United States
Environmental Protection
Agency

Wastewater Technology Fact Sheet

Disinfection for Small Systems

DESCRIPTION

The impact of untreated and partially treated domestic wastewater on rivers and community water sources continues to raise health and safety concerns. The organisms of concern in domestic wastewater include enteric bacteria, viruses, and protozoan cysts. Table 1 summarizes the most common microorganisms found in domestic wastewater and the types of human diseases associated with them. Based on health and safety concerns associated with microorganisms present in wastewater, EPA has increased its efforts to address the wastewater treatment needs of all communities across the United States. As a result, small community wastewater treatment needs are an EPA priority.

According to the EPA, a small system can either be a septic system, sand filter, or any system that serves individual houses or groups of homes, strip malls, or trailer parks. These systems can handle flows from 3.8 to 76 m^3/d (1,000 - 20,000 gpd). EPA estimates that more than 20 million homes in small communities are not connected to public sewers and that nearly one million homes in small communities across the United States have no form of sewage treatment at all (USEPA, 1999). In addressing small community needs, disinfection is considered a primary mechanism for inactivating/destroying pathogenic organisms and preventing the spread of waterborne diseases to downstream users and the environment. Some of the most commonly used disinfectants for decentralized applications include chlorine, iodine, and ultraviolet (UV) radiation.

Wastewater must be adequately treated prior to disinfection in order for any disinfectant to be effective. Reduction of suspended solids (SS) and biological oxygen demand (BOD) is recommended prior to disinfection. SS may absorb UV radiation, shield microorganisms, and increase chlorine demand. Removing SS also reduces the number of microorganisms present. Organic compounds associated with BOD also consume added chlorine.

TABLE 1 INFECTIOUS AGENTS POTENTIALLY PRESENT IN UNTREATED DOMESTIC WASTEWATER

Organism	Disease Caused
Bacteria	
Escherichia coli	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Giardiasis
Helminths	
Ascaris lumbricoides	Ascariasis
Taena solium	Taeniasis
Trichuris trichiura	Trichuriasis
Viruses	
Enteroviruses (72 types) e.g., polio echo and coxsackie viruses	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

Source: Adapted from Crites and Tchobanoglous (1998), with permission from The McGraw-Hill Companies.

This fact sheet focuses on the use of UV disinfection and chlorination to disinfect small community septic systems.

APPLICABILITY

Chlorination and UV radiation can be used to inactivate potentially infectious organisms. As a result, communities and homeowners should carefully select a disinfection technology. A number of factors to consider when choosing a disinfection system are presented in Table 2.

The effectiveness of a UV disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. Disinfection success in any decentralized system is directly related to the concentration of colloidal and particulate constituents in the wastewater.

The most common UV system used for small systems is a low-pressure, low-intensity system. Low-pressure signifies the pressure of the mercury in the lamp, which is typically 13.8 Pa (0.002 lbs/in^2). The term intensity refers to the lamp power. Standard low-pressure, low-intensity lamps typically have a power of 65 watts. These lamps are generally efficient in producing germicidal wavelengths necessary for damaging DNA in bacteria. The low-pressure, low-intensity lamp typically has 40 percent of its output at 253.7 nm, which is within the ideal range for inactivating bacteria. This type of system can be configured vertically or horizontally. This allows systems to be configured to fit the available space. Safety considerations associated with UV disinfection include UV light itself, and potential release of mercury from lamp bulbs if damaged.

Chlorine is one of the most practical and widely used disinfectants for wastewater. Chlorination is commonly used because it can kill disease-causing bacteria and control nuisance organisms such as iron-reducing bacteria, slime, and sulfate-reducing bacteria. Chlorine destroys target organisms by oxidizing the cellular material of bacteria. Chlorine can be supplied in many forms and in liquid, solid, or gaseous phases. Common chlorine-containing disinfection products include chlorine gas,

TABLE 2 APPLICABILITY OF CHLORINATION AND UV RADIATION

Consideration	Chlorination	UV Radiation
Size of plant	All sizes	Small to medium[1]
Applicable level of treatment prior to disinfection	All levels, but chlorine required will vary	Secondary
Equipment reliability	Good	Fair to good
Process control	Well developed	Fairly well developed
Relative complexity of technology	Simple to moderate	Simple to moderate
Transportation on site	Substantial	Minimal
Bactericidal	Good	Good
Virucidal	Poor	Good
Cysticidal	Poor	Variable[2]
Fish toxicity	Potentially toxic	Nontoxic
Hazardous byproducts	Yes	No
Persistent residual	Long	None
Contact time	Long	Short
Contribute dissolved oxygen	No	No
Reacts with ammonia	Yes	No
Increased dissolved solids	Yes	No
pH dependent	Yes	No
Operation and maintenance sensitive	Minimal	Moderate
Corrosive	Yes	No

Source: Adapted from U.S. EPA, 1986.

[1] Early installations of UV disinfection facilities took place primarily in small to medium size plants because the technology was relatively new. Plants currently in design or construction phases tend to be larger.

[2] Recent studies have shown that UV radiation may be effective against oocysts.

hypochlorite solutions, and chlorine compounds in solid or liquid form. Liquid sodium hypochlorite and solid calcium hypochlorite tablets are the most common forms of chlorine used for small systems because they are less hazardous than chlorine gas.

ADVANTAGES AND DISADVANTAGES

UV Radiation

Advantages

- Effective inactivation of most viruses, bacteria, and spores. May be effective against some cysts.
- Physical process rather than a chemical disinfectant.
- No residual effect that could harm humans or aquatic life.
- Equipment requires less space than other methods.

Disadvantages

- Low dosages may not effectively inactivate some viruses, spores, and cysts.
- Turbidity and total suspended solids (TSS) in the wastewater can render UV disinfection ineffective.
- May require a large number of lamps.

Chlorination

Advantages

- Chlorine is reliable and effective against a wide spectrum of pathogenic organisms.
- Chlorine is more cost-effective than UV or ozone disinfection.
- The chlorine residual that remains in the wastewater effluent can prolong disinfection even after initial treatment and can be measured to evaluate the effectiveness.
- Dosing rates are flexible and can be controlled easily.

Disadvantages

- The chlorine residual is toxic to aquatic life and the system may require dechlorination, even when low concentrations of chlorine are used.
- All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping, and handling chlorine poses a risk and requires increased safety - especially in light of the new Uniform Fire Code.
- Chlorine reacts with certain types of organic matter in wastewater, creating hazardous compounds (e.g., trihalomethanes).
- Chlorine residuals are unstable in the presence of high concentrations of chlorine-demanding materials (BOD). Thus, wastewater with high BOD may require higher chlorine doses for adequate disinfection.

DESIGN CRITERIA

UV Radiation

A UV disinfection system consists of mercury arc lamps, a contact vessel, and ballasts. The source of UV radiation is either a low- or a medium-pressure mercury arc lamp with low or high intensity. Medium- pressure lamps are generally used for large facilities. The optimum wavelength to effectively inactivate microorganisms is in the range of 250 to 270 nm. The intensity of the radiation emitted by the lamp dissipates as the distance from the lamp increases. Low-pressure lamps emit essentially monochromatic light at a wavelength of 253.7 nm. Standard lengths of the low-pressure lamps are 0.75 and 1.5 m (2.5 and 5.0 ft), with diameters of 15 to 20 mm (0.6-0.8 inches). The ideal lamp wall temperature is between 35 and 50EC (95-122EF). The United States Public Health Service requires that UV disinfection equipment have a minimum UV dosage of 16,000 FW@s/cm^2.

There are two types of UV disinfection reactor configurations: contact and noncontact. In both types, wastewater can flow either perpendicular or parallel to the lamps. In the contact reactor, a series of mercury lamps are enclosed in quartz sleeves to minimize the cooling effects of the wastewater. Flap gates or weirs are used to control the level of the wastewater. In the noncontact reactor, UV lamps are suspended outside a transparent conduit which carries the wastewater to be disinfected. In both types of reactors, a ballast—or control box—provides a starting voltage for the lamps and maintains a continuous current.

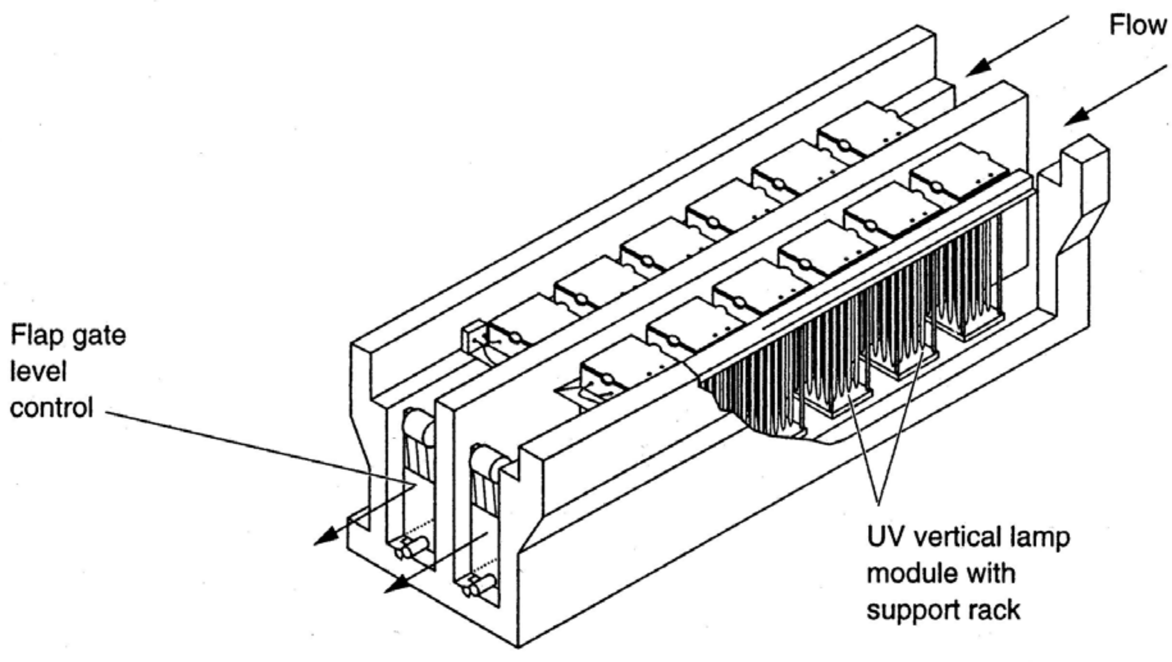
Because of capital cost advantages at low flow rates and the ease of managing a system with a small number of lamps, the majority of UV systems handling less than 0.4 m^3/s (1 MGD) are low-pressure, low-intensity systems. A 0.4 m^3/s (1 MGD) system should have fewer than 100 low-pressure lamps, so the impact of further reducing the number of lamps will not be substantial. Figure 1 presents a schematic of a low pressure contact UV disinfection system.

Several wastewater characteristics must be evaluated before selecting UV disinfection as a treatment method. The following list of characteristics can affect the performance and design of a UV disinfection system:

- Flow Rate: Wastewater flow can vary daily and seasonally, affecting the required size of a UV disinfection facility. As a result, the peak hourly flow rate typically is used as the design flow rate. The applied UV dosage is a function of UV intensity and the duration of exposure; the dosage rate achieved is directly proportional to flow rate.

- UV Transmittance: UV transmittance is a measure of the quantity of UV light at the characteristic wavelength of 253.7 nm transmitted through wastewater per unit depth. Historically, a 50 percent UV transmittance has been accepted as the minimum transmittance for which UV disinfection is practical. High turbidity and/or high concentrations of BOD, certain metals, TDS, TSS, and color may decrease transmittance, lessening the effectiveness of UV radiation.

- TSS Concentration: TSS levels significantly affect UV disinfection because UV light can be blocked by suspended solids. This can



Source: Crites and Tchobanoglous, 1998.

FIGURE 1 LOW PRESSURE CONTACT UV DISINFECTION SYSTEM

shield microorganisms from the disinfecting effects of the light. As a result, measuring the particle size distribution in wastewater can be helpful in determining the feasibility of this disinfection technology. Particles with a diameter of <10 microns allow for easy UV penetration. Particles with diameters between 10 and 40 microns can be completely penetrated, but with increased UV demand.

- Microorganism Concentration: UV disinfection performance evaluations indicate that the microorganism density remaining after exposure to a given UV dose is proportional to initial microorganism density. As a result, it is beneficial to consider the concentration of microorganisms before disinfection.

- Hardness: Carbonate deposition (scaling) on lamp sleeves becomes an issue when handling wastewater with high levels of hardness. Carbonate accumulation on lamp sleeves reduces the intensity of UV light reaching the wastewater.

- Iron Concentration: Dissolved iron concentrations in wastewater can absorb UV light, reducing the light intensity reaching the microorganisms. Adsorbed iron on suspended solids may also shield microorganisms from UV light. Iron hydroxides may precipitate on lamp bulbs, decreasing their intensity.

- Organics: Dissolved organics or oils and grease can reduce UV transmittance. The size of the organic compounds is important in determining whether they will interfere with the UV transmittance: the larger the molecular weight of the compounds, the more they will interfere. This effect is primarily the result of increasing color and/or turbidity in the water.

- Inorganics: Some inorganic salts (e.g., bromide) can absorb UV light and thereby reduce UV effectiveness.

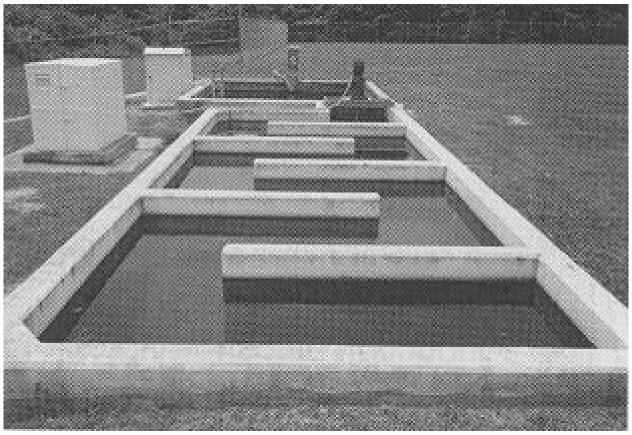
Systems using an aerobic household wastewater treatment system are usually installed at or below grade level and the effluent pipe may be as much as 60 cm (24 in) below grade. To maintain gravity flow, the UV unit must be below grade and must have very low flow resistance. During construction, the components of an underground UV system must be easily accessed for service and low voltage should be used for safety.

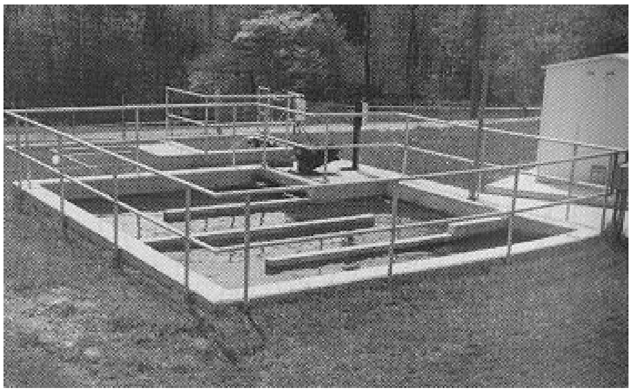
Chlorination

For optimum performance, a chlorine disinfection system should provide rapid initial mixing and a plug flow contact regime. The goal of proper mixing is to enhance disinfection by initiating a reaction between free chlorine and ammonia nitrogen. This helps to prevent free chlorine from reacting with organic carbon compounds and forming hazardous byproducts. In order to allow appropriate time for the disinfection reaction, the contact chamber should be designed with rounded corners to eliminate dead flow areas. It should also be baffled to minimize short-circuiting. This design allows for adequate contact time between the microorganisms and a minimal chlorine concentration for a specific period of time. Figure 2 illustrates plug flow chlorine contact basins.

Chemical feed systems are used for adding sodium and/or calcium hypochlorite solutions. For sodium hypochlorite, the basic components of a chemical feed system include a plastic or fiber glass storage reservoir, metering pumps, and an injection device to inject the hypochlorite solution into a contact tank or pipeline. Calcium hypochlorite can typically be added to the wastewater either by mixing calcium hypochlorite powder in a mixing device and then injecting it into the wastewater stream, or by immersing chlorine tablets in the wastewater using a tablet chlorinator. Tablet chlorinator systems are described in more detail below.

A typical calcium hypochlorite tablet chlorinator consists of a cylindrical PVC tank with a diameter ranging from 230 to 610 mm (9-24 in) and a height ranging from 0.6 to 1.2 m (24-48 in). A sieve plate





Source: Crites and Tchobanoglous, 1998.

FIGURE 2 TYPICAL PLUG FLOW CHLORINE CONTACT BASINS FOR SMALL FLOWS

with holes supports the 80 mm (3-in) diameter calcium hypochlorite tablets. Tablet chlorinator systems can typically provide between 1 and 295 kg (2-650 lbs) of chlorine per day. A side stream from the main flow is piped into the chlorinator at the bottom of the tank. The flow rises through the holes in the sieve plate, contacting and eroding the bottom layer of tablets. The tablets erode at a predictable rate based on the amount of water that enters the chlorinator. An accurate chlorine dosage can be achieved by controlling the water flow rate through the chlorinator. The chlorinator effluent is returned to the main stream, providing the desired level of available chlorine to meet operational requirement.

The required degree of disinfection can be achieved by varying the dose and the contact time for any chlorine disinfection system. Chlorine dosage will vary based on chlorine demand, wastewater characteristics, and discharge requirements. The dose usually ranges from 5 to 20 mg/L. Table 3 describes some common wastewater characteristics and their impact on chlorine. Several other factors

TABLE 3 WASTEWATER PROPERTIES AFFECTING CHLORINATION AND UV DISINFECTION PERFORMANCE

Property	Effects on Chlorination	Effects on UV Disinfection
Ammonia	Forms chloramines when combined with chlorine.	Minor effect, if any.
Nitrite	Reduces effectiveness of chlorine and results in THMs.	At high concentrations may absorb UV light and reduce transmittance.
Nitrate	Minor effect, if any.	At high concentrations may absorb UV light and reduce transmittance.
Bio-chemical oxygen demand (BOD)	Organic compounds associated with BOD can consume added chlorine.	Minor effect, if any. If a large portion of the BOD is humic and/or unsaturated (or conjugated) compounds, then UV transmittance may be diminished.
Hardness	Minor effect, if any.	Affects solubility of metals that can absorb UV light. Can lead to the precipitation of carbonates on quartz tubes.
Humic materials, Iron	Minor effect, if any.	High absorbency of UV radiation.
pH	Affects distribution between hypochlorous acid and hypochlorite ions and among the various chloramine species.	Affects solubility of metals and carbonates, and thus scaling potential.
TSS	Shielding of embedded bacteria and chlorine demand.	Absorbs UV radiation and shields embedded bacteria.

Source: Adapted from Darby, et al., 1995, with permission from the Water Environment Research Foundation.

ensure optimum conditions for disinfection, including temperature, alkalinity, and nitrogen content. Wastewater pH affects the distribution of chlorine between hypochlorous acid and hypochlorite. A lower pH favors hypochlorous acid, which is a better disinfectant. High concentrations of hypochlorous acid, however, may result in production of chlorine gas, which may be hazardous.

PERFORMANCE

Performance of chlorination and UV disinfection varies between facilities based on maintenance techniques and wastewater characteristics. Researchers at Baylor University are evaluating existing on-site systems using different disinfection units.

OPERATION AND MAINTENANCE

UV Radiation

A routine operation and maintenance (O&M) schedule should be developed and implemented for any disinfection system. A proper O&M program for a UV disinfection system should ensure that sufficient UV radiation is transmitted to the organisms to inactivate them. All surfaces between the UV radiation and the target organisms must be cleaned, while ballasts, lamps, and the reactor must be functioning properly. Inadequate cleaning is one of the most common causes of ineffective UV systems. The quartz sleeves or Teflon tubes should be cleaned regularly, either manually or through mechanical methods. Common cleaning methods include mechanical wipers, ultrasonic baths, or chemicals. Cleaning frequency is site-specific.

Chemical cleaning is most commonly performed with citric acid or commercially available cleaning solutions. Other cleaning agents include mild vinegar solutions and sodium hydrosulfite. A combination of cleaning agents should be tested to find those that are most suitable for the specific wastewater characteristics without producing harmful or toxic by-products. Non-contact reactor systems are most effectively cleaned with sodium hydrosulfite.

Average lamp life ranges from 8,760 to 14,000 working hours (between approximately 12 and 18 months of continuous use), but lamps are usually replaced after 12,000 hours of use. Operating procedures should be set to reduce the on/off cycles of the lamps, because repeated cycles reduce their effectiveness. In addition, spare UV lamps should be kept on hand at all times along with accurate records of lamp use and replacement. The UV output gradually decreases over the life of the lamp and the lamp must be replaced based on the hours of use or a UV monitor. The quartz sleeves that fit over the lamps will last about 5 to 8 years but are generally replaced every 5 years.

The ballast must be compatible with the lamps and should be ventilated to prevent excessive heating, which may shorten its life or even result in fires. The life cycle of ballasts is approximately 10 to 15 years, but they are usually replaced every 10 years.

Operation and maintenance of an on-site system is usually the responsibility of the homeowner, but some home sewage systems are sold with service contracts that call for a trained serviceman to inspect the system and perform necessary maintenance every six months. As a result, it is necessary to determine who is responsible for operation and maintenance of the UV system.

Chlorination

O&M for a chlorine disinfection system should include the following activities:

- Follow all manufacturer recommendations and test and calibrate equipment as recommended by the manufacturer.
- Disassemble and clean system components, including meters and floats, every six months.
- Inspect and clean valves and springs annually.
- If the system includes metering pumps, maintain pumps on a regular basis.

- Remove iron and manganese deposits with muriatic acid or other removal agents.

- If gaseous chlorine is stored on-site, develop an emergency response plan in case of accidents or spills.

It is essential to properly and safely store all chemical disinfectants when using chlorine. The storage of chlorine is strongly dependent on the compound phase. Heat, light, storage time, and impurities such as iron accelerate the degradation of sodium hypochlorite. Calcium hypochlorite is unstable under normal atmospheric conditions and should be stored in a dry location. Hypochlorites are destructive to wood, corrosive to most common metals, and will irritate skin and eyes if there is contact. For further details on the safe use and storage of chlorine refer to the Material Safety Data Sheets (MSDS) for the specific chemicals of interest. MSDSs are readily available from the internet by doing a search on the chemical name.

COSTS

The costs associated with chlorination and UV treatment are predominantly dictated by dosage, which in turn is related to peak flows, suspended solids, temperature and bacterial counts. The following summaries describe some of the costs that a homeowner and/or community may encounter when considering chlorination or UV treatment to disinfect wastewater.

UV Radiation

Table 4 provides capital cost summaries for UV systems. Systems include the wastewater channel, UV module assemblies with lamps and quartz sleeves, and ballasts. The ballasts include meters for run times and UV intensity. The last two systems in the table also include costs for delivery of the equipment to the site.

Chlorination

Most decentralized systems use chlorine tablets to disinfect their wastewater because they are simple to use, and they are less expensive than liquid chlorine. These units can range from $325-$700, depending on the flow to be chlorinated. Tablets are sold in tablets or drums based on weight. For example, a 100 kg (45 lb) pail of tablets ranges in cost from $69-$280, depending on the vendor.

TABLE 4 UV SYSTEM COSTS

UV System description	Cost
Peak flow: 19 m^3/d (5,000 gpd)	$2,500[1]
Peak flow: 95 m^3/d (25,000 gpd)	$3,750[1]
Peak flow: 49 m^3/d (12,960 gpd)	$4,000[2]
Peak flow: 98 m^3/d (25,920 gpd)	$4,700[2]

Sources:

[1] Tipton Environmental International, Inc., 2003.

[2] Infilco Degremont, Inc., 1999.

Liquid chlorinators are more complex because the liquid must be pumped into the system. A hypochlorinator system sized to treat a flow range of 9.5 to 76 m^3/d (2,500 to 20,000 gpd), consisting of one 210-L (55-gal) polyethylene drum, two metering pumps, and injector valve, costs approximately $4,200.

Cost Comparison

Cost comparisons between UV and chlorination disinfection systems are difficult because of the cost differences based on the volume of flow. In addition, while the initial capital costs of one system may be low relative to another system, subsequent operation and maintenance costs for each type of system must be evaluated before the overall cost-effectiveness of one system vs. another can be determined. For example, while the capital costs of a chlorination system may be low compared to the capital costs for a UV system, dechlorination equipment and supplies will increase the overall cost associated with this disinfection method.

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September 1999

Ultraviolet Disinfection
EPA 832-F-99-064
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