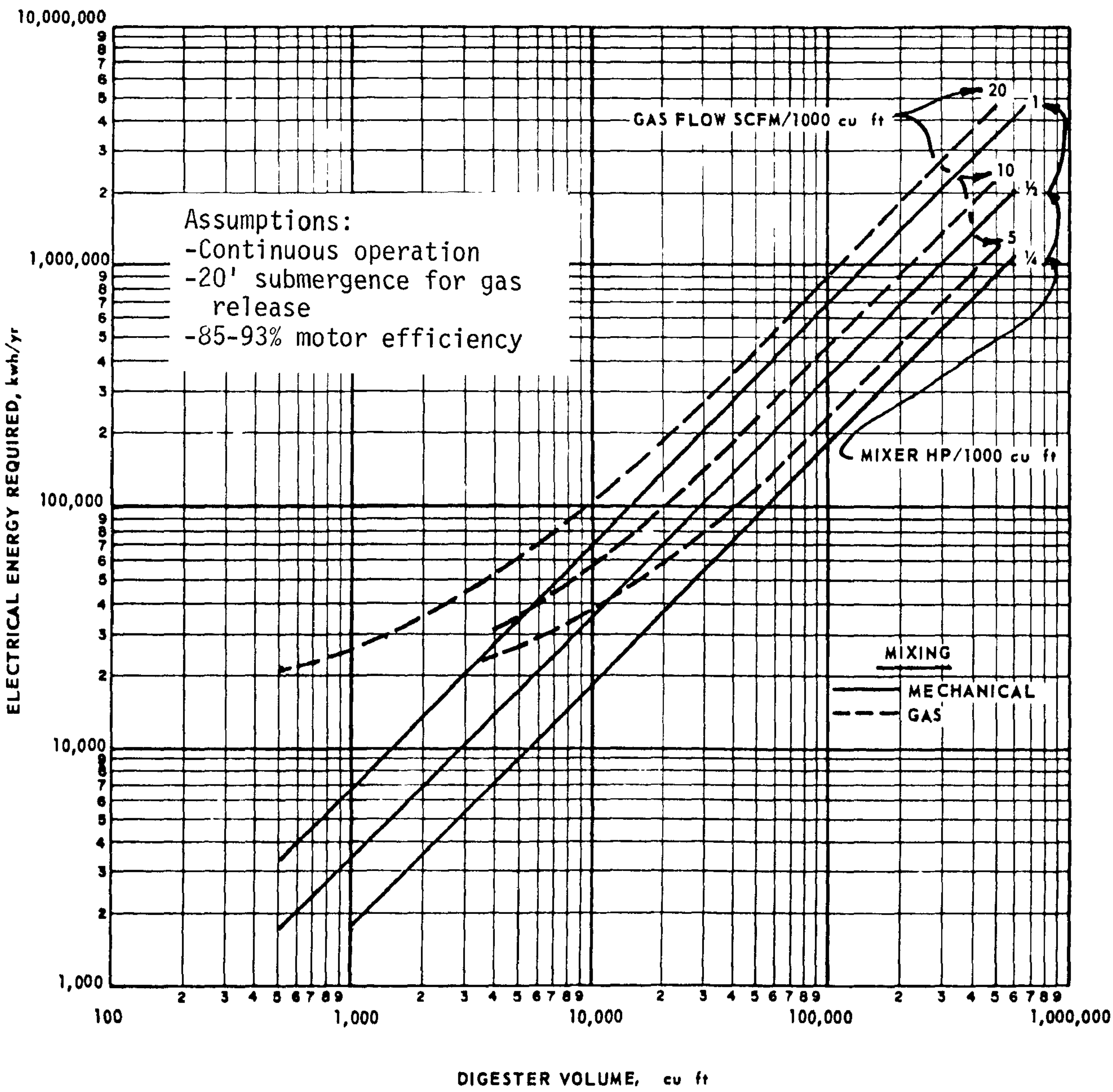


FIGURE D-7

SLUDGE PUMPING ENERGY
FOR HEAT EXCHANGE

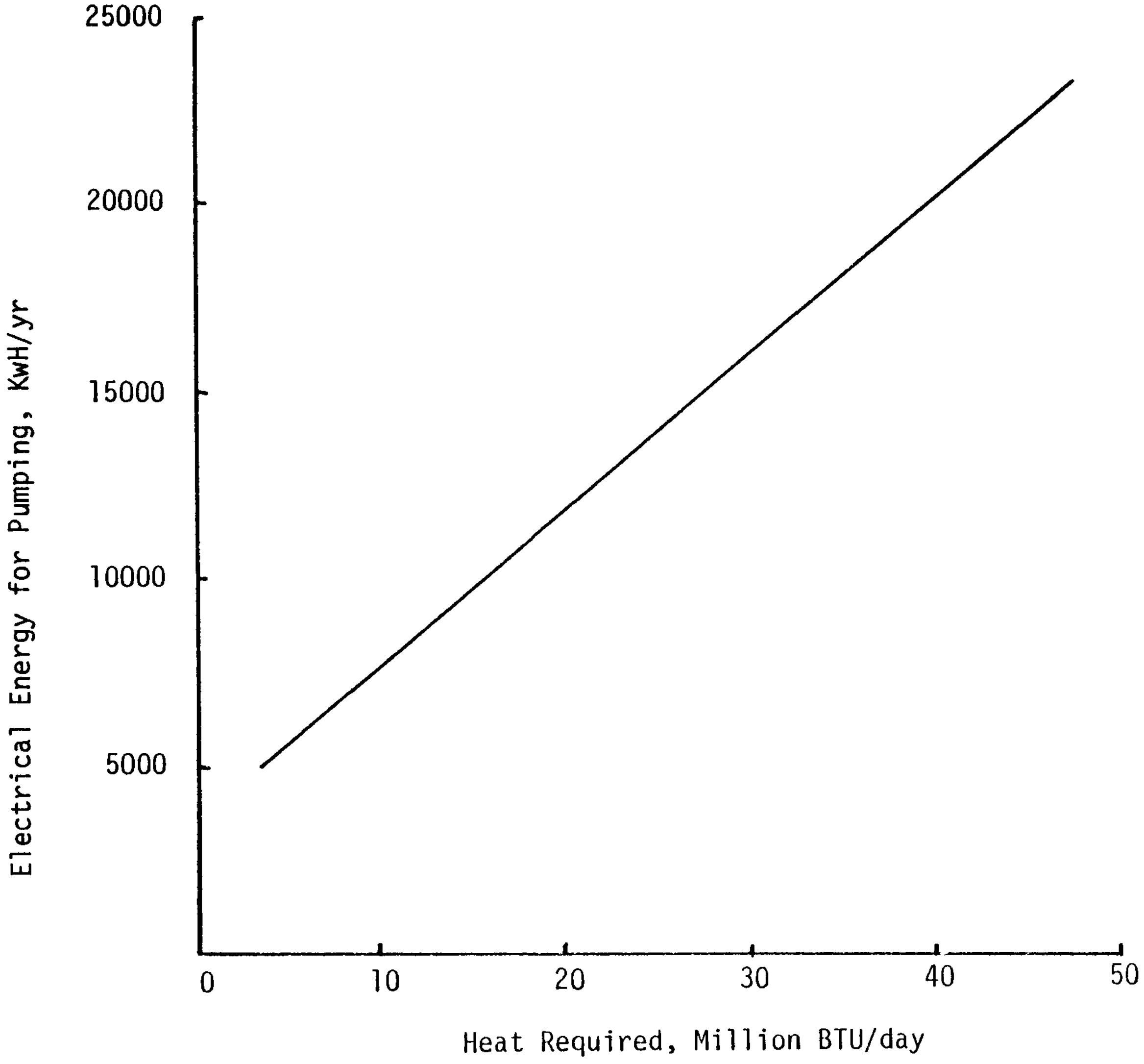


FIGURE D-7 (a)

ANAEROBIC DIGESTER HEAT REQUIREMENTS

FOR PRIMARY SLUDGE

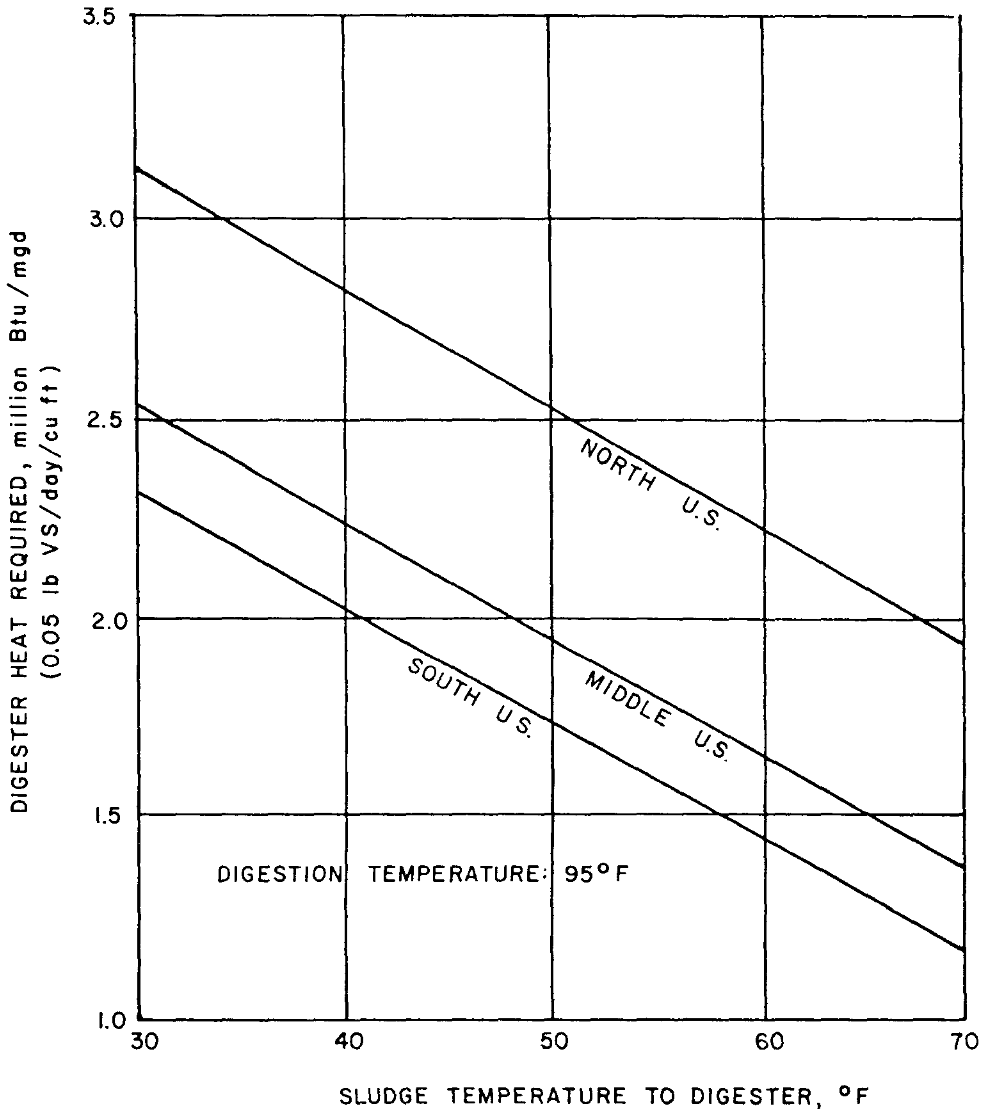


FIGURE D-7 (b)

ANAERBIC DIGESTER HEAT REQUIREMENTS FOR
PRIMARY PLUS WASTE ACTIVATED SLUDGE

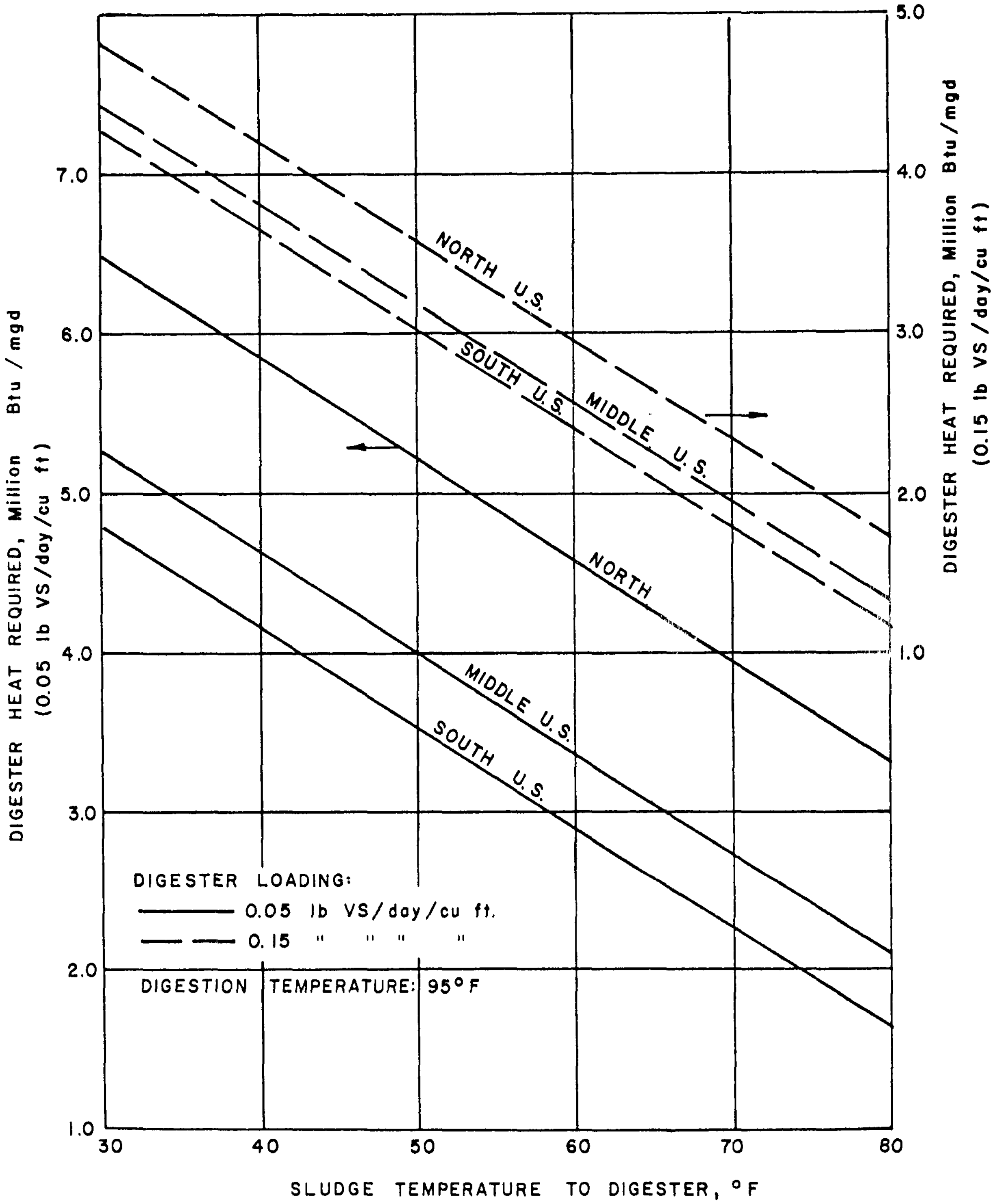


FIGURE D-8

FRACTION OF SOLIDS VS WATER CONTENT

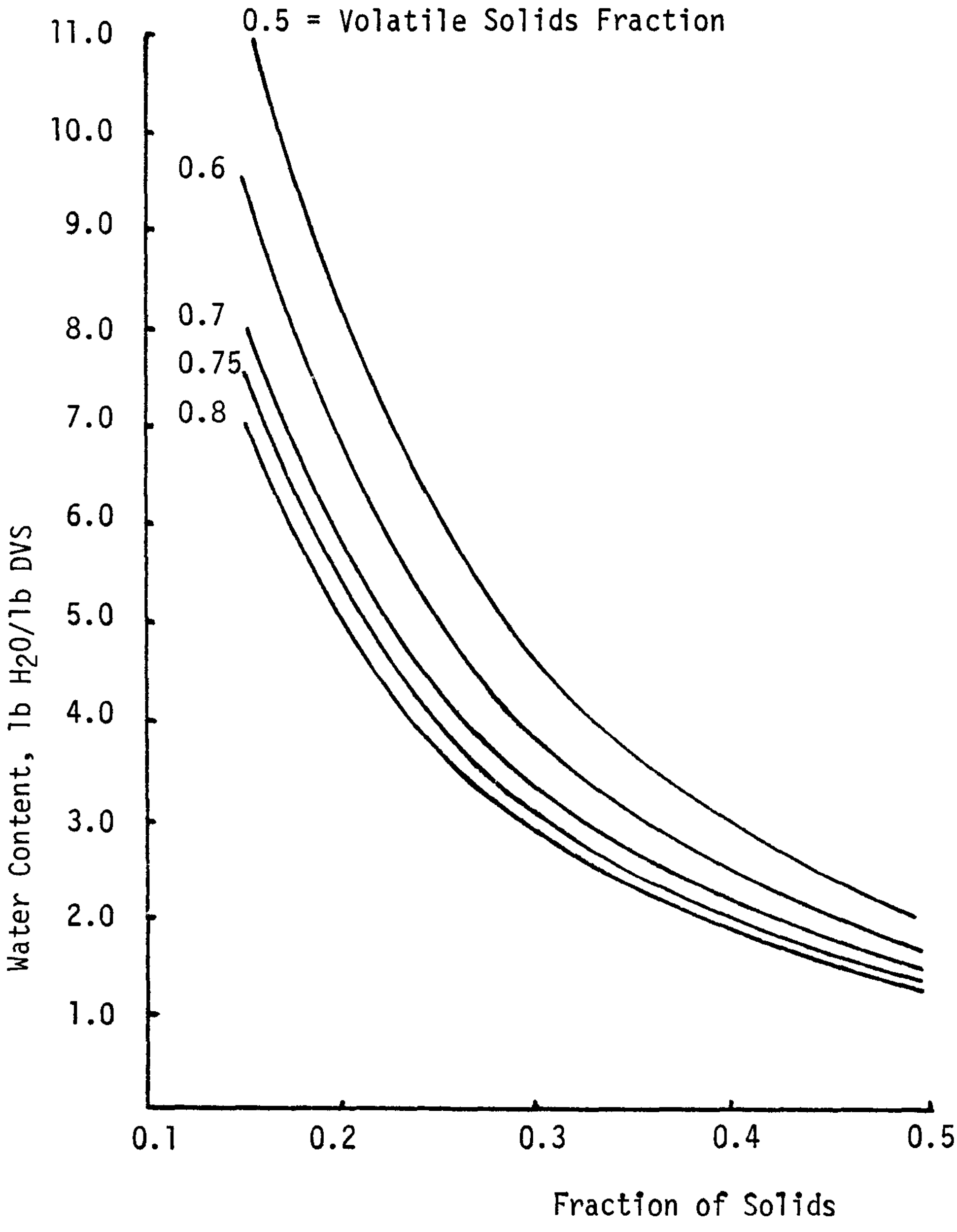


FIGURE D-9

FLUE GAS TEMPERATURE
ATTAINABLE AT DIFFERENT WATER CONTENT

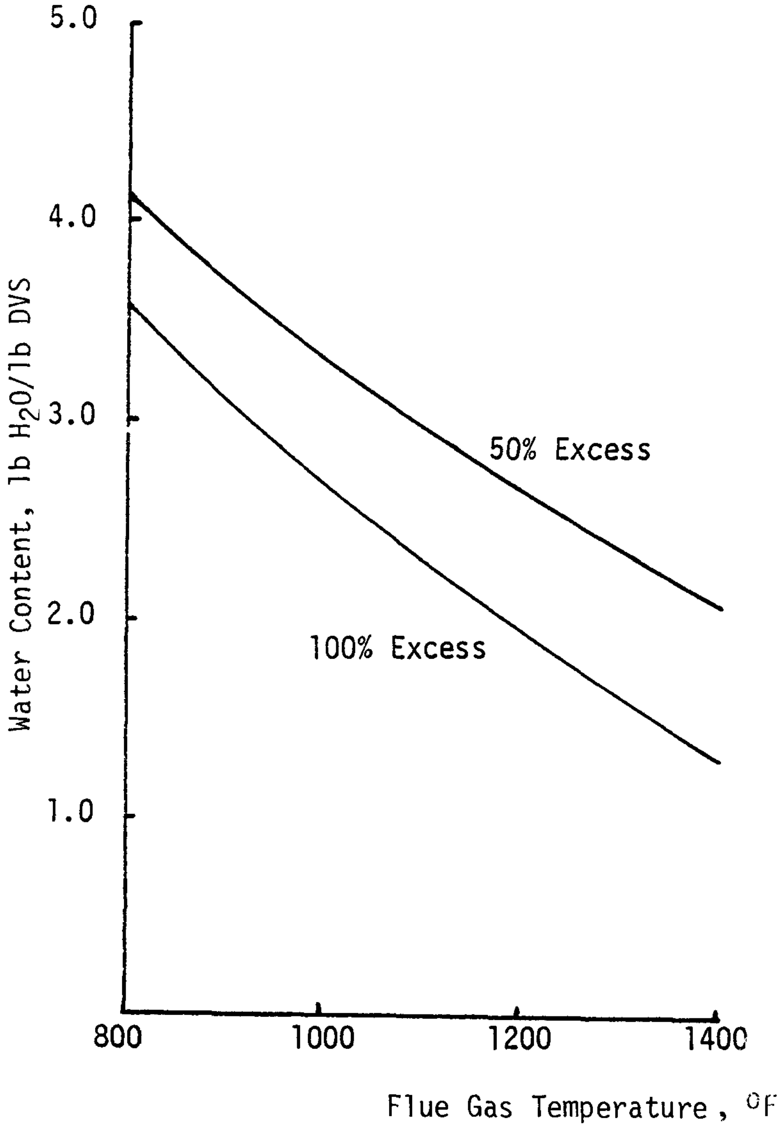


FIGURE D-10

SUPPLEMENTAL FUEL REQUIREMENT
AT 50% EXCESS AIR

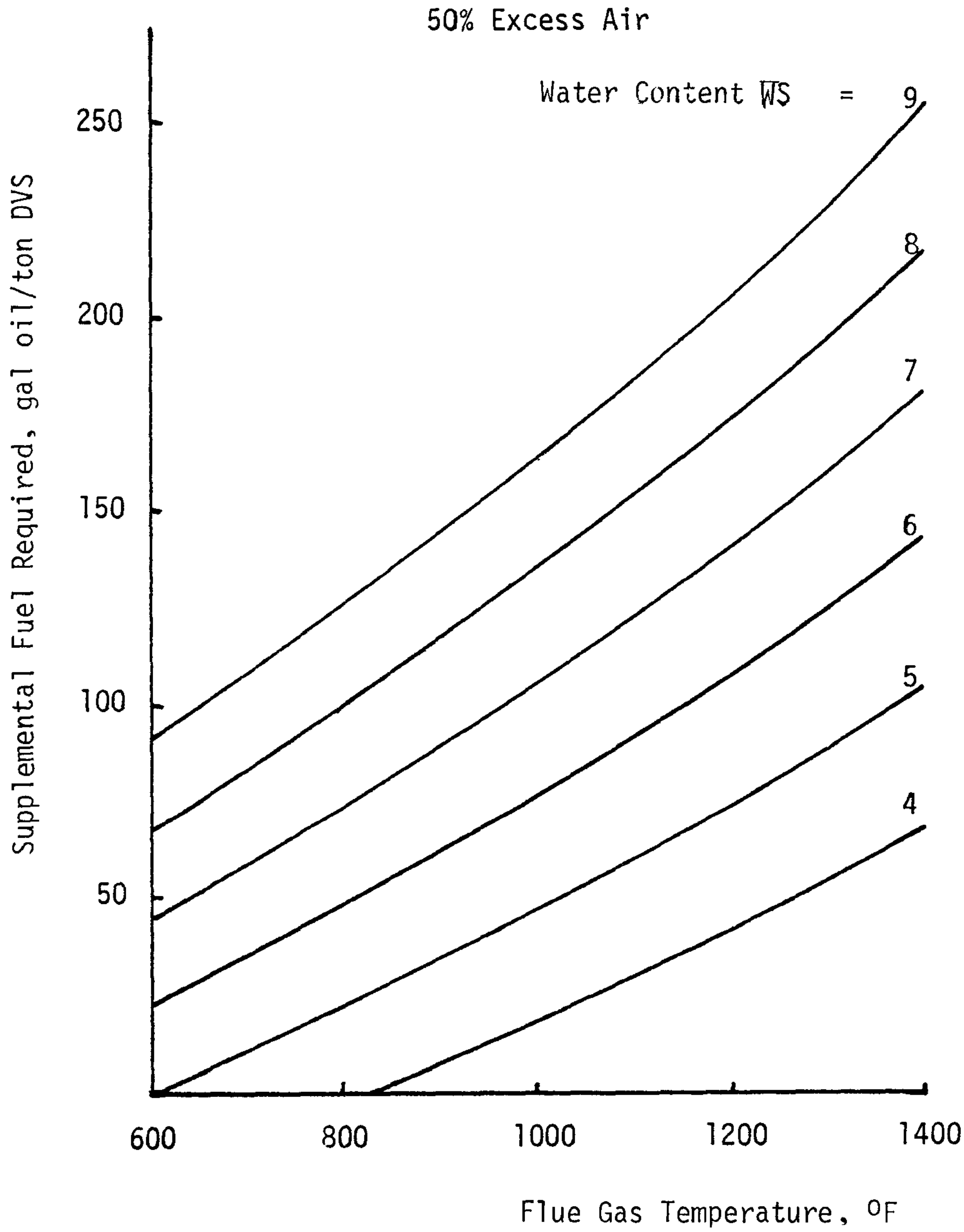


FIGURE D-11

SUPPLEMENTAL FUEL REQUIREMENT
AT 100% EXCESS AIR

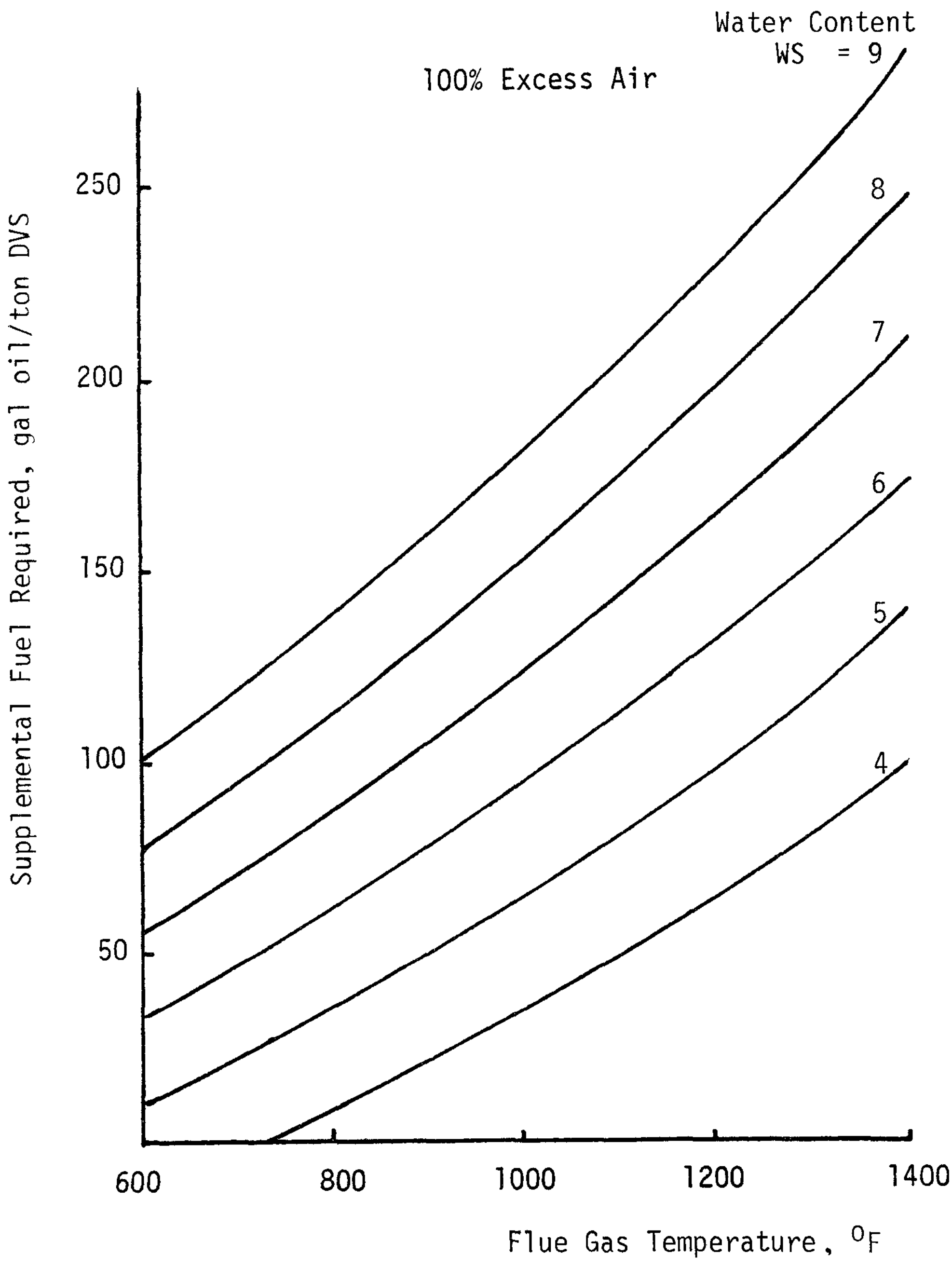


FIGURE D-12

EXCESS AIR REQUIREMENT

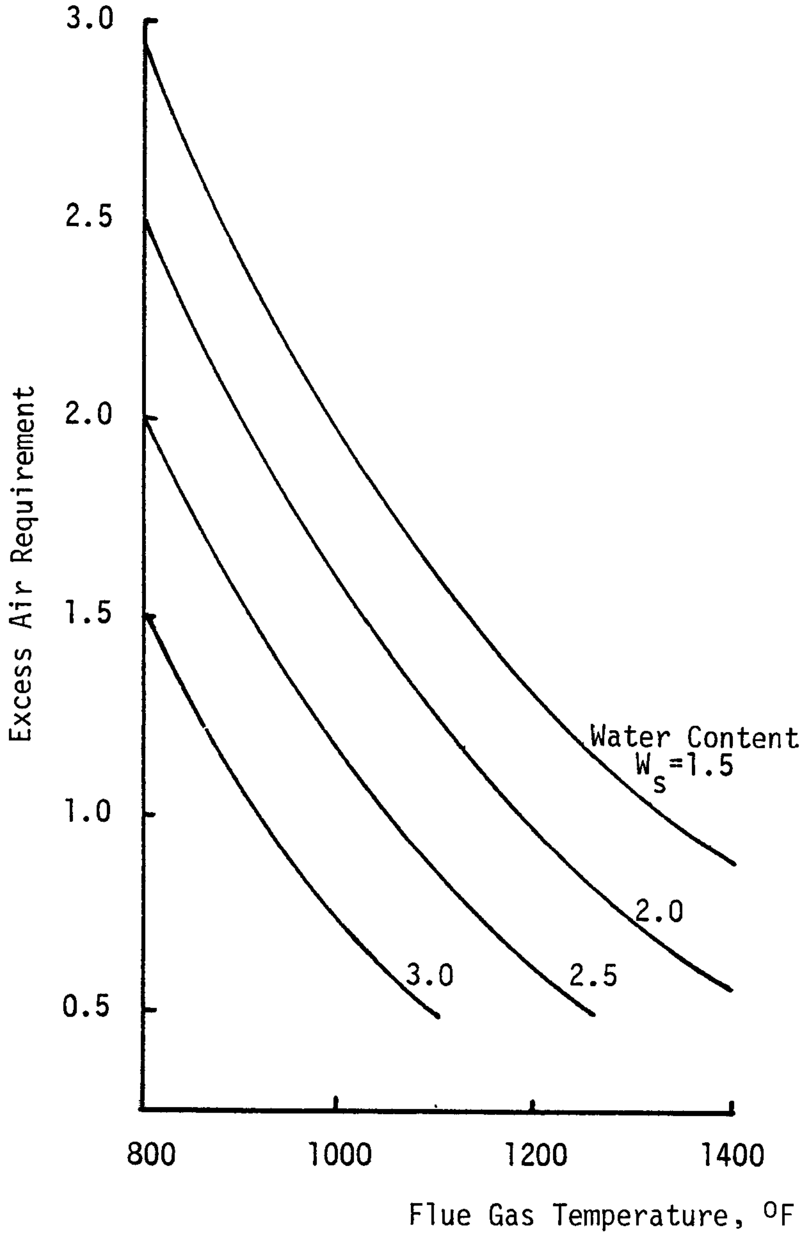


FIGURE D-13

HEAT RECOVERY FROM WASTE HEAT BOILER

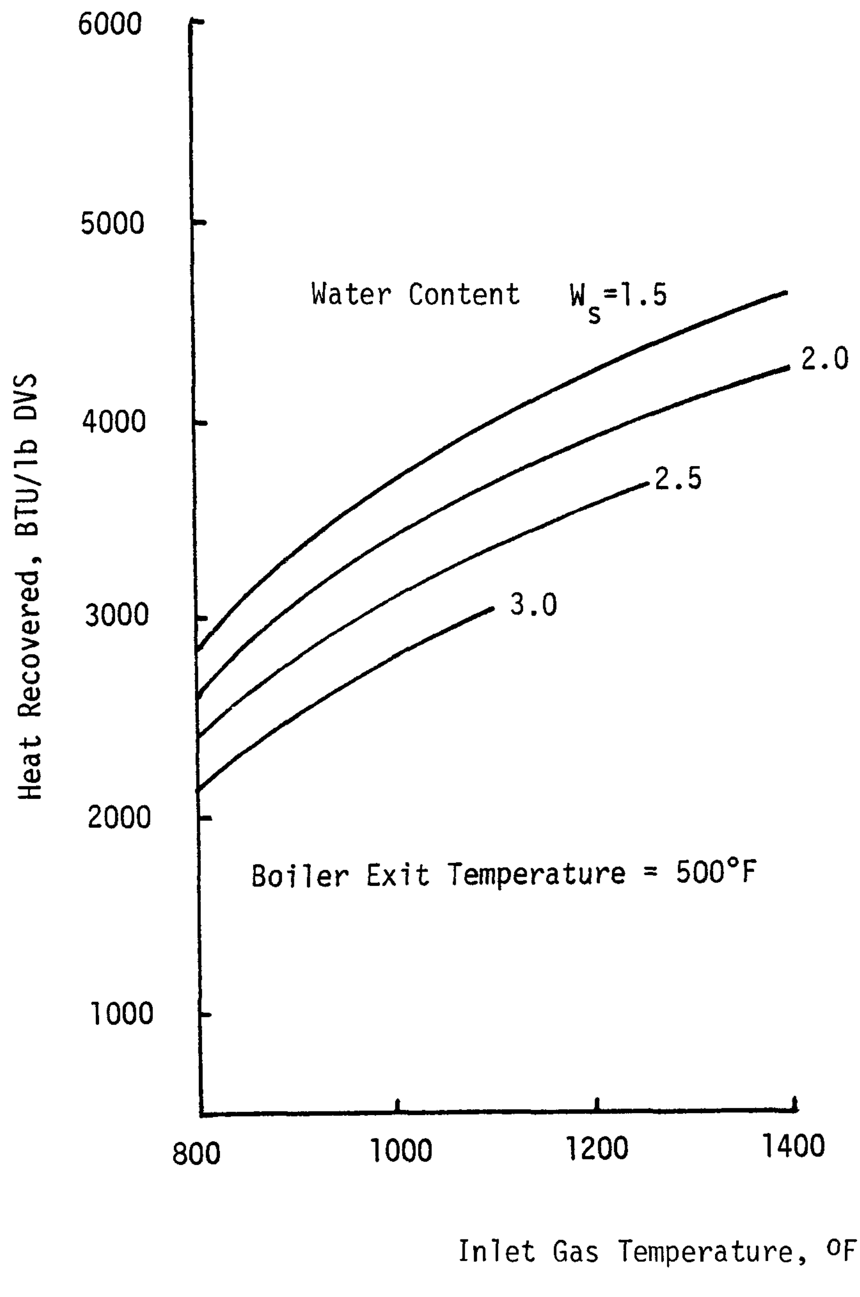
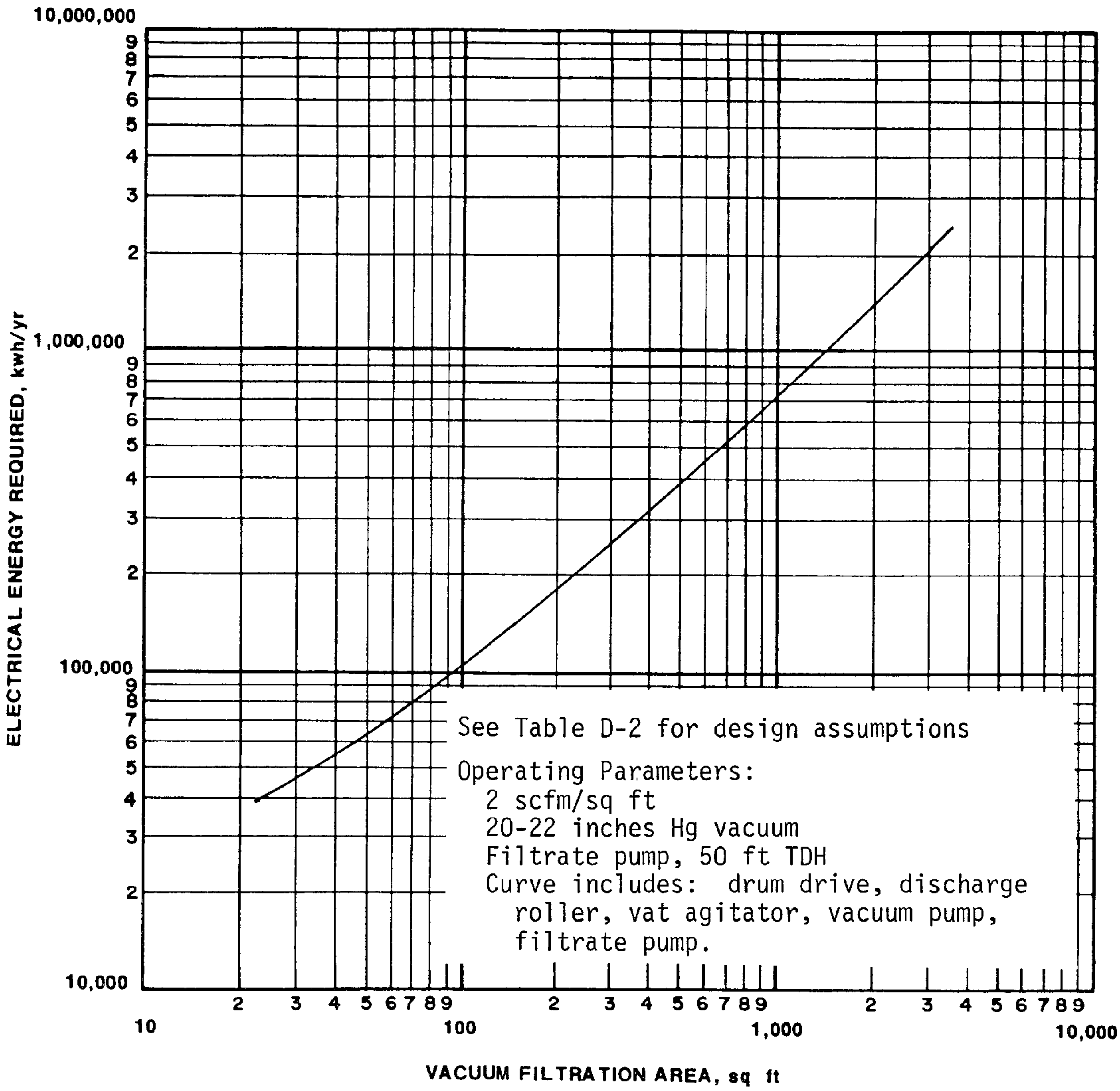


FIGURE D-14

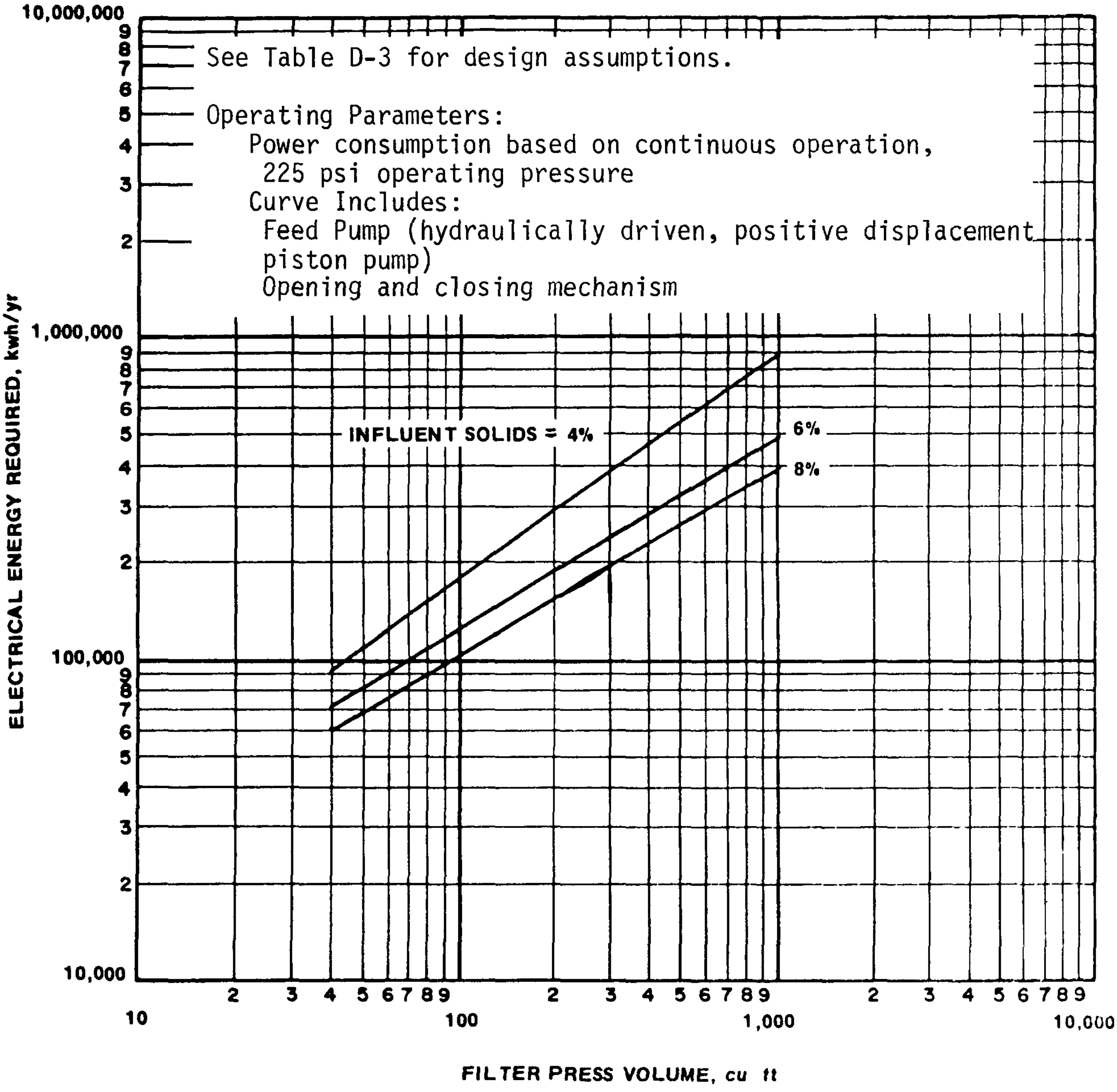
ENERGY REQUIREMENTS FOR VACUUM FILTRATION



Source: Wesner, G.M., et al, Energy Conservation in Municipal Wastewater, MCD-32, EPA-430/9-77-011, March 1978

FIGURE D-15

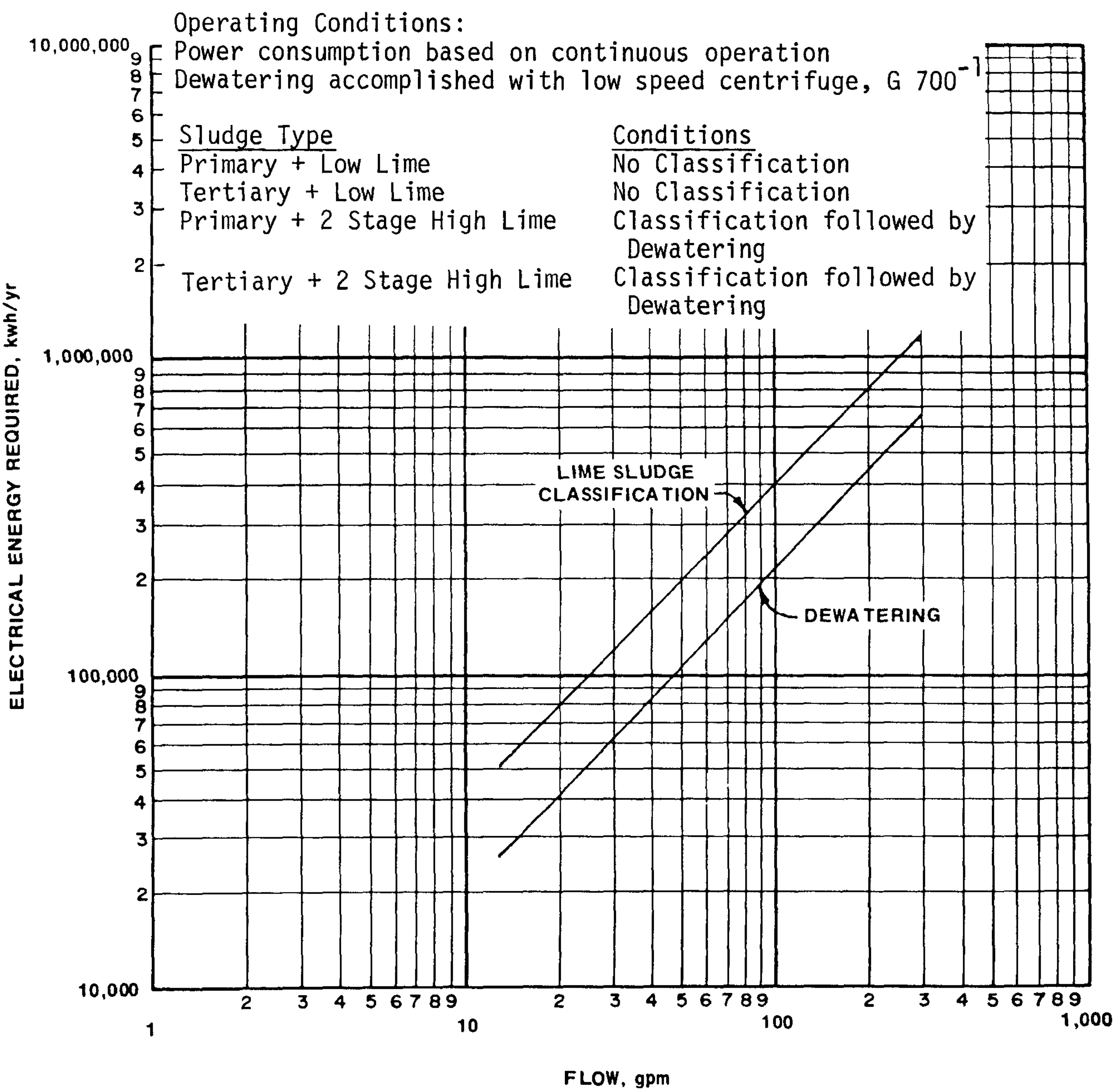
ENERGY REQUIREMENTS FOR FILTER PRESSING



Source: Wesner, G.M., et al, Energy Conservation in Municipal Wastewater, MCD-32, EPA-430/9-77-011, March 1978

FIGURE D-16

ENERGY REQUIREMENTS FOR CENTRIFUGING



Source: Wesner, G.M., et al, Energy Conservation in Municipal Wastewater, MCD-32, EPA-430/9-77-011, March 1978

APPENDIX E

INNOVATIVE AND ALTERNATIVE TECHNOLOGY GUIDELINES

1. *Purpose.* These guidelines provide the criteria for identifying and evaluating innovative and alternative waste water treatment processes and techniques. The Administrator may publish additional information.

2. *Authority.* These guidelines are provided under section 304(d)(3) of the Clean Water Act.

3. *Applicability.* These guidelines apply to:

a. The analysis of innovative and alternative treatment processes and techniques under § 35.917-1(d)(8);

b. Increased grants for eligible treatment works under §§ 35.930-6 (b) and (c) and 35.908(b)(1);

c. The funding available for innovative and alternative processes and techniques under § 35.915-1(b);

d. The funding available for alternatives to conventional treatment works for small communities under § 35.915-1(e);

e. The cost-effectiveness preference given innovative and alternative processes and techniques in section 7 of appendix A to this subpart;

f. The treatment works that may be given higher priority on State project priority lists under § 35.915(a)(1)(iii);

g. Alternative and innovative treatment systems in connection with Federal facilities;

h. Individual systems authorized by § 35.918, as modified in that section to include unconventional or innovative sewers;

i. The access and reports conditions in § 35.935-20.

4. *Alternative processes and techniques.* Alternative waste water treatment processes and techniques are proven methods which provide for the reclaiming and reuse of water, productively recycle waste water constituents or otherwise eliminate the discharge of pollutants, or recover energy.

a. In the case of processes and techniques for the treatment of effluents, these include land treatment, aquifer recharge, aquaculture, silviculture, and direct reuse for industrial and other nonpotable purposes, horticulture and revegetation of disturbed land. Total containment ponds and ponds for the treatment and storage of waste water prior to land application and other processes necessary to provide minimum levels of preapplication treatment are considered to be part of alternative technology systems for the purpose of this section.

b. For sludges, these include land application for horticultural, silvicultural, or agricultural purposes (including supplemental processing by means such as composting or drying), and revegetation of disturbed lands.

c. Energy recovery facilities include codisposal measures for sludge and refuse which produce energy; anaerobic digestion facilities (*Provided,* That more than 90 percent of the methane gas is recovered and used as fuel); and equipment which provides for the use of digester gas within the treatment works. Self-sustaining incineration may also be included provided that the energy recovered and productively used is greater than the energy consumed to dewater the sludge to an autogenous state.

d. Also included are individual and other onsite treatment systems with subsurface or other means of effluent disposal and facilities constructed for the specific purpose of septage treatment.

e. The term "alternative" as used in these guidelines includes the terms "unconventional" and "alternative to conventional" as used in the Act.

f. The term "alternative" does not include collector sewers, interceptors, storm or sanitary sewers or the separation thereof; or major sewer rehabilitation, except insofar as they are alternatives to conventional treatment works for small communities under § 35.915-1(e) or part of individual systems under § 35.918.

5. *Innovative processes and techniques.* Innovative waste water treatment processes and techniques are developed methods which have not been fully proven under the circumstances of their contemplated use and which represent a significant advancement over the state of the art in terms of meeting the national goals of cost reduction, increased energy conservation or recovery, greater recycling and conservation of water resources (including preventing the mixing of pollutants with water), reclamation or reuse of effluents and resources (including increased productivity of arid lands), improved efficiency and/or reliability, the beneficial use of sludges or effluent constituents, better management of toxic materials or increased environmental benefits. For the purpose of these guidelines, innovative waste water treatment processes and techniques are generally limited to new and improved applications of those alternative processes and techniques identified in accordance with paragraph 4 of these guidelines, including both treatment at centralized facilities and individual and other onsite treatment. Treatment processes based on the conventional concept of treatment (by means of biological or physical/chemical unit processes) and discharge to surface waters shall not be considered innovative waste water treatment processes and techniques except where it is demonstrated that these processes and techniques, as a

minimum, meet either the cost-reduction or energy-reduction criterion described in section 6 of these guidelines. Treatment and discharge systems include primary treatment, suspended-growth or fixed-growth biological systems for secondary or advance waste water treatment, physical/chemical treatment, disinfection, and sludge processing. The term "innovative" does not include collector sewers, interceptors, storm or sanitary sewers or the separation of them, or major sewer rehabilitation, except insofar as they meet the criteria in paragraph 6 of these guidelines and are alternatives to conventional treatment works for small communities under § 35.915-1(e) or part of individual systems under § 35.918.

6. *Criteria for determining innovative processes and techniques.* a. The Regional Administrator will use the following criteria in determining whether a waste water treatment process or technique is innovative. The criteria should be read in the context of paragraph 5. These criteria do not necessarily preclude a determination by the Regional Administrator that a treatment system is innovative because of local variations in geographic or climatic conditions which affect treatment plant design and operation or because it achieves significant public benefits through the advancement of technology which would otherwise not be possible. The Regional Administrator should consult with EPA headquarters about determinations made in other EPA regions on similar processes and techniques.

b. New or improved applications of alternative waste water treatment processes and techniques may be innovative for the purposes of this regulation if they meet one or more of the criteria in paragraphs e(1) through e(6) of this paragraph. Treatment and discharge systems (i.e., systems which are not new or improved applications of alternative waste water treatment processes and techniques in accordance with paragraph 4 of these guidelines) must meet the criteria of either paragraph 6e(1) or 6e(2), as a minimum, in order to be innovative for the purposes of these guidelines.

c. These six criteria are essentially the same as those used to evaluate any project proposed for grant assistance. The principal difference is that some newly developed processes and techniques may have the potential to provide significant advancements in the state of the art with respect to one or more of these criteria. Inherent in the concept of advancement of technology is a degree of risk which is necessary to initially demonstrate a method on a full, operational scale under the circumstances of its contemplated use. This risk, while recognized to be a necessary element in the implementation of innovative technology, must be minimized by limiting the projects funded to those which have been fully developed and shown to be feasible through operation on a smaller scale. The risk must also be commensurate with the potential benefits (i.e., greater potential benefits must be possible in the case of innovative technology projects where greater risk is involved).

d. Increased Federal funding under 35.908(b) may be made only from the reserve in § 35.915-1(b). The Regional Administrator may fund a number of projects using the same type of innovative technology if he desires to encourage certain innovative processes and techniques because the potential benefits are great in comparison to the risks, or if operation under differing conditions of climatic, geology, etc., is desirable to demonstrate the technology.

e. The Regional Administrator will use the following criteria to determine whether waste water treatment processes and techniques are innovative:

(1) The life cycle cost of the treatment works is at least 15 percent less than that for the most cost-effective alternative which does not incorporate innovative waste water treatment processes and techniques (i.e., is no more than 85 percent of the life cycle cost of the most cost-effective noninnovative alternative).

(2) The net primary energy requirements for the operation of the treatment works are at least 20 percent less than the net energy requirements of the least net energy alternative which does not incorporate innovative waste water treatment processes and techniques (i.e., the net energy requirements are no more than 80 percent of those for the least net energy noninnovative alternative). The least net energy noninnovative alternative must be one of the alternatives selected for analysis under section 5 of appendix A.

(3) The operational reliability of the treatment works is improved in terms of decreased susceptibility to upsets or interference, reduced occurrence of inadequately treated discharges and decreased levels of operator attention and skills required.

(4) The treatment works provides for better management of toxic materials which would otherwise result in greater environmental hazards.

(5) The treatment works results in increased environmental benefits such as water conservation, more effective land use, improved air quality, improved ground water quality, and reduced resource requirements for the construction and operation of the works.

(6) The treatment works provide for new or improved methods of joint treatment and management of municipal and industrial wastes that are discharged into municipal systems.

[FR Doc. 78-27241 Filed 9-26-78; 8:45 am]

APPENDIX F

THE COST EFFECTIVENESS ANALYSIS GUIDELINES

1. *Purpose.* These guidelines represent Agency policies and procedures for determining the most cost-effective waste treatment management system or component part.

2. *Authority.* These guidelines are provided under sections 212(2)(C) and 217 of the Clean Water Act.

3. *Applicability.* These guidelines, except as otherwise noted, apply to all facilities planning under step 1 grant assistance awarded after September 30, 1978. The guidelines also apply to State or locally financed facilities planning on which subsequent step 2 or step 3 Federal grant assistance is based.

4. *Definitions.* Terms used in these guidelines are defined as follows:

a. *Waste treatment management system.* Used synonymously with "complete waste treatment system" as defined in § 35.905 of this subpart.

b. *Cost-effectiveness analysis.* An analysis performed to determine which waste treatment management system or component part will result in the minimum total resources costs over time to meet Federal, State, or local requirements.

c. *Planning period.* The period over which a waste treatment management system is evaluated for cost-effectiveness. The planning period begins with the system's initial operation.

d. *Useful life.* The estimated period of time during which a treatment works or a component of a waste treatment management system will be operated.

e. *Disaggregation.* The process or result of breaking down a sum total of population or economic activity for a State or other jurisdiction (i.e., designated 208 area or SMSA) into smaller areas or jurisdictions.

5. *Identification, selection, and screening of alternatives.* a. *Identification of alternatives.* All feasible alternative waste management systems shall be initially identified. These alternatives should include systems discharging to receiving waters, land application systems, on-site and other non-centralized systems, including revenue generating applications, and systems employing the reuse of wastewater and recycling of pollutants. In identifying alternatives, the applicant shall consider the possibility of no action and staged development of the system.

b. *Screening of alternatives.* The identified alternatives shall be systematically screened to determine those capable of meeting the applicable Federal, State and local criteria.

c. *Selection of alternatives.* The identified alternatives shall be initially analyzed to determine which systems have cost-effective potential and which should be fully evaluated according to the cost-effectiveness analysis procedures established in the guidelines.

d. *Extent of effort.* The extent of effort and the level of sophistication used in the cost-effectiveness analysis should reflect the project's size and importance. Where processes or techniques are claimed to be innovative technology on the basis of the cost reduction criterion contained in paragraph 6e(1) of appendix E to this subpart, a sufficiently detailed cost analysis shall be included to substantiate the claim to the satisfaction of the Regional Administrator.

6. *Cost-effectiveness analysis procedures.*

a. *Method of analysis.* The resources costs shall be determined by evaluating opportunity costs. For resources that can be expressed in monetary terms, the analysis will use the interest (discount) rate established in paragraph 6e. Monetary costs shall be calculated in terms of present worth values or equivalent annual values over the planning period defined in section 6b. The analysis shall descriptively present nonmonetary factors (e.g., social and environmental) in order to determine their significance and impact. Nonmonetary factors include primary and secondary environmental effects, implementation capability, operability, performance reliability and flexibility. Although such factors as use and recovery of energy and scarce resources and recycling of nutrients are to be included in the monetary cost analysis, the non-monetary evaluation shall also include them. The most cost-effective alternative shall be the waste treatment management system which the analysis determines to have the lowest present worth or equivalent annual value unless nonmonetary costs are overriding. The most cost-effective alternative must also meet the minimum requirements of applicable effluent limitations, groundwater protection, or other applicable standards established under the Act.

b. *Planning period.* The planning period for the cost-effectiveness analysis shall be 20 years.

c. *Elements of monetary costs.* The monetary costs to be considered shall include the total value of the resources which are attributable to the waste treatment management system or to one of its component parts. To determine these values, all monies necessary for capital construction costs and operation and maintenance costs shall be identified.

(1) Capital construction costs used in a cost-effective analysis shall include all contractors' costs of construction including overhead and profit, costs of land, relocation, and right-of-way and easement acquisi-

tion; costs of design engineering, field exploration and engineering services during construction; costs of administrative and legal services including costs of bond sales; startup costs such as operator training; and interest during construction. Capital construction costs shall also include contingency allowances consistent with the cost estimate's level of precision and detail.

(2) The cost-effectiveness analysis shall include annual costs for operation and maintanance (including routine replacement of equipment and equipment parts). These costs shall be adequate to ensure effective and dependable operation during the system's planning period. Annual costs shall be divided between fixed annual costs and costs which would depend on the annual quantity of waste water collected and treated.

Annual revenues generated by the waste treatment management system through energy recovery, crop production, or other outputs shall be deducted from the annual costs for operation and maintenance in accordance with guidance issued by the Administrator.

d. *Prices.* The applicant shall calculate the various components of costs on the basis of market prices prevailing at the time of the cost-effectiveness analysis. The analysis shall not allow for inflation of wages and prices, except those for land, as described in paragraph 6h(1) and for natural gas. This stipulation is based on the implied assumption that prices, other than the exceptions, for resources involved in treatment works construction and operation, will tend to change over time by approximately the same percentage. Changes in the general level of prices will not affect the results of the cost-effectiveness analysis. Natural gas prices shall be escalated at a compound rate of 4 percent annually over the planning period, unless the Regional Administrator determines that the grantee has justified use of a greater or lesser percentage based upon regional differentials between historical natural gas price escalation and construction cost escalation. Land prices shall be appreciated as provided in paragraph 6h(1). Both historical data and future projections support the gas and land price escalations relative to those for other goods and services related to waste water treatment. Price escalation rates may be updated periodically in accordance with Agency guidelines.

e. *Interest (discount) rate.* The rate which the Water Resources Council establishes annually for evaluation of water resource projects shall be used.

f. *Interest during construction.* (1) Where capital expenditures can be expected to be fairly uniform during the construction period, interest during construction may be calculated at $I=1/2PCi$ where:

I=the interest accrued during the construction period.
P=the construction period in years.
C=the total capital expenditures.
i=the interest rate (discount rate in section 6e).

(2) Where expenditures will not be uniform, or when the construction period will be greater than 4 years, interest during construction shall be calculated on a year-by-year basis.

g. *Useful life.* (1) The treatment works' useful life for a cost-effectiveness analysis shall be as follows:

Land—permanent.
Waste water conveyance structures (includes collection systems, outfall pipes, interceptors, force mains, tunnels, etc.)—50 years.
Other structures (includes plant building, concrete process tankage, basins, lift stations structures, etc.)—30-50 years.
Process equipment—15-20 years.
Auxiliary equipment—10-15 years.

(2) Other useful life periods will be acceptable when sufficient justification can be provided. Where a system or a component is for interim service, the anticipated useful life shall be reduced to the period for interim service.

h. *Salvage value.* (1) Land purchased for treatment works, including land used as part of the treatment process or for ultimate disposal of residues, may be assumed to have a salvage value at the end of the planning period a least equal to its prevailing market value a the time of the analysis. In calculating the salvage value of land, the land value shall be appreciated at a compound rate of 3 percent annually over the planning period, unless the Regional Administrator determines that the grantee has justified the use of a greater or lesser percentage based upon historical differences between local land cost escalation and construction cost escalation. The land cost escalation rate may be updated periodically in accordance with Agency guidelines. Right-of-way easements shall be considered to have a salvage value not greater than the prevailing market value at the time of the analysis.

(2) Structures will be assumed to have a salvage value if there is a use for them at the end of the planning period. In this case, salvage value shall be estimated using straight line depreciation during the useful life of the treatment works.

(3) The method used in paragraph 6h(2) may be used to estimate salvage value at the end of the planning period for phased additions of process equipment and auxiliary equipment.

(4) When the anticipated useful life of a facility is less than 20 years (for analysis of interim facilities), salvage value can be claimed for equipment if it can be clearly demonstrated that a specific market or reuse opportunity will exist.

7. *Innovative and alternative wastewater treatment processes and techniques.*

a. Beginning October 1, 1978, the capital costs of publicly owned treatment works which use processes and techniques meeting the criteria of appendix E to this subpart and which have only a water pollution control function, may be eligible if the present worth cost of the treatment works is not more than 115 percent of the present worth cost of the most cost-effective pollution control system, exclusive of collection sewers and interceptors common to the two systems being compared, by 115 percent, except for the following situation.

b. Where innovative or alternative unit processes would serve in lieu of conventional unit processes in a conventional waste water treatment plant, and the present worth costs of the nonconventional unit processes are less than 50 percent of the present worth costs of the treatment plant, multiply the present worth costs of the replaced conventional processes by 115 percent, and add the cost of nonreplaced unit processes.

c. The eligibility of multipurpose projects which combine a water pollution control function with another function, and which use processes and techniques meeting the criteria of appendix E to this subpart, shall be determined in accordance with guidance issued by the Administrator.

d. The above provisions exclude individual systems under § 35.918. The regional Administrator may allow a grantee to apply the 15-percent preference authorized by this section to facility plans prepared under step 1 grant assistance awarded before October 1, 1978.

8. *Cost-effective staging and sizing of treatment works.*

a. *Population projections.* (1) The disaggregation of State projections of population shall be the basis for the population forecasts presented in individual facility plans, except as noted. These State projections shall be those developed in 1977 by the Bureau of Economic Analysis (BEA), Department of Commerce, unless, as of June 26, 1978, the State has already prepared projections. These State projections may be used instead of the BEA projections if the year 2000 State population does not exceed that of the BEA-projection by more than 5 percent. If the difference exceeds this amount, the State must either justify or lower its projection. Justification must be based on the historical and current trends (e.g., energy and industrial development, military base openings) not taken into account in the BEA projections. The State must submit for approval to the Administrator the request and justification for use of State projections higher than the BEA projections. By that time, the State shall issue a public notice of the request. Before the Administrator's approval of the State projection, the Regional Administrator shall solicit public comments and hold a public hearing if important issues are raised about the State projection's validity. State projections and disaggregations may be updated periodically in accordance with Agency guidelines.

(2) Each State, working with designated 208 planning agencies, organizations certified by the Governor under section 174(a) of the Clean Air Act, as amended, and other regional planning agencies in the State's nondesignated areas, shall disaggregate the State population projection among its designated 208 areas, other standard metropolitan statistical areas (SMSA's) not included in the 208 area, and non-SMSA counties or other appropriate jurisdictions. States that had enacted laws, as of June 26, 1978, mandating disaggregation of State population totals to each county for areawide 208 planning may retain this requirement. When disaggregating the State population total, the State shall take into account the projected population and economic activities identified in facility plans, areawide 208 plans and municipal master plans. The sum of the disaggregated projections shall not exceed the State projection. Where a designated 208 area has, as of June 26, 1978, already prepared a population projection, it may be used if the year 2000 population does not exceed that of the disaggregated projection by more than 10 percent. The State may then increase its population projection to include all such variances rather than lower the population projection totals for the other areas. If the 208 area population forecast exceeds the 10 percent allowance, the 208 agency must lower its projection within the allowance and submit the revised projection for approval to the State and the Regional Administrator.

(3) The State projection totals and the disaggregations will be submitted as an output of the statewide water quality management process. The submission shall include a list of designated 208 areas, all SMSA's, and counties or other units outside the 208 areas. For each unit the disaggregated population shall be shown for the years 1980, 1990, and 2000. Each State will submit its projection totals and disaggregations for the Regional Administrator's approval before October 1, 1979. Before this submission, the State shall hold a public meeting on the disaggregations and shall

provide public notice of the meeting consistent with part 25 of this chapter. (See § 35.917(e).)

(4) When the State projection totals and disaggregations are approved they shall be used thereafter for areawide water quality management planning as well as for facility planning and the needs surveys under section 516(b) of the Act. Within areawide 208 planning areas, the designated agencies, in consultation with the States, shall disaggregate the 208 area projections among the SMSA and non-SMSA areas and then disaggregate these SMSA and non-SMSA projections among the facility planning areas and the remaining areas. For those SMSA's not included within designated 208 planning areas, each State, with assistance from appropriate regional planning agencies, shall disaggregate the SMSA projection among the facility planning areas and the remaining areas within the SMSA. The State shall check the facility planning area forecasts to ensure reasonableness and consistency with the SMSA projections.

(5) For non-SMSA facility planning areas not included in designated areawide 208 areas, the State may disaggregate population projections for non-SMSA counties among facility planning areas and remaining areas. Otherwise, the grantee is to forecast future population growth for the facility planning area by linear extrapolation of the recent past (1960 to present) population trends for the planning area, use of correlations of planning area growth with population growth for the township, county or other larger parent area population, or another appropriate method. A population forecast may be raised above that indicated by the extension of past trends where likely impacts (e.g., significant new energy developments, large new industries, Federal installations, or institutions) justify the difference. The facilities plan must document the justification. These population forecasts should be based on estimates of new employment to be generated. The State shall check individual population forecasts to insure consistency with overall projections for non-SMSA counties and justification for any difference from past trends.

(6) Facilities plans prepared under step 1 grant assistance awarded later than 6 months after Agency approval of the State disaggregations shall follow population forecasts developed in accordance with these guidelines.

b. *Wastewater flow estimates.* (1) In determining total average daily flow for the design of treatment works, the flows to be considered include the average daily base flows (ADBF) expected from residential sources, commercial sources, institutional sources, and industries the works will serve plus allowances for future industries and nonexcessive infiltration/inflow. The amount of nonexcessive infiltration/inflow not included in the base flow estimates presented herein, is to be determined according to the Agency guidance for sewer system evaluation or Agency policy on treatment and control of combined sewer overflows (PRM 75-34).

(2) The estimation of existing and future ADBF, exclusive of flow reduction from combined residential, commercial and institutional sources, shall be based upon one of the following methods:

(a) *Preferred method.* Existing ADBF is estimated based upon a fully documented analysis of water use records adjusted for consumption and losses or on records of wastewater flows for extended dry periods less estimated dry weather infiltration. Future flows for the treatment works design should be estimated by determining the existing per capita flows based on existing sewered resident population and multiplying this figure by the future projected population to be served. Seasonal population can be converted to equivalent full time residents using the following multipliers:

Day-use visitor	0.1 to 0.2
Seasonal visitor	0.5 to 0.8

The preferred method shall be used wherever water supply records or wastewater flow data exist. Allowances for future increases of per capita flow over time will not be approved.

(b) *Optional method.* Where water supply and wastewater flow data are lacking, existing and future ADBF shall be estimated by multiplying a gallon per capita per day (gpcd) allowance not exceeding those in the following table, except as noted below, by the estimated total of the existing and future resident populations to be served. The tabulated ADBF allowances, based upon several studies of municipal water use, include estimates for commercial and institutional sources as well as residential sources. The Regional Administrator may approve exceptions to the tabulated allowances where large (more than 25 percent of total estimated ADBF) commercial and institutional flows are documented.

Description	Gallons per capita per day
Non-SMSA cities and towns with projected total 10-year populations of 5,000 or less	60 to 70
Other cities and towns	65 to 80

c. *Flow reduction.* The cost-effectiveness analysis for each facility planning area shall include an evaluation of the costs, cost savings, and effects of flow reduction measures unless the existing ADBF from the area is less than 70 gpcd, or the current population of the applicant municipality is under 10,000, or the Regional Administrator exempts the area for having an effective existing flow reduction program. Flow reduction measures include public education, pricing and regulatory approaches or a combination of these. In preparing the facilities plan and included cost effectiveness analysis, the grantee shall, as a minimum:

(1) Estimate the flow reductions implementable and cost effective when the treatment works become operational and after 10 and 20 years of operation. The measures to be evaluated shall include a public information program; pricing and regulatory approaches; installation of water meters, and retrofit of toilet dams and low-flow showerheads for existing homes and other habitations; and specific changes in local ordinances, building codes or plumbing codes requiring installations of water saving devices such as water meters; water conserving toilets, showerheads, lavatory faucets, and appliances in new homes, motels, hotels, institutions, and other establishments.

(2) Estimate the costs of the proposed flow reduction measures over the 20-year planning period, including costs of public information, administration, retrofit of existing buildings and the incremental costs, if any, of installing water conserving devices in new homes and establishments.

(3) Estimate the energy reductions; total cost savings for wastewater treatment, water supply and energy use; and the net cost savings (total savings minus total costs) attributable to the proposed flow reduction measures over the planning period. The estimated cost savings shall reflect reduced sizes of proposed wastewater treatment works plus reduced costs of future water supply facility expansions.

(4) Develop and provide for implementing a recommended flow reduction program. This shall include a public information program highlighting effective flow reduction measures, their costs, and the savings of water and costs for a typical household and for the community. In addition, the recommended program shall comprise those flow reduction measures which are cost effective, supported by the public and within the implementation authority of the grantee or another entity willing to cooperate with the grantee.

(5) Take into account in the design of the treatment works the flow reduction estimated for the recommended program.

d. *Industrial flows.* (1) The treatment works' total design flow capacity may include allowances for industrial flows. The allowances may include capacity needed for industrial flows which the existing treatment works presently serves. However, these flows shall be carefully reviewed and means of reducing them shall be considered. Letters of intent to the grantee are required to document capacity needs for existing flows from significant industrial users and for future flows from all industries intending to increase their flows or relocate in the area. Requirements for letters of intent from significant industrial dischargers are set forth in § 35.925-11(c).

(2) While many uncertainties accompany forecasting future industrial flows, there is still a need to allow for some unplanned future industrial growth. Thus, the cost-effective (grant eligible) design capacity and flow of the treatment works may include (in addition to the existing industrial flows and future industrial flows documented by letters of intent) a nominal flow allowance for future nonidentifiable industries or for unplanned industrial expansions, provided that 208 plans, land use plans and zoning provide for such industrial growth. This additional allowance for future unplanned industrial flow shall not exceed 5 percent (or 10 percent for towns with less than 10,000 population) of the total design flow of the treatment works exclusive of the allowance or 25 percent of the total industrial flow (existing plus documented future), whichever is greater.

e. *Staging of treatment plants.* (1) The capacity of treatment plants (i.e., new plants, upgraded plants, or expanded plants) to be funded under the construction grants program shall not exceed that necessary for wastewater flows projected during an initial staging period determined by one of the following methods:

(a) *First method.* The grantee shall analyze at least three alternative staging periods (10 years, 15 years, and 20 years). He shall select the least costly (i.e., total present worth or average annual cost) staging period.

(b) *Second method.* The staging period shall not exceed the period which is appropriate according to the following table.

STAGING PERIODS FOR TREATMENT PLANTS

Flow growth factors (20 years)*	Staging period [1] (years)
Less than 1.3	20
1.3 to 1.8	15
Greater than 1.8	10

*Ratio of wastewater flow expected at end of 20 year planning period to initial flow at the time the plant is expected to become operational.

[1] Maximum initial staging period.

(2) A municipality may stage the construction of a treatment plant for a shorter period than the maximum allowed under this policy. A shorter staging period might be based upon environmental factors (secondary impacts, compliance with other environmental laws under § 35.925-14, energy conservation, water supply), an objective concerning planned modular construction, the utilization of temporary treatment plants, or attainment of consistency with locally adopted plans including comprehensive and capital improvement plans. However, the staging period in no case may be less than 10 years, because of associated cost penalties and the time necessary to plan, apply for and receive funding, and construct later stages.

(3) The facilities plan shall present the design parameters for the proposed treatment plant. Whenever the proposed treatment plant components' size or capacity would exceed the minimum reliability requirements suggested in the EPA technical bulletin, "Design Criteria for Mechanical, Electric, and Fluid System and Component Reliability," a complete justification, including supporting data, shall be provided to the Regional Administrator for his approval.

f. *Staging of interceptors.* Since the location and length of interceptors will influence growth, interceptor routes and staging of construction shall be planned carefully. They shall be consistent with approved 208 plans, growth management plans and other environmental laws under § 35.925-14 and shall also be consistent with Executive orders for flood plains and wetlands.

(1) Interceptors may be allowable for construction grant funding if they eliminate existing point source discharges and accommodate flows from existing habitations that violate an enforceable requirement of the Act. Unless necessary to meet those objectives, interceptors should not be extended into environmentally sensitive areas, prime agricultural lands and other undeveloped areas (density less than one household per 2 acres). Where extension of an interceptor through such areas would be necessary to interconnect two or more communities, the grantee shall reassess the need for the interceptor by further consideration of alternative wastewater treatment systems. If the reassessment demonstrates a need for the interceptor, the grantee shall evaluate the interceptor's primary and secondary environmental impacts, and provide for appropriate mitigating measures such as rerouting the pipe to minimize adverse impacts or restricting future connections to the pipe. Appropriate and effective grant conditions (e.g., restricting sewer hookups) should be used where necessary to protect environmentally sensitive areas or prime agricultural lands from new development. NPDES permits shall include the conditions to insure implementation of the mitigating measures when new permits are issued to the affected treatment facilities in those cases where the measures are required to protect the treatment facilities against overloading.

(2) Interceptor pipe sizes (diameters for cylindrical pipes) allowable for construction grant funding shall be based on a staging period of 20 years. A larger pipe size corresponding to a longer staging period not to exceed 40 years may be allowed if the grantee can demonstrate, wherever water quality management plans or other plans developed for compliance with laws under § 35.925-14 have been approved, that the larger pipe would be consistent with projected land use patterns in such plans and that the larger pipe would reduce overall (primary plus secondary) environmental impacts. These environmental impacts include:

(a) *Primary impacts.* (i) Short-term disruption of traffic, business and other daily activities.

(ii) Destruction of flora and fauna, noise, erosion, and sedimentation.

(b) Secondary impacts. (i) Pressure to rezone or otherwise facilitate unplanned development.

(ii) Pressure to accelerate growth for quicker recovery of the non-Federal share of the interceptor investments.

(iii) Effects on air quality and environmentally sensitive areas by cultural changes.

(3) The estimation of peak flows in interceptors shall be based upon the following considerations:

(a) Daily and seasonal variations of pipe flows, the timing of flows from the various parts of the tributary area, and pipe storage effects.

(b) The feasibility of off-pipe storage to reduce peak flows.

(c) The use of an appropriate peak flow factor that decreases as the average daily flow to be conveyed increases.

9. *State guidelines.* If a State has developed or chooses to develop comprehensive guidelines on cost-effective sizing and staging of treatment works, the Regional Administrator may approve all or portions of the State guidance for application to step 1 facility plans. Approved State guidance may be used instead of corresponding portions of these guidelines, if the following conditions are met:

a. The State guidance must be at least as stringent as the provisions of these guidelines.

b. The State must have held at least one public hearing on proposed State guidance, under regulations in part 25 of this chapter, before submitting the guidance for Agency approval.

10. *Additional capacity beyond the cost-effective capacity.* Treatment works which propose to include additional capacity

beyond the cost-effective capacity determined in accordance with these guidelines may receive Federal grant assistance if the following requirements are met:

a. The facilities plan shall determine the most cost-effective treatment works and its associated capacity in accordance with these guidelines. The facilities plan shall also determine the actual characteristics and total capacity of the treatment works to be built.

b. Only a portion of the cost of the entire proposed treatment works including the additional capacity shall be eligible for Federal funding. The portion of the cost of construction which shall be eligible for Federal funding under sections 203(a) and 202(a) of the Act shall be equivalent to the estimated construction costs of the most cost-effective treatment works. For the eligibility determination, the costs of construction of the actual treatment works and the most cost-effective treatment works must be estimated on a consistent basis. Up-to-date cost curves published by EPA's Office of Water Program Operations or other cost estimating guidance shall be used to determine the cost ratios between cost-effective project components and those of the actual project. These cost ratios shall be multiplied by the step 2 cost and step 3 contract costs of actual components to determine the eligible step 2 and step 3 costs.

c. The actual treatment works to be built shall be assessed. It must be determined that the actual treatment works meets the requirements of the National Environmental Policy Act and all applicable laws, regulations, and guidance, as required of all treatment works by §§ 35.925-8 and 35.925-14. Particular attention should be given to assessing the project's potential secondary environmental effects and to ensuring that air quality standards will not be violated. The actual treatment works' discharge must not cause violations of water quality standards.

d. The Regional Administrator shall approve the plans, specifications, and estimates for the actual treatment works under section 203(a) of the Act, even though EPA will be funding only a portion of its designed capacity.

e. The grantee shall satisfactorily assure the Agency that the funds for the construction costs due to the additional capacity beyond the cost-effective treatment works' capacity as determined by EPA (i.e., the ineligible portion of the treatment works), as well as the local share of the grant eligible portion of the construction costs will be available.

f. The grantee shall execute appropriate grant conditions or releases providing that the Federal Government is protected from any further claim by the grantee, the State, or any other party for any of the costs of construction due to the additional capacity.

g. Industrial cost recovery shall be based upon the portion of the Federal grant allocable to the treatment of industrial wastes.

h. The grantee must implement a user charge system which applies to the entire service area of the grantee, including any area served by the additional capacity.

*U.S. Government Printing Office: 1980-O-677-094/1112