July 2004
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Environmental Technology Verification Report

Separation of Manure Solids from Flushed Swine Waste

Hoffland Environmental Inc.
Drag Screen and Clarifier

Prepared for

NSF International

Prepared by

Biological & Agricultural Engineering
NC STATE UNIVERSITY

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

ETV ETV ETV

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**SOLIDS SEPARATOR**
APPLICATION:	**SEPARATION OF MANURE SOLIDS FROM FLUSHED SWINE WASTE**
TECHNOLOGY NAME:	**DRAG SCREEN AND CLARIFIER**
COMPANY:	**HOFFLAND ENVIRONMENTAL INC.**
ADDRESS:	**303 SILVER SPRING RD CONROE, TX 77303** **PHONE: (936) 856-4515 FAX: (936) 856-4589**

NSF International (NSF), in cooperation with the U.S. Environmental Protection Agency (EPA), operates the Water Quality Protection Center under EPA's Environmental Technology Verification (ETV) Program. As part of the Water Quality Protection Center's activities in verifying the performance of source water protection technologies, the ETV Program evaluated the performance of a drag screen and clarifier system for separating solids from flushed swine waste. This verification statement summarizes the test results for the Hoffland Environmental Inc. drag screen and clarifier, hereinafter referred to as the Hoffland Separator. The verification testing was conducted by North Carolina State University's Biological and Agricultural Engineering Department in Raleigh, North Carolina.

EPA created the ETV Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with testing organizations and stakeholder advisory groups consisting of buyers, vendor organizations, and permitters, and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

Technology Description

The following description of the Hoffland Separator was provided by the vendor and does not represent verified information.

The Hoffland Separator consists of an inclined perforated metal screen with a motorized drag conveyor to which incoming wastewater flows, an integral wastewater collection tank that collects and recycles the liquid that passes through the screen, and a solids concentrator (clarifier) that receives input from the wastewater collection tank. The inclined screen removes large solids from the wastewater. Liquid and fine solids that pass through the screen are collected in the wastewater collection tank. Wastewater is pumped from the bottom of the wastewater collection tank to the solids concentrator through a two-inch diameter PVC pipe, entering the concentrator in a central stilling well 30 inches below the effluent weir. Inside the concentrator, the momentum of the liquid is reduced and flow becomes non-turbulent. Thickened solids are moved to the center of the solids concentrator by a sludge rake and flow by gravity from the bottom of the solids concentrator through a six-inch PVC pipe to the screen tank so they are added to the influent stream and are processed by the drag screen. A rubber skimmer that rotates with the sludge rake moves floating solids and scum in the concentrator into a collection box at the top of the unit and out through a four inch pipe connected to the underflow pipe. All liquid effluent leaves the treatment system through the overflow weir at the top of the clarifier. Floating solids are prevented from getting to the effluent weir by a baffle approximately two inches inside the effluent weir. Containers for recovered solids and clarified liquid were used when evaluating the system. The electrical configuration for the Hoffland Separator can be adapted to what is needed in a particular installation. The system was installed at the test site utilizing 240V single-phase power.

The following is a summary of the characteristics of the Hoffland Separator:

Type	Inclined drag screen; bottom feed; and a gravity clarifier
Screen Size	32 in. x 120 in
Screen Perforation	0.09 in
Clarifier Diameter	120 in
Clarifier Depth	191 in
Average Capacity	40 gallons per minute

Verification Testing Description

Test Site

Verification testing was conducted at the North Carolina State University (NCSU) Lake Wheeler Road Field Laboratory Swine Educational Unit. This farm is designed and operated as a research and teaching facility. The farm capacity is 250 sows for farrow to wean (birth to wean). The farm can finish (grow to a market weight of 250 lb) approximately half of the pigs weaned each year. Under normal operating conditions, waste at the site is removed by flushing under-slat pits with treated wastewater from the on-site anaerobic lagoon. Flushed waste then flows back to the lagoon for treatment. During the verification test, the flushed waste was diverted to a 2,500 gal glass-lined influent mixing tank of 12-ft diameter and 10-ft depth. The influent mixing tank was equipped with a 5-hp mixer with a 2-ft diameter impeller, designed to keep solids suspended while minimizing aeration and physical changes to the wastewater.

An all-in/all-out closed loop process was developed to eliminate problems and errors associated with flow measurement and sampling. All of the waste generated over a two-day period was left in the under-slat pits until it was flushed and collected in the influent mixing tank. This wastewater was then pumped from the influent mixing tank to the test system. Liquid discharged from the test system was collected in the effluent tank, and the separated solids were collected in a 300-gallon open poly tank.

Methods and Procedures
Verification testing began on Friday, September 26, 2003 and ended on November 5, 2003. Technology evaluation and sampling procedures were carried out three days per week (Monday, Wednesday, and Friday) for a total of twelve testing events.

At the beginning of each test day, the Hoffland Separator was started and the unit was visually inspected to verify that the conveyor was working correctly. To achieve a balance between the required batch process at the test site and the designed continuous flow process of the Hoffland system, the sludge rake and skimming arm were turned on while wastewater was being collected from the farm.

Wastewater from the swine unit was collected and mixed in the influent mixing tank to equally distribute suspended solids throughout the tank. Wastewater was typically held in the influent mixing tank for less than five minutes, but never more than thirty minutes before being pumped to the Hoffland Separator at a nominal flow rate of 35 gallons per minute. The pump in the wastewater collection tank was operated continuously to transfer wastewater to the clarifier. Wastewater entering the clarifier caused the contained wastewater to overflow the weir and flow through the collection box to the effluent tank. The underflow valve was opened automatically for 10-15 seconds every 5 minutes. At the conclusion of each day's testing, the underflow valve was opened manually for 10-15 seconds every 1.5 minutes for 15 minutes. After the first week of operation, the testing organization and vendor together determined the rake and skimmer should be operated continuously just as they would be in a full-scale, continuous installation.

Measurements made each test day included volume of wastewater entering the system, volume of the effluent stream, weight of solids discharged, and concentrations of quality parameters in each of the sampled components (influent, effluent, and recovered solids). The influent and effluent volumes were determined based on the waste depths and dimensions of each tank. The weight of the solids was determined as the difference in the weights of large containers with and without the solids. Weights were measured at the testing location using appropriate scales. Concentrations of the quality parameters were determined by laboratory analysis of grab samples collected in triplicate. The analyses performed included solids (total, suspended, and volatile), total organic carbon (TOC), nutrients, metals, pH, conductivity, and bulk density. The mean daily concentrations were multiplied by the appropriate volume or mass measured to obtain the mass in each component. The mass balance of each parameter was calculated based on the values obtained over the entire test period. Samples were also collected once per week and analyzed for *E. coli* and total coliform. The difference in concentrations of the various parameters before and after testing was taken into account in the mass balance. The contents of the clarifier were sampled at the end of the set up period after opening the underflow control valve until the consistency of the material exiting the clarifier changed from sludge to wastewater. At the conclusion of testing, the contents of the clarifier were transferred to the influent mixing tank in several batches where the volume could be measured and the material sampled for analysis.

Performance Verification

System Performance
The mass balance approach allowed for the determination of how the suspended solids and nutrients partitioned through the Hoffland Separator. For each parameter, the total mass recovered in each phase (effluent, solids, and clarifier liquid) is shown in Table 1 as the percent of the mass in the influent. The calculated recoveries from the mass balance are ideally ±10 percent for this type of work, although recoveries outside of this range are common due to the complex nature of both the wastewater and separated solids. The data quality indicators, such as accuracy and precision measurements of laboratory analyses, were all within established limits over the course of the verification test. Because of this, nothing can or should be inferred from mass balance recoveries not equal to 100 percent.

Table 1. Partitioning and Recovery of Parameters from Influent

Parameter	Percent Found In: Recovered Solids	Liquid Effluent	Clarifier Liquid	Total (Solids, Effluent, Clarifier)
Total Solids	9.7	46	24	79
Dry Solids	12			
Suspended Solids		29	26	67
Total Nitrogen	5.2	67	22	94
Total Phosphorus	5.6	62	23	90
Potassium	0.37	85	12	97
Copper	4.5	37	38	80
Zinc	6.0	44	45	95
Chloride	0.69	87	8	95

Note: The data in Table 1 are based on twelve samples.

The characteristics of the liquid effluent and the recovered solids are shown in Tables 2 and 3, respectively. All values presented in the table reflect means calculated over the test period. Over the entire test period, the effluent stream from the Hoffland Separator had an average suspended solids concentration of 2,650 mg/L, which, when converted to mass based on the volume of the effluent, represents 29% of the mass of suspended solids in the influent. Solids recovered by the Hoffland Separator contained 13.4 percent dry matter (86.6 percent moisture). The Hoffland Separator recovered 273 lb of dry solids, representing 12 percent of the 2,310 lb of suspended solids in the influent. Suspended solids remaining in the clarifier at the end of the test accounted for 26 percent of the influent suspended solids, leaving 33 percent of the suspended solids for which the mass balance analysis could not account.

Table 2. Influent / Effluent Characteristics

Parameter	Units	Influent	Effluent
Total solids	mg/L	10,600	5,100
Volatile solids	mg/L	7,490	3,030
Suspended solids	mg/L	8,690	2,650
Total organic carbon	mg/L	1,590	1,250
Total Kjeldahl nitrogen	mg/L	799	561
Ammonia nitrogen	mg/L	347	388
Total phosphorus	mg/L	297	192
Ortho phosphorus	mg/L	140	142
Potassium	mg/L	383	341
Chloride	mg/L	240	219
Copper	mg/L	5.23	2.02
Zinc	mg/L	7.58	3.47
N:P:K ratio		2.7:1:1.3	2.9:1:1.8
pH		7.49	7.04
Conductivity	µmhos/cm	4,061	4,072
Total coliform	MPN/100mL	8.8×10^7	1.3×10^7
E. coli	MPN/100mL	5.9×10^7	1.0×10^7

Note: The data in Table 2 are based on twelve samples.

Table 3. Recovered Solids Characteristics

Parameter	Units	Concentration
Dry matter	percent by weight	13.4
Volatile solids	percent by weight	11.5
Total carbon	percent by weight	1.68
Total nitrogen	percent by weight	0.54
Total phosphorus	µg/g	2,180
Potassium	µg/g	185
Chloride	µg/g	216
Copper	µg/g	30.7
Zinc	µg/g	59.3
Bulk density	g/mL	0.997
Total coliform	MPN/g	5.3×10^7
E. coli	MPN/g	3.9×10^7
N:P:K ratio		2.5:1:0.1

Note: The data in Table 3 are based on twelve samples.

Operation and Maintenance Results

Operational Observations

On October 6th, a pipe supplying flush water to the swine barns broke, postponing the verification test on that day. Investigation into the cause of that break found additional plumbing problems that caused the flush system to shut down from October 10th to October 13th. Regular verification testing resumed on October 15th after the swine houses were cleaned and waste was collected for two days, as stated in the test plan. Another pipe break on October 22nd caused the system to shut down until October 27th. Testing resumed two days later without further problems, after cleaning the swine houses and collecting the waste.

Maintenance Observations

The only operational problem with the Hoffland Separator resulted from floating solids that may have occurred, in part, because of delays due to the plumbing problems described above. After the first two weeks of operation, floating solid flocs began to appear at the effluent weir and soon began to block effluent flow from individual weir outlets. The weir was cleaned by hosing and scraping away the solids. Because access was limited to about 20 degrees on either side of a ladder mounted on the outside wall of the clarifier, clearing all of the individual weir outlets was difficult and less than completely effective. The situation recurred after another 3-4 days of operation and the cleaning procedures were repeated. All material removed during the cleaning process was recovered in the effluent tank and included in the mass balance. Floating solids were also observed in the central stilling well of the clarifier.

A permanent installation would be expected to require some maintenance over time, such as lubricating bearings and washing the screen. The drip pan under the upper portion of the screen that extends beyond the sump must also be cleaned periodically. The manufacturer's operations manual did not include a routine maintenance schedule.

Electrical Requirements

The Hoffland Separator required 240 V, single-phase electrical power to operate the two electric motors (totaling five hp). Units for installation with three-phase power and voltages up to 575 V are available. The Hoffland Separator's two motors were wired to the main connection box. Electrical installation consisted of supplying power to the unit and making the appropriate connections at the unit's control panel.

A data logger measured current and voltage and calculated values of kilowatts, which were recorded every ten seconds. Peak power consumption usually occurs when motors are first started, either at the beginning of the test or after a pause in motor operation as indicated by a drop in power consumption. The mean peak power consumption during the verification test was 1.41 kW. The overall mean power consumption during operation was 0.96 kW. During the entire verification test, the Hoffland Separator used approximately 0.51 kW-h of energy per 1,000 gallons of wastewater treated.

Quality Assurance/Quality Control (QA/QC)

During testing, NSF International completed QA audits of the NCSU Biological and Agricultural Engineering Department's Environmental Analysis Laboratory and Swine Educational Unit, Lake Wheeler Road Field Laboratory. NSF personnel completed (1) a technical systems audit to assure the testing was in compliance with the test plan, (2) a performance evaluation audit to assure that the measurement systems employed by the laboratory and the field technicians were adequate to produce reliable data, and (3) a data quality audit of at least ten percent of the test data to assure that the reported data represented the data generated during the testing. In addition to the quality assurance audits performed by NSF International, EPA QA personnel conducted a quality systems audit of NSF International's QA Management Program.

Original signed by
Lawrence W. Reiter, Ph.D. *9/1/04*

Lawrence W. Reiter, Ph.D. Date
Acting Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original signed by
Gordon E. Bellen *9/13/04*

Gordon E. Bellen Date
Vice President
Research
NSF International

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report in no way constitutes an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents

Copies of the *ETV Test Plan for the Verification of Technologies for Separation of Manure Solids from Flushed Swine Waste,* dated April 2002, the Verification Statement, and the Verification Report are available from the following sources:

ETV Water Quality Protection Center Manager (order hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140
(734) 769-8010

NSF web site: http://www.nsf.org/etv (electronic copy)
EPA web site: http://www.epa.gov/etv (electronic copy)

NOTE: Appendices are not included in the Verification Report. Appendices are available from NSF upon request.

July 2004

Environmental Technology Verification Report

Separation of Manure Solids from Flushed Swine Waste

Hoffland Environmental Inc.
Drag Screen and Clarifier

Prepared for:
NSF International
Ann Arbor, MI 48105

Prepared by:
John Classen, Ph.D.
Mark Rice
Frank Humenik, Ph.D.
North Carolina State University
Raleigh, NC 27695

Under a cooperative agreement with the U.S. Environmental Protection Agency

Raymond Frederick, Project Officer
ETV Water Quality Protection Center
National Risk Management Research Laboratory
Water Supply and Water Resources Division
U.S. Environmental Protection Agency
Edison, New Jersey 08837

Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under a Cooperative Agreement. This verification effort was supported by the source water protection area of the Water Quality Protection Center, operating under the Environmental Technology Verification (ETV) Program. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Contents

Figures

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Acronyms and Abbreviations

cfm	Cubic feet per minute
Cl^-	Chloride
Cu	Copper
DQI	Data quality indicators
EPA	United States Environmental Protection Agency
ETV	Environmental technology verification
g	Grams
gal	Gallons
gpm	Gallons per minute
h	Hour
K	Potassium
lb	Pounds
mg/L	Milligrams per liter
mL	Milliliters
mo	Month
MPN	Most probable number
N	Normal
NH_3	Ammonia nitrogen
NSF	NSF International
NRMRL	National Risk Management Research Laboratory
OP	Ortho phosphorus
QA	Quality assurance
QC	Quality control
rpm	Revolutions per minute
SAG	Stakeholder advisory group
sec	Seconds
SOP	Standard operating procedure
SWP	Source water protection area
TC	Total carbon
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TO	Testing organization
TOC	Total organic carbon
TS	Total solids
TSS	Total suspended solids
VO	Verification organization
VS	Volatile solids
VTP	Verification test plan
WQPC	Water Quality Protection Center
Zn	Zinc

Acknowledgments

The Testing Organization (TO) for this technology verification was North Carolina State University. The verification test was performed by a team of principal investigators led by John J. Classen and consisting of Frank J. Humenik, Jean Spooner, J. Mark Rice, Craig Baird, and Pedro Luna-Orea, of the Biological and Agricultural Engineering Department, and C.M. Williams and Leonard S. Bull of the Animal and Poultry Waste Management Center. This team was responsible for all elements in the testing sequence, including collection of samples, calibration and verification of instruments, sample analysis, data management, data interpretation and the preparation of this report. All correspondence should be directed to:

Dr. John J. Classen
179 Weaver Labs
North Carolina State University
Campus Box 7625
Raleigh, NC 27695-7625
919-515-6800
Email: john_classen@ncsu.edu

The laboratory that conducted the analytical work for this study was:

Environmental Analysis Laboratory
Biological and Agricultural Engineering Department
North Carolina State University
Campus Box 7625
Raleigh, NC 27695-7625
919-515-6766
Contact: Ms. Rachel Huie
Email: huie@eos.ncsu.edu

The principal investigators acknowledge Ms. Rachel Huie, Mr. Jerome Brewster, and Ms. Tracey Daly Whiteneck for their technical expertise and professionalism in performing the analytical work for this verification test. Mr. Mark Watkins and Mr. Carl Wissnet provided substantial support during set up and testing.

The manufacturer of the solids separation technology was:

Hoffland Environmental Inc.
303 Silver Spring Rd.
Conroe, TX 77303
Contact: Bob Hoffland, President
Voice: 936-856-4515
Fax: 936-856-4589

The principal investigators thank NSF International, especially Mr. Thomas Stevens, Project Manager, and Ms. Maren Roush, Project Coordinator, for providing guidance and program management.

Chapter 1
Project Description and Organization

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to further environmental protection by accelerating the commercialization of innovative environmental technologies through performance verification and dissemination of information. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; with stakeholder groups that consist of buyers, vendor organizations, consulting engineers, and regulators; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory test (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF), in cooperation with EPA, operates the ETV Water Quality Protection Center. This Center oversaw the verification testing of the Hoffland Environmental Inc. Separator, which is a drag screen and clarifier system designed to separate solids from liquid swine waste. The potential market for this equipment includes swine producers who could benefit from having suspended solids removed from the liquid manure stream. The separated solids represent a reduced organic and nutrient load to any subsequent liquid treatment system as well as a potential feedstock for value added products such as compost or soil amendments. The verification test did not address the performance of any procedure for processing the recovered solids.

1.2 Participant Roles and Responsibilities

Verification testing of the Hoffland Separator was a cooperative effort among the following parties:

Organization	Role in Verification Testing
NSF International	Verification organization
U.S. Environmental Protection Agency	Program sponsor and authority
North Carolina State University	Testing organization
Hoffland Environmental Inc.	Vendor
Technology Panel	Technical assistance and oversight

1.2.1 NSF International – Verification Organization

The ETV Water Quality Protection Center is administered through a cooperative agreement between EPA and NSF. NSF is the verification organization for the ETV Water Quality Protection Center.

For all technology verifications performed through the ETV Water Quality Protection Center, NSF's responsibilities as the verification organization include:

- Reviewing and commenting on the site-specific verification test plan (VTP).
- Coordinating with peer-reviewers to review and comment on the VTP.
- Coordinating with the EPA Project Officer and the technology vendor to approve the VTP prior to the initiation of verification testing.
- Reviewing and approving the quality systems of the testing organization (TO) prior to conducting any verification testing activities.
- Overseeing the technology evaluation and associated laboratory testing.
- Carrying out an on-site audit of test procedures.
- Overseeing the development of a verification report and verification statement.
- Coordinating with peer-reviewers to review and comment on the verification report and verification statement.
- Coordinating with EPA to approve the verification report and verification statement.
- Providing quality assurance/quality control (QA/QC) review and support for the TO.

Key contacts at NSF for the verification organization are:

Mr. Tom Stevens, Project Manager
NSF International
P.O. Box 130140
Ann Arbor, MI 48113-0140
v. 734-769-5347 f. 734-769-5195
email: stevenst@nsf.org

Ms. Maren Roush, Project Coordinator
NSF International
P.O. Box 130140
Ann Arbor, MI 48113-0140
v. 734-827-6821 f. 734-769-0109
email: mroush@nsf.org

1.2.2 Environmental Protection Agency – Program Sponsor and Authority

The EPA Office of Research and Development, through the Urban Watershed Management Branch, Water Supply and Water Resources Division, National Risk Management Research Laboratory (NRMRL), provides administrative, technical, and quality assurance guidance and oversight on all ETV Water Quality Protection Center activities. EPA reviews and approves each phase of the verification project. The EPA's responsibilities with respect to verification testing include but are not limited to:

- VTP review and approval;
- Verification report review and approval; and
- Verification statement review and approval.

The key EPA contact for the ETV Water Quality Protection Center is:

Mr. Ray Frederick, Project Officer, ETV Water Quality Protection Center
U.S. EPA, NRMRL, Water Supply and Water Resources Division
2890 Woodbridge Ave. (MS-104)
Edison, NJ 08837-3679
v. 732-321-6627 f. 732-321-6640
email: frederick.ray@epa.gov

1.2.3 North Carolina State University – Testing Organization

The Biological and Agricultural Engineering Department of North Carolina State University (NCSU) has been a leader in various aspects of animal waste management for many years. The department's Environmental Analysis Laboratory operates under Good Laboratory Practices in addition to an established QA/QC program. NCSU provided the location and infrastructure for the verification test. The principal investigators developed the VTP and put together a team to conduct the verification test according to the approved plan. The testing organization's responsibilities included:

- Coordinating with the verification organization and vendor relative to preparing and finalizing the VTP.
- Conducting the technology verification in accordance with the VTP, with oversight by the verification organization.
- Analyzing all influent, effluent, and recovered solid samples collected during the technology verification process in accordance with the procedures outlined in the VTP and attached standard operating procedures (SOPs).
- Coordinating with and reporting to the verification organization during the technology verification process.
- Providing analytical results of the technology verification to the verification organization.
- Documenting changes in plans for testing and analysis, and notifying the verification organization of any and all such changes before they were executed.

The main NCSU contacts for the technology verification were:

Dr. John J. Classen, Associate Professor
Biological and Agricultural Engineering
Campus Box 7625
Raleigh, NC 27695
v: 919-515-6800 f: 919-515-7760
email: john_classen@ncsu.edu

Dr. Frank J. Humenik, Coordinator
Animal Waste Management Programs
Campus Box 7927
Raleigh, NC 27695
v: 919-515-6767 f: 919-513-1023
email: frank_humenik@ncsu.edu

Dr. C. M. (Mike) Williams, Director
Animal and Poultry Waste Mgmt. Center
Campus Box 7608
Raleigh, NC 27695
v: 919-515-5386 f: 919-513-1762
email: mike_williams@ncsu.edu

Mr. J. Mark Rice
Biological and Agricultural Engineering
Campus Box 7927
Raleigh, NC 27695
v: 919-515-6794 f: 919-513-1023
email: mark_rice@ncsu.edu

1.2.4 Hoffland Environmental Inc. – Vendor

Hoffland Environmental Inc. (Hoffland Environmental) was responsible for providing the equipment to be verified under the test program and for supporting the testing organization by ensuring the equipment was properly installed and operated during the verification test. Hoffland Environmental's specific responsibilities included:

- Assisting in the preparation of the VTP for technology verification and approving the final version of the VTP.
- Providing a complete field-ready version of the technology of the selected capacity for verification and assisting the testing organization with installation at the test site.
- Providing start-up services and technical support as required during the period prior to the evaluation.
- Providing technical assistance to the testing organization during operation and monitoring of the equipment undergoing verification testing, as requested.
- Removing equipment associated with the technology following the technology verification.
- Providing funding for verification testing.

The contact for this project at Hoffland Environmental was:

Mr. Robert O. Hoffland, President
Hoffland Environmental, Inc.
303 Silver Spring Rd
Conroe, TX 77303
v: 936-856-4515 f: 936-856-4589
rh@hoffland.net

1.2.5 Technology Panel

The ETV Animal Waste Treatment Technology Panel assisted with the development of the generic *Test Plan for the Verification of Technologies for Separation of Manure Solids from Flushed Swine Waste*. In developing the generic test plan, the Technology Panel ensured that data to be generated during verification testing would be relevant and that the method of evaluation for different technologies would be fair and consistent. A list of the Technology Panel participants is available from the ETV Water Quality Protection Center.

1.3 Description of Environmental Problem

Animal production is an important component of U.S. agriculture. Wherever there are animals, there is manure and the possibility of ground or surface water contamination. Because different animal species are raised in vastly different ways, there are different approaches to preventing water contamination for each species.

1.3.1 Swine Waste Collection and Treatment

Swine production has recently received heightened attention in North Carolina and nationally because of the industry's growth and the associated problems with the waste. Swine waste is handled differently in different parts of the country, depending on the goals and needs of the individual producer.

In the midwest, swine waste is valued for its nitrogen and phosphorus. The goal of producers in this region is to store the manure in concentrated form and preserve nutrients until it can be applied to cropland, usually to cornfields. Waste collection systems at these facilities typically employ slurry systems that use no added water.

In the southeast, swine farms are often on smaller tracts of land that cannot utilize the available nutrients for corn production. These areas typically utilize water wash systems and anaerobic lagoon treatment to improve the air quality in the production houses and reduce odor generated during storage. These systems produce a dilute wastewater compared to the slurry systems. Wastewater for these systems may range between 0.5 percent and 2 percent suspended solids. Compared to domestic wastewater, however, this is a high solids waste. While some of the solid material is inert, a large portion contains significant organic carbon that exerts an additional load on the waste treatment system over and above the dissolved organic matter.

Several problems are associated with treating suspended solids in the wastewater. The organic load from the solids requires a larger treatment system (lagoon), first to break down the suspended material to soluble components, and then to treat the added organic matter. Another problem is that some suspended material that settles in the bottom of the system remains there for long periods of time and requires additional capacity in the treatment system. Finally, the suspended solids that are treated also represent lost resources that could have been put to beneficial use. The particular use depends on the amount of solids that can be recovered and the characteristics of those solids.

1.3.2 Current Solids Removal Systems

When solids separation has been desired as part of a swine waste treatment system, settling basins have typically been employed. Although these systems can reduce the amount of suspended solids entering the treatment system, they require time and attention to keep them operating free of odors and fly problems. Vendors selling solids separation technologies have approached swine producers, but the producers are often unwilling to purchase a system without knowing how well the equipment operates.

1.4 Test Site Description

Verification testing was conducted at NCSU's Lake Wheeler Road Field Laboratory Swine Educational Unit. This farm is designed and operated as a research and teaching facility. The farm capacity is 250 sows for farrow to wean (birth to wean). The farm can finish (grow to market weight of 250 lb) approximately half of the pigs weaned each year. Under normal operating conditions, waste at the site is removed by flushing under-slat pits with treated wastewater from the on-site lagoon. Flushed waste then flows to the anaerobic lagoon for treatment. This is a common method of waste management in the southeast.

During the verification test, the flushed waste was diverted to a 2,500 gal glass-lined influent mixing tank of 12-ft diameter and 10-ft depth. To minimize aeration and physical changes to the wastewater, the influent mixing tank was equipped with a 5-hp mixer with a 2-ft diameter impeller, designed to keep solids suspended with minimum turbulence. According to the design of the testing facility, wastewater from the influent mixing tank could be sent to the lagoon or to the pumping system. During the verification test, wastewater was pumped from the influent mixing tank to the Hoffland Separator using a variable frequency pump. Once treated, effluent from the unit was collected in an effluent tank for sampling and quantification. Valves in the influent mixing and effluent tanks provided additional means for circulating the wastewater to ensure that it was well mixed. All final effluent from the effluent tank was discharged to the lagoon. Figure 1-1 is a schematic diagram of the testing facility.

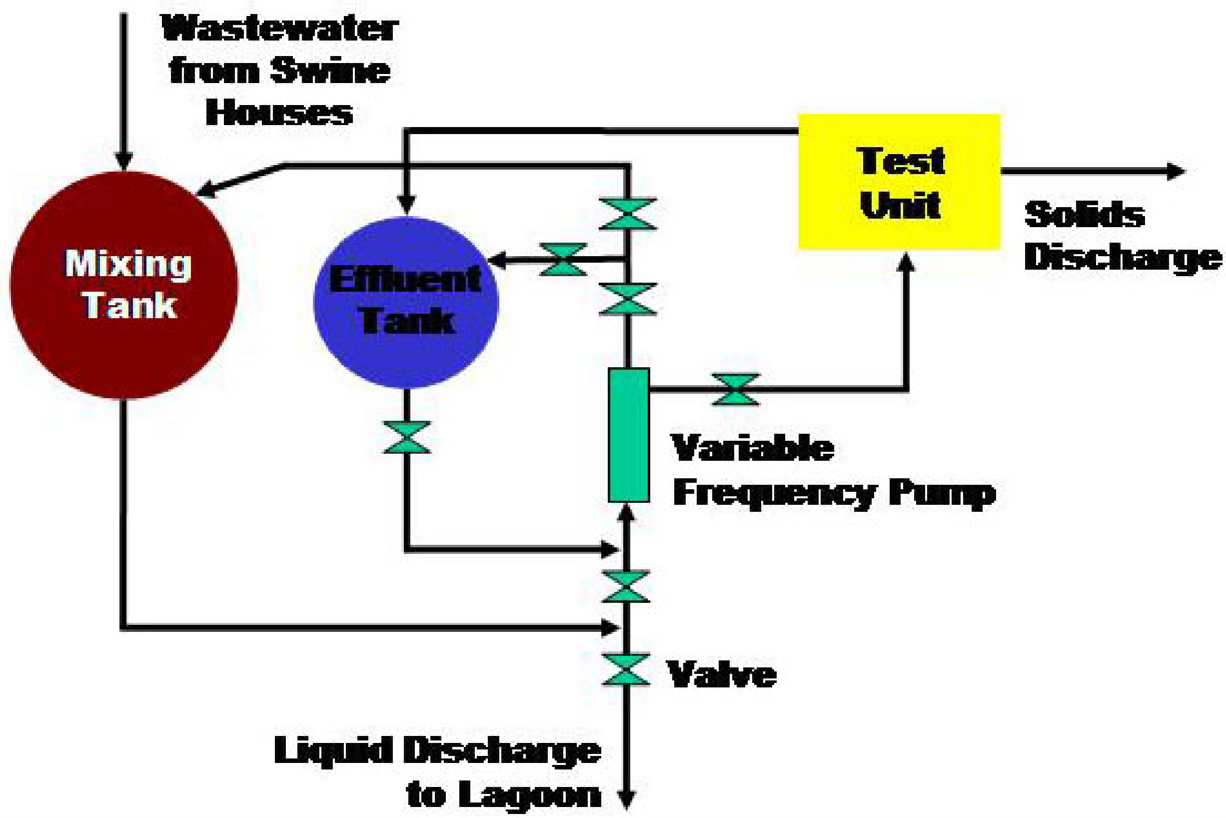

Figure 1-1. Test site schematic for NCSU's Lake Wheeler Road Field Laboratory.

An all-in/all-out closed loop process was developed to minimize problems and errors associated with flow measurement and sampling. All of the waste generated over a two-day period was left in the under-slat pits until it was flushed and collected in the influent mixing tank. This wastewater was pumped from the influent mixing tank to the test unit. Effluent from the test unit was collected in the effluent tank, and the separated solids were collected on the adjacent concrete pad.

Chapter 2
Technology Capabilities and Description

2.1 Equipment Description and Vendor Claims

The Hoffland Separator is designed to remove suspended solids from flushed swine waste and other animal waste slurries (Figures 2-1 and 2-2). The Hoffland Separator can process an average of 40 gpm with peak flow of twice the average flow for up to 10 minutes. The Hoffland Separator returns an effluent with less organic content, reduces subsequent wastewater treatment capacity requirements, and provides a solid material that can be used as fertilizer/soil amendment. The verification test was conducted at a nominal flow rate of 35 gpm.

The following is a summary of the characteristics of the Hoffland Separator:

Type	Inclined drag screen; bottom feed; gravity clarifier
Screen Size	32 in x 120 in
Screen Perforation	0.09 in
Clarifier Diameter	120 in
Clarifier Depth	191 in
Average Capacity	40 gallons per minute

The Hoffland Separator is designed to remove the suspended solids fraction from the waste stream. As such, it cannot reduce soluble constituents in the wastewater. The actual removal efficiency for specific constituents during the test period was dependent on the ratio of soluble to non-soluble forms of those constituents in the influent.

2.2 Basic Operation of the Equipment

The Hoffland Separator consists of an inclined perforated metal screen with a motorized drag conveyor to which incoming wastewater flows, an integral wastewater collection tank that collects and recycles the liquid that passes through the screen, and a solids concentrator (clarifier) that receives input from the wastewater collection tank. The inclined screen removes large solids from the wastewater. Liquid and fine solids that pass through the screen are collected in the wastewater collection tank. Solids are dragged off the top of the screen into suitable containers. Wastewater is pumped from the bottom of the wastewater collection tank to the solids concentrator through a two-inch diameter PVC pipe, entering the tank in a central stilling well 30 inches below the effluent weir. Because the stilling well extends below the wastewater entrance point and above the effluent weir, wastewater must move down approximately three feet before rising to the discharge point. The momentum of the liquid is reduced in the clarifier and the flow becomes non-turbulent, allowing solids to settle and thicken. Thickened solids are moved to the center of the solids concentrator by a sludge rake and flow by gravity from the bottom of the solids concentrator through a six-inch PVC pipe and underflow control valve to the screen tank so they are added to the influent stream and are processed by the drag screen. A rubber skimmer (Figure 2-3) that rotates with the sludge rake moves floating solids and scum in the concentrator into a collection box at the top of the unit and out through a four inch pipe connected to the underflow pipe (Figure 2-4). All liquid effluent leaves the treatment system through the overflow weir at the top of the clarifier. Floating solids are prevented from getting to the effluent weir by a baffle approximately two inches inside the effluent weir (Figure 2-5). Containers for recovered solids and clarified liquid were also used to evaluate the system. The electrical configuration for the Hoffland Separator can be adapted to what is needed in a particular installation. The system was installed at the test site utilizing 240V single-phase power.

Figure 2-1. Hoffland Environmental Inc. clarifier.

Figure 2-2. Hoffland Environmental Inc. inclined screen.

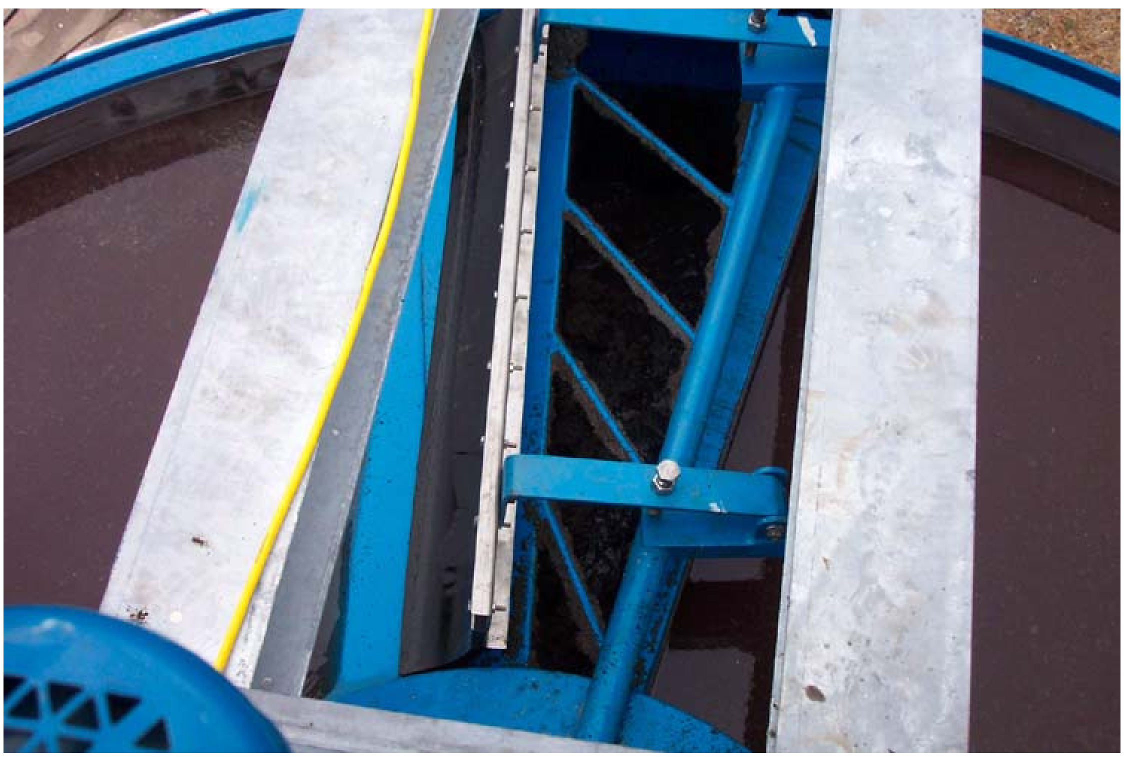

Figure 2-3. Floating solids skimmer box.

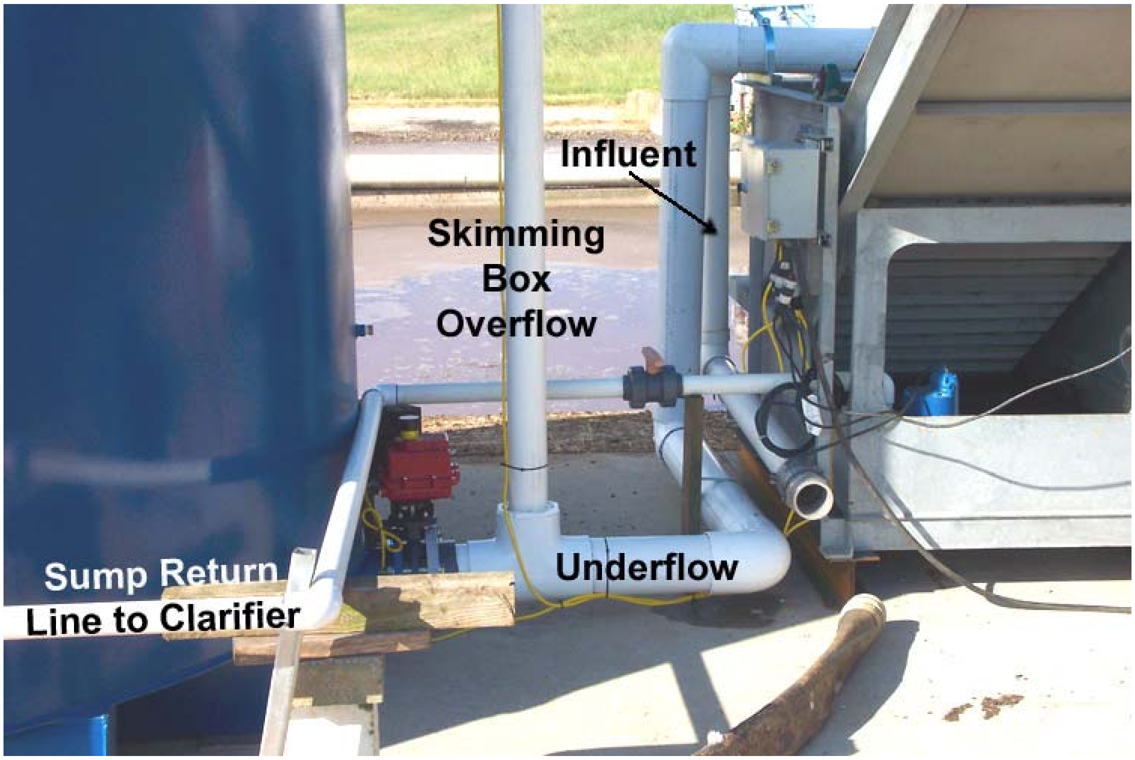

Figure 2-4. Hoffland Separator plumbing detail.

Figure 2-5. Effluent weir and baffle.

Chapter 3
Verification Procedures and Methods

3.1 Verification Objectives

Although the primary purpose of a solids separator is to recover and remove solid material, use of this equipment has an impact on the entire waste management system of a farm. Therefore, it is necessary to quantify the effect this equipment has on the partitioning of other waste constituents of interest such as nitrogen, phosphorus, potassium, copper, zinc, and pathogen indicators. Technical professionals need this information to determine the value of the separated material and to design subsequent waste treatment and land application operations. Qualitative operation and maintenance requirements of the solids separator are also important to individuals responsible for putting equipment like this into service. Operation and maintenance parameters measured during the testing included ease of cleaning, frequency of operational problems during testing, and extent of required operator oversight. Because the test period lasted only four weeks, the verification process did not indicate what long term operational problems would be likely to occur for the technology. Power consumption was verified as an important component of equipment performance.

In summary, the key objectives of the verification test were to:

1. Determine the separation efficiency of the Hoffland Separator with regard to the mass of suspended solids.
2. Characterize the separated solids and resulting liquid stream with respect to nutrients, metals, and pathogen indicators.
3. Gather qualitative information about the operation and maintenance requirements of the system.

To meet these objectives, a VTP was prepared and approved for verification of the Hoffland Separator, and is attached to this report as Appendix A. This VTP detailed the procedures and analytical methods to be used to perform the verification test. It included tasks designed to verify the performance of the solids separation system with respect to the partitioning of solids and other waste constituents. In addition, the VTP was designed to obtain information on the installation, operation, and maintenance requirements of the system. Verification consisted of two distinct phases: (1) installation and start up of the system and (2) verification testing of the operational system.

Each of the testing elements performed during the technology verification is described in the following sections. In addition to a description of equipment installation, equipment operation, and sample collection methods, this chapter describes the analytical protocols used. Quality assurance and quality control procedures along with details related to data management and calculations are discussed in detail in the VTP.

3.2 Installation Procedures

The Hoffland Separator arrived at the Lake Wheeler Road Field Laboratory Swine Educational Unit on September 5, 2003. Plumbing and electricity were connected and on September 15th, the unit was started for shakedown testing. Shakedown testing continued through September 25th, while the vendor adjusted the operating conditions and final adjustments were made to control the flow rate at 35 gallons per minute.

3.3 Verification Testing Procedures

The test period for verification of the Hoffland Separator was 40 days. Sampling and evaluation procedures were carried out three days per week (Monday, Wednesday, and Friday) for four weeks of valid operation. "Valid operation" means that procedures and equipment were operating correctly (pumps working, hoses intact, waste flowing) but is not an indication of technology performance. A total of twelve sets of triplicate samples of influent, effluent, and solids were collected, one set on each of the twelve sampling days during the verification period. There were several delays due to problems at the farm site. On October 6th, a pipe supplying flush water to the swine barns broke, postponing the verification test on that day. Investigation into the cause of that break found additional plumbing problems that caused the flush system to shut down from October 10th to October 13th; regular verification testing resumed on October 15th. Another pipe break on October 22nd caused the system to shut down again until October 27th. Testing resumed two days later and was completed without further problems. For safety considerations, at least two NCSU personnel were present during each testing operation.

3.3.1 Daily Operation

At the end of the set up period, prior to the beginning of verification testing, the contents of the clarifier were sampled after opening the underflow control valve until the consistency of the material exiting the clarifier changed from sludge to wastewater. Analysis of these samples along with the volume of sludge measured enabled calculation of the mass of material that was in the clarifier at the start of testing.

Daily operation of the verification test was consistent to the greatest extent possible. Testing took place in the morning hours to ensure that samples were transferred to the lab for timely processing.

Wastewater from the swine unit was collected in the influent mixing tank. Floating solids larger than 9/16th inches were excluded with an expanded metal screen because they are characteristic of sow farms rather than finishing farms, which are the source of most of the flushed swine waste in production systems. After the influent-mixing tank was filled, the depth of wastewater was measured. A quiescent surface is necessary for accurate measurement of depth, so the mixing impeller was not started until after the tank was full and the depth was measured. The impeller is able to keep solid material suspended in the liquid but is not able to re-suspend particles that settled during the filling and depth measurement. To re-suspend solids, the wastewater was circulated by the variable frequency pump from the influent mixing tank through the pipes and back to the influent mixing tank for at least five minutes (Figure 1-1). Wastewater was typically held in the mixing tank for less than five minutes while mixed with the impeller, but never more than thirty minutes prior to being pumped to the inclined screen. Wastewater was pumped to the Hoffland Separator inclined screen at a nominal flow rate of 35 gallons per minute.

The wastewater level in the screen tank of the Hoffland Separator increased as wastewater flowed through the screen. The sump pump that transferred liquid to the clarifier was in constant operation as long as the system was in operation. Daily operation included opening the underflow control valve for 10-15 seconds every 1.5 minutes for 15 minutes to remove thickened solids from the clarifier and avoid decomposition, rising solids, and gas formation. The drag screen operation continued until as much material as possible was removed over the screen or was pumped back to the clarifier.

Measurements made each test day included volume of wastewater entering the unit, volume of the effluent stream, weight of solids recovered from the unit, and concentrations of quality parameters in each of the sampled components. The influent and effluent volumes were determined based on the waste depths and dimensions of each tank. The weight of the solids was determined as the difference in the weight of large containers with and without the solids. Weights were measured at the testing location using appropriate scales. Concentrations of the quality parameters were determined by laboratory analysis of grab samples collected in triplicate. Table 3-1 lists the constituents that were measured in the influent, effluent, and recovered solids samples. It also lists the analytical methods and preservation/holding times for each parameter.

At the conclusion of the verification test period, the contents of the clarifier were transferred to the influent mixing tank in several batches where the volume could be measured and the material sampled. The samples were analyzed for the same quality parameters as the rest of the liquid samples and provided a measure of the material that was in the clarifier at the end of testing. The difference between the material in the clarifier at the end and at the beginning of testing was included in the mass balance calculations.

Table 3-1. Quality Parameters and Analytical Methods

Parameter	Liquid Method Reference[1]	Solid Method Reference[1]	Preservative	Holding Time
Total solids/ moisture content	EPA 160.3	EPA 160.3	Refrigerate	7 d
Suspended solids	EPA 160.2		Refrigerate	7 d
Volatile solids	EPA 160.4	EPA 160.4	Refrigerate	7 d
E. coli [2]	SM 9223 B	SM 9223 B	None	30 h
Conductivity	SM 2510		None	None
Total organic carbon	SM 5310 B		H_2SO_4 to pH<2	7 d
Total carbon		AOAC 990.03	Refrigerate	7 d
Total nitrogen		AOAC 973.47	Refrigerate	7 d
pH	EPA 150.1	EPA 150.1	None	2 h
Ammonia nitrogen	SM 4500-NH_3 G	Methods of Soil Analysis (1982) 84-2 as modified[3]	Refrigerate	7 d
Chloride	SM 4500-Cl^- E	Methods of Soil Analysis (1982) 84-2 as modified[3]	None	28 d
Total Kjeldahl nitrogen	EPA 351.2		Refrigerate	7 d
Total phosphorus	SM 4500-P BC	Digestion per Soil Sci. Soc. Amer. Proc., V37, 1973. Analysis as liquid	Refrigerate	48 h
Ortho phosphorus	SM 4500-P F	Methods of Soil Analysis (1982) 78-4.2.1[4]	Refrigerate	48 h
Copper	SM 3111 B	Methods of Soil Analysis (1982) 78-4.2.1[4]	HNO_3 to pH<2	6 mo
Zinc	SM 3111 B	Methods of Soil Analysis (1982) 78-4.2.1[4]	HNO_3 to pH<2	6 mo
Potassium	SM 3111 B	Methods of Soil Analysis (1982) 78-4.2.1[4]	HNO_3 to pH<2	6 mo
Bulk density		Methods of Soil Analysis (1982) 30-2.1	None	None

[1] EPA: *EPA Methods and Guidance for the Analysis of Water* procedures; SM: *Standard Methods for the Examination of Water and Wastewater (19th edition)* procedures; AOAC: Association of Official Analytical Chemists procedures

[2] Although not required according to the *ETV Test Plan for the Verification of Technologies for Separation of Manure Solids from Flushed Swine Waste*, MPN values for total coliform bacteria were also calculated when analyzing samples for *E. coli* using SM 9223B.

[3] The extraction for ammonia, nitrite, and nitrate with 1.0 N KCl was modified to use 1.25 N K_2SO_4. This allowed for the analysis of chloride in the same extract according to the liquid method.

[4] This method was modified according to North Carolina Department of Agriculture Methods. The extract was then analyzed according to the liquid method.

3.3.2 Sampling Methods

Triplicate samples from the influent mixing tank were taken just prior to pumping the influent to the Hoffland Separator. Figure 3-1 shows the influent mixing tank and wastewater just before the filling operation was complete. After processing the wastewater through the Hoffland Separator, the liquid effluent was mixed for ten minutes by pumping it through an internal recycle loop and triplicate samples were taken for analysis.

Influent and effluent samples were taken using separate sampling containers of at least 500 mL capacity suspended on a pole approximately two feet below the wastewater surface. Replicate samples were collected from roughly the same location in the tank. The samples were transferred immediately to labeled plastic sample bottles provided by the Environmental Analysis Laboratory. Duplicate analyses for QA/QC purposes were taken from the same sample bottle at the laboratory, by laboratory staff.

Representative samples from the recovered solids were produced by dividing the material into quarter sections and mixing alternate sections. This process was repeated at least three times during at least five minutes of mixing. After the third test, this procedure was modified because of higher moisture content of the separated solids. The fluid consistency of the separated solids required that the mixing take place in the collection tank rather than on the concrete pad. Triplicate samples of at least 50 g each were taken with a shovel, one from each of three different locations within the stacked solids. Each replicate was analyzed as an independent sample and the results were averaged.

Figure 3-1. Mixing tank receiving wastewater influent.

All samples were iced and transported to the Environmental Analysis Laboratory by NCSU staff within one hour after the last sample of a day's test had been collected. For the standard parameters listed in Table 3-1, no preservation methods except refrigeration are necessary if sample analyses commence within twenty-four hours of sample collection (with the exception of analyses performed on-site). All samples were processed within their holding times. Unused samples were held in refrigerated storage in the Environmental Analysis Laboratory until the laboratory manager completed the QA/QC checks. All analyses met QA/QC standards so none of the samples had to be reanalyzed.

Each sample container was labeled with the vendor name, sample location, date, time, replicate number, and name/initials of the person who collected the sample. Daily sampling records were also maintained, recording sample location, date and time of sampling, replicate number, type of sample (influent, effluent, or solids), and name/initials of the person collecting the sample. Sampling records were forwarded to the verification organization at the completion of testing. Field logbook entries are included as Appendix D.

3.3.3 Analytical Protocols

The Environmental Analysis Laboratory of the Biological and Agricultural Engineering Department at NCSU performed all analyses except pH and measurement of the recovered solids mass, which were performed at the test site. Analytical methods used were those methods routinely used by the laboratory. These procedures are based on EPA-approved methods and methods detailed in *Standard Methods for the Examination of Water and Wastewater, 19th edition* (Standard Methods), as modified by the laboratory to accommodate differences in solids content and flow characteristics between water and animal wastewater. The methods are referenced in Table 3-1. Detailed operating procedures are maintained by the testing organization and are included as Appendix B.

The analytical methods employed by the Environmental Analysis Laboratory differ from EPA-approved methods and Standard Methods only in the sizes of some pump tubes and dialyzer, and, in the case of TKN, a reduction in the amount of HgO (from 8g to 1g) used to prevent coating of the autoanalyzer flow cells. Determination of bulk density of separated manure solids differed from that of soil in that the manure solids were not dried at 105°C; the bulk density was determined as is. A plastic 50 mL beaker with the top cut down to the 50 mL marker was filled to the top with the separated solids without packing and then leveled. The total weight was recorded. The tare weight of the beaker was subtracted from the total weight and the result was divided by 50 mL. The determination was made three times per sample and the average recorded. Results are expressed as g/mL.

Chapter 4
Verification Test Results

The laboratory analyses provided concentrations of each parameter of interest, and the field measurements allowed for the calculation of total flow and total mass for the different components in the influent and effluent. The design and operation of the Hoffland Separator did not allow for measurement and sampling of the thickened waste on a daily basis, as explained in Chapter 3. Subsequently, an overall mass balance for the entire test period was performed. The mean concentration of each parameter in each component of the waste stream was determined by considering the results of the entire four-week test. Equation (4-1) shows the calculation for the mean concentration of parameters in the daily-recovered solids, while equation (4-2) shows the calculation for the two liquid phases (influent and effluent).

$$\overline{C}_i = \frac{\sum_{d=1}^{12}\left(M_d \times C_{i,d}\right)}{\sum_{d=1}^{12} M_d} \tag{4-1}$$

$$\overline{C}_{i,j} = \frac{\sum_{d=1}^{12}\left(V_{j,d} \times C_{i,j,d}\right)}{\sum_{d=1}^{12} V_{j,d}} \tag{4-2}$$

Where:

$\overline{C}_i$ = average concentration of parameter i in solids

$\overline{C}_{i,j}$ = average concentration of parameter i in component j

$C_{i,j,d}$ = concentration of i in j on day d

M_d = mass of solids recovered on day d

$V_{j,d}$ = volume of j on day d

parameter i = N, P, K, ...

component j = influent, effluent

The total mass was also used in calculations of mass removal and parameter concentration in the recovered solids and liquid effluent. Again, the mass removal values for the recovered solids and liquid effluent were calculated using the combined data from all tests rather than using the data from each day of testing separately, as shown in equations (4-3) and (4-4) for solids and liquids, respectively.

$$R_{solids,i} = \frac{\text{total mass of parameter } i \text{ recovered in solids}}{\text{total mass of parameter } i \text{ in influent}} \times 100\% \qquad (4\text{-}3)$$

$$R_{liquid\ effluent,i} = \frac{\text{total mass of parameter } i \text{ recovered in liquid effluent}}{\text{total mass of parameter } i \text{ in influent}} \times 100\% \qquad (4\text{-}4)$$

Where:
R = Percent recovery of parameter *i* in solids or liquid effluent, mass basis

These mass balance calculations were carried out for the following parameters: total solids/dry matter, suspended solids, total nitrogen, total phosphorus, potassium, copper, zinc, and chloride. Other quality parameters were measured that are not appropriate for mass balance analysis but are important for the characterization of the recovered solids and liquid effluent.

The following sections discuss the performance of the Hoffland Separator in terms of mass removal and final concentrations of the various quality parameters, as well as the results of the pathogen indicator tests. Operational notes taken during the verification test are also presented. The overall performance of the laboratory and experimental site are discussed in Chapter 5.

4.1 Mass Balance Results and Characterization

The mass balance approach allowed for the determination of the proportion and mass of the recovered solids and how the nutrients partitioned between the solid and liquid phases. These results are shown in Table 4-1. For each parameter of interest, the total mass recovered from the separator (in the effluent and recovered solids) is shown in Table 4-1 as a percent of the mass in the influent. The difference between the mass in the clarifier at the end of the test and at the beginning of the test is shown in Table 4-1 as the percent of the influent found in the clarifier liquid. As shown in Table 4-1, 29 percent of the mass of suspended solids in the influent was found in the effluent stream of the Hoffland Separator. Overall, the suspended solids *concentration* in the Hoffland Separator effluent was 30.5 percent of the *concentration* of suspended solids in the influent.

Table 4-1. Partitioning and Recovery of Parameters in Influent

Parameter	Percent Found In: Recovered Solids	Liquid Effluent	Clarifier Liquid	Total (Solids, Effluent, Clarifier)
Total Solids	9.7	46	24	79
Dry Matter	12			
Suspended Solids		29	26	67
Total Nitrogen	5.2	67	22	94
Total Phosphorus	5.6	62	23	90
Potassium	0.37	85	12	97
Copper	4.5	37	38	80
Zinc	6.0	44	45	95
Chloride	0.69	87	8	95

Nutrients and metals were recovered in different proportions in the recovered solids and liquid effluent from the Hoffland Separator, as shown in Table 4-1. The majority of all nutrients and metals was found either in the liquid effluent or remained in the clarifier liquid, while only a small proportion was recovered in the solids. The recoveries from the mass balance are ideally within ± 10 percent of 100 for this type of work, although recoveries outside of this range are common due to the complex nature of both the wastewater and separated solids. The data quality indicators for this verification test were all within established limits. Because of this, nothing can or should be inferred from total recoveries not equal to 100 percent for the mass balance.

4.1.1 Characterization of Liquids and Solids

The characteristics of both the liquid effluent and the recovered solids are important for the planning, design, and operation of further treatment or utilization operations. The characteristics of the liquid effluent and the recovered solids are shown in Tables 4-2 and 4-3, respectively. The average influent suspended solids concentration was 0.869 percent (8,690 mg/L). Over the entire test period, 273 lb of solids weighed on a dry basis were recovered by the Hoffland Separator, representing 12 percent of the 2,310 lb of suspended solids in the influent. The recovered solids contained 13.4 percent dry matter (the solids contained 86.6 percent moisture). Effluent from the Hoffland Separator contained 29 percent of the influent suspended solids as measured on a mass basis. Even though 26 percent of the suspended solids remained in the clarifier at the end of the verification period, only a total of 67 percent of the suspended solids were found.

An important measurement is the ratio of nitrogen, phosphorus, and potassium (N:P:K ratio). The N:P:K ratio of the effluent was slightly higher than that of the influent in both nitrogen and potassium. The N:P:K ratio of the solids (Table 4-3) showed that nitrogen was substantially greater than phosphorus and there was very little potassium.

Table 4-2. Liquid Characteristics

Parameter	Units	Influent	Effluent	Clarifier
Total solids	mg/L	10,600	5,100	11,200
Volatile solids	mg/L	7,490	3,030	8,030
Suspended solids	mg/L	8,690	2,650	9,160
Total organic carbon	mg/L	1,590	1,250	2,020
Total Kjeldahl nitrogen	mg/L	799	561	860
Ammonia nitrogen	mg/L	347	388	410
Total phosphorus	mg/L	297	192	349
Ortho phosphorus	mg/L	140	142	205
Potassium	mg/L	383	341	384
Chloride	mg/L	240	219	210
Copper	mg/L	5.23	2.02	7.54
Zinc	mg/L	7.58	3.47	13.6
N:P:K ratio		2.7:1:1.3	2.9:1:1.8	2.5:1:1.1
pH		7.49	7.04	
Conductivity	µmhos/cm	4,061	4,072	4,033

Table 4-3. Recovered Solids Characteristics

Parameter	Units	Concentration
Dry matter	percent by weight	13.4
Volatile solids	percent by weight	11.5
Total carbon	percent by weight	1.68
Total nitrogen	percent by weight	0.54
Total phosphorus	µg/g	2,180
Potassium	µg/g	185
Chloride	µg/g	216
Copper	µg/g	30.7
Zinc	µg/g	59.3
Bulk density	g/mL	0.997
N:P:K ratio		2.5:1:0.1

4.1.2 Evaluation of System Steady State

The duration of this ETV test was selected as a balance between the cost in time and money of a robust evaluation over a long time period and the limited usefulness of information obtained from operating a system on a single day. One of the assumptions upon which this selection was based is that the system performance will not change appreciably over the course of the evaluation and that there is no systematic change that occurs during that time. The VTP for evaluation of the Hoffland Separator included provisions to quantify the contents of the clarifier at the beginning and at the end of the test period to account for any accumulation of material in the system and to document changes in concentration.

As indicated in section 4.1.1 above, 26 percent of the influent suspended solids were found in the clarifier at the end of the verification period. The average concentration of suspended solids in the clarifier at the conclusion of the test was 9,160 mg/L while at the beginning of the test, the concentration was only 850 mg/L. Figures 4-1 and 4-2 show the influent and effluent concentrations of suspended solids and potassium, respectively, over the course of the evaluation and serve to point out two important points about the system.

First, the effluent concentration generally increased throughout the verification period. This was generally true for all quality parameters (data not shown). The twelve test days over the nominal four-week test period seems to be inadequate for the clarifier to reach steady state. It is not possible to predict from the data collected how much time the clarifier needs to reach steady state nor what the steady state effluent concentrations might be.

The second important point that can be made about Figures 4-1 and 4-2 is that the influent concentration is much more variable than the effluent concentration and can be lower than the effluent concentration. For example, the difference between the suspended solids concentration in the influent and the effluent became small on October 29th when the influent concentration dropped significantly but the effluent concentration did not (Figure 4-1). This is because the influent is collected from different houses on different days, depending on the operation of the farm and the number of pigs in the various houses on any given day. This time period coincides with the plumbing problems described earlier so differences in the waste characteristics are not surprising. The effluent concentration, however, is influenced to a large degree by the contents of the clarifier, which does not change drastically from one day to the next. Obviously the contents of the clarifier are also influenced by the influent to the system. From Figure 4-2, influent and effluent concentrations of potassium, one can see the delay in how the effluent concentration responds to influent concentration. The influent concentration of potassium dropped on October 29th and rose on each of the following test days while the effluent concentration of potassium actually rose on October 29th, dropped on subsequent days in response to the drop in influent concentration, and then rose again on the last test day.

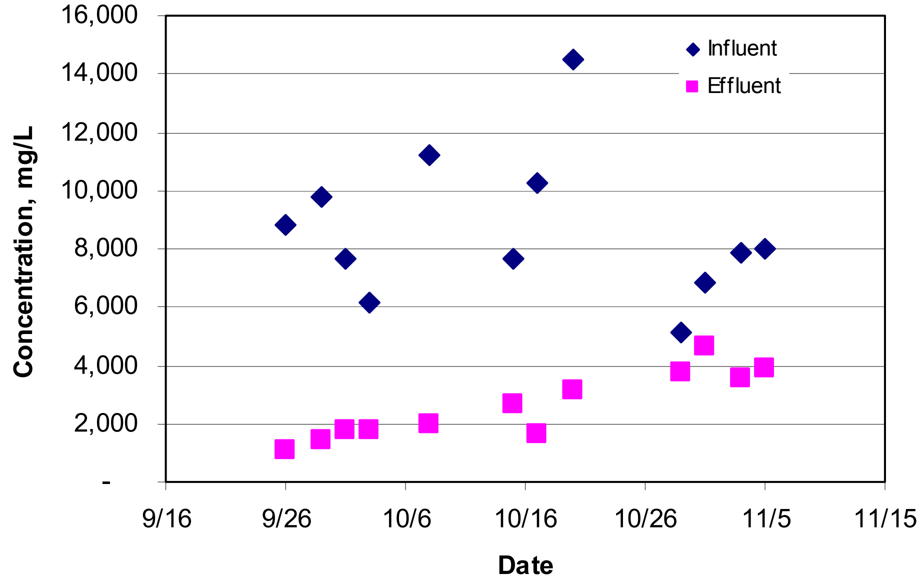

Figure 4-1. Suspended solids concentration through the course of the verification test.

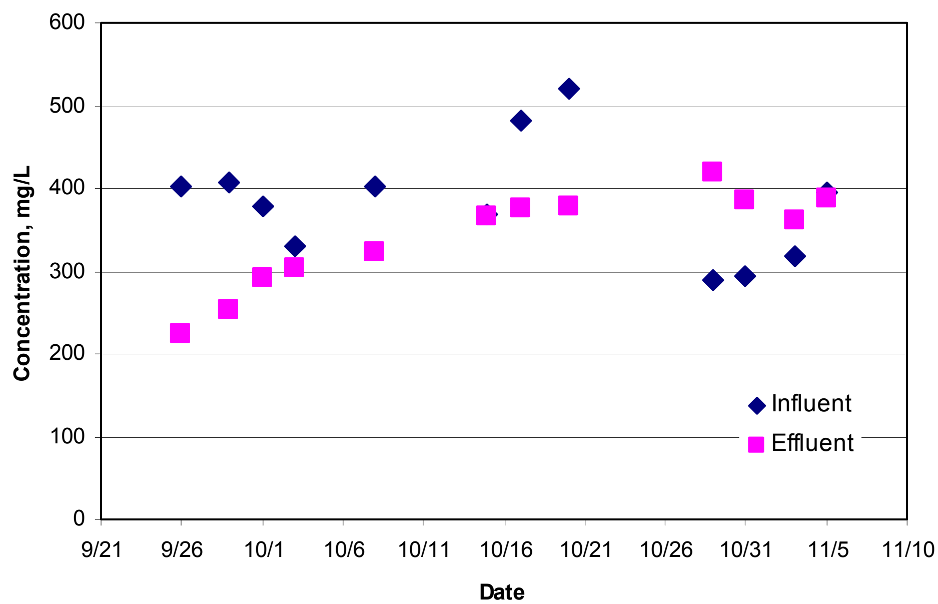

Figure 4-2. Potassium concentration through the course of the verification test.

4.2 Results of Pathogen Indicator Tests

Samples were tested for total coliform bacteria and *E. coli* once per week during the test using the most probable number (MPN) technique. This technique gives a statistical representation of the organisms that are present in a sample, not an analytical result that could be used as an exact count or mass. As such, the mass balance approach of this verification test does not extend to the results of the pathogen indicator tests. The results shown in Table 4-4 are, therefore, simple means of the MPN results from analyses of influent, effluent, and solids samples. The clarifier liquid measured at the end of the verification test was not analyzed for pathogen indicators.

Table 4-4. Pathogen Indicator Test Results

	Influent (MPN/100 mL)	**Effluent** (MPN/100 mL)	**Solids** (MPN/g)
Total coliform bacteria	8.8×10^7	1.3×10^7	5.3×10^7
E. coli	5.9×10^7	1.0×10^7	3.9×10^7

It is important to note the different units used for the liquid and solid samples. The results are consistent in that the total coliform values are greater than the *E. coli* values. The results indicate that all of the material has significant numbers of pathogen indicators.

4.3 Operation and Maintenance

4.3.1 Field Notes on Operation and Maintenance Requirements

The three day per week testing procedure seems to have impacted the Hoffland Separator by allowing time for the material in the clarifier unit to decompose. This decomposition is believed to have produced gas, causing some of the settled solids to float to the surface. Some of this material was simply removed by the skimmer but as early as the third test day on October 1st, some material also floated up between the baffle and the effluent weir. By the fifth test day on October 8th, the solids were thick enough to clog some of the individual weir outlets (Figure 4-3). This material was washed with a hose and scraped away from the weir outlets that could be reached from the catwalk atop the clarifier. Material removed during the cleaning operation was collected in the effluent tank and included in the mass balance. The system operation was changed slightly to address this issue by allowing the sludge rake and skimmer to run continuously. The cleaning procedure had to be repeated three times during the course of the verification.

Figure 4-3. Floating solids block effluent weir.

4.3.2 Operation and Maintenance Manual Evaluation

A manual was provided to NCSU and NSF in MS Word format when the Hoffland Separator was submitted for verification testing. This document provided a description of the solids separation process employed by the Hoffland Separator and outlined the necessary steps for installation and basic operation of the unit. Sections describing routine maintenance requirements and corrective actions for upset conditions would make useful additions to the existing document.

4.4 Power Requirements

The standard electrical installation of the Hoffland Separator is 240 V, single-phase power, capable of operating the two electric motors (totaling five hp). Units for installation with three-phase power and voltages up to 575 V are available. All motors associated with the Hoffland Separator are wired to the main connection box. Electrical installation consisted of supplying power to the unit and making the appropriate connections at the unit's control panel.

An Extech, Model 380940 clamp-on power data logger measured current and voltage and calculated values of kilowatts, which were recorded every ten seconds. These power data are summarized in Table 4-5. Peak power consumption usually occurs when motors are first started, either at the beginning of the test or after a pause in motor operation as indicated by a drop in power consumption. The mean peak power consumption during the verification test was 1.41 kW. The overall mean power consumption during operation was only 0.96 kW. The value of specific energy use, energy per unit volume treated, was calculated for each day. The mean value of specific energy use was calculated from the total energy used and the total volume sent to the unit over the 12 test days. During the entire verification test, the Hoffland Separator used approximately 0.51 kW-h of energy per 1,000 gallons of wastewater treated.

Table 4-5. Power Consumption

Test #	Peak Power (kW)	Average Power (kW)	Total Test Duration (h)	Specific Energy Use (kW-h/1,000 gallon)
1	1.26	0.70	1.38	0.373
2	1.44	1.12	1.35	0.584
3	1.46	1.15	1.30	0.567
4	1.55	1.25	1.23	0.581
5	1.69	0.90	1.73	0.559
6	1.82	1.09	1.47	0.601
7	1.85	0.82	1.85	0.577
8	1.24	1.12	0.50	0.206
9	1.23	1.02	1.43	0.543
10	1.24	0.85	1.65	0.536
11	1.08	0.78	1.67	0.498
12	1.08	0.75	1.63	0.459
Average	1.41	0.96	1.43	0.507

Chapter 5
Data Quality and System Performance

5.1 Laboratory Quality Assurance/Quality Control

The Quality Assurance/Quality Control (QA/QC) plan for this project was described in detail in the VTP. The QA/QC plan ensured accurate and consistent operation of the analytical equipment and procedures. The basic operation of the equipment was checked with standards and laboratory blanks. Laboratory blanks (distilled deionized water used to prepare standards and dilutions) were run after every six samples. A trip blank (laboratory water subjected to the same conditions and procedures as samples) was included on seven of the twelve verification test days, representing at least 5% of the experimental samples, per the VTP. Duplicate samples were analyzed to verify the precision of the analyses. Spiked samples were analyzed to verify the accuracy of the analyses and to determine the presence of effects due to the matrix sample. Duplicate and spiked samples were run every ten samples. The results of the QA/QC tests are discussed below.

Table 5-1 shows the average laboratory quality indicators during the verification test. The complete set of quality indicators is included in the analytical data in Appendix C. Analyses were within control limits at all times during the test. All laboratory blanks and trip blanks met the acceptance criteria (response below the method detection limit or less than ten percent of the median of all sample values). The data set was 100 percent complete for this verification test; there were no missing field measurements or analytical results. Data completeness refers to the proportion of valid, acceptable data generated using each method.

Table 5-1. Laboratory Quality Control Performance

Parameter	Liquid Samples		Solid Samples	
	Spikes Percent Recovery	Duplicates Percent Difference	Spikes Percent Recovery	Duplicates Percent Difference
Target	85-115	±25	85-115	±25
Total nitrogen	96	8.66	99	N/A[1]
Ammonia	96	5.15	101	4.8
Total phosphorus	94	0.97	95	8.99
Ortho phosphorus	103	10.66	100	1.0
Potassium	99	2.10	95	3.1
Chloride	101	0.81	105	3.93
Copper	103	3.11	101	2.6
Zinc	101	3.6	101	3.4

[1] N/A = not available

5.2 Verification System Performance

The verification test is based on accounting for all of the mass of each quality parameter of interest, which is the mass recovered in the solids and in the liquid effluent. The system performance is measured by the completeness of the mass balance – whether all of the mass of each parameter going into the Hoffland Separator is what comes out of the Hoffland Separator. The recovery is different for each quality parameter as previously shown in Table 4-1. Total recoveries of most parameters were between 90 and 97 percent of the influent mass, which is considered acceptable for this type of fieldwork. Recoveries of suspended solids (67 percent) and copper (80 percent) were significantly lower than for the other parameters. The analytical results were all within established limits, and all blanks and checks were acceptable.

References

1) AOAC, International. Method 990.03, Protein (crude) in Animal Feed, Combustion Method. *Journal of AOAC International*, Vol. 72, p. 770, Gaithersburg, MD, 1989.

2) APHA, AWWA, and WEF: *Standard Methods for the Examination of Water and Wastewater*, 19th ed. Washington, DC, 1995.

3) United States Environmental Protection Agency: *Methods and Guidance for Analysis of Water*, EPA 821-C-99-008, Office of Water, Washington, DC, 1999.

4) ETV Water Quality Protection Center, *Test Plan for the Verification of Technologies for Separation of Manure Solids from Flushed Swine Waste*, Ann Arbor, MI, 2000.

5) ETV Water Quality Protection Center, Test Plan for the Verification of Technologies for Separation of Manure Solids from Flushed Swine Waste: Triton Systems, LLC, Ann Arbor, MI, 2002.

6) Page, A. L., ed. Methods of Soil Analysis. Madison, WI: American Society of Agronomy, Inc., Soil Science Society of America, Inc., 1982.

Appendices

A Verification Test Plan for the Hoffland Separator

B Standard Operating Procedures for NCSU's Biological and Agricultural Engineering Environmental Analysis Laboratory

C Test Data

D Field Log Book Entries

Appendices are not included in the verification report. Appendices are available from NSF International upon request.

Glossary

Accuracy - a measure of the closeness of an individual measurement or the average of a number of measurements to the true value and includes random error and systematic error.

Completeness – a quantitative term that expresses confidence that all necessary data have been included.

Precision - a measure of the agreement between replicate measurements of the same property made under similar conditions.

Protocol/generic test plan – a written document that clearly states the objectives, goals, scope and procedures for the study. A protocol or generic test plan shall be used for reference when developing a technology- and site-specific test plan detailing how an individual technology will be evaluated under the ETV Program. A generic test plan differs from a protocol in that it may contain information specific to an approved test site while remaining generic with respect to the technology to be evaluated.

Quality Assurance Project Plan – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

Representativeness - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point, a process condition, or environmental condition.

Standard operating procedure (SOP) – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Technology Panel - a group of individuals established by the VO with expertise and knowledge in solids separation technologies.

Testing Organization (TO) – an independent organization qualified by the Verification Organization to conduct studies and testing of solids separation technologies in accordance with approved protocols and test plans.

Vendor – a business that assembles or sells solids separation technologies.

Verification – to establish evidence on the performance of solid separation technologies under specific conditions, following a predetermined study protocol(s) and test plan(s).

Verification organization (VO) – an organization qualified by EPA to oversee the verification of environmental technologies and issue Verification Statements and Verification Reports.

Verification report – a written document detailing the procedures and methods used during a verification test and the results of the test, including appendices with all raw and analyzed data, all QA/QC data sheets, descriptions of all collected data, and all QA/QC results. The VTP shall be included as part of this document.

Verification statement – a document that summarizes the Verification Report and is reviewed and approved by EPA.

Verification Test Plan (VTP) – A written document prepared to describe the procedures for conducting a test or study according to the verification protocol/generic test plan requirements for a given solids separator at a particular test site. At a minimum, the Verification Test Plan includes detailed instructions for sample and data collection, sample handling and preservation, and quality assurance and quality control requirements relevant to the specific technology as installed at the test site.