September 2003
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Environmental Technology Verification Report

Separation of Manure Solids from Flushed Swine Waste

Triton Systems, LLC
Solid Bowl Centrifuge, Model TS-5000

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:	**SOLID BOWL CENTRIFUGE MODEL TS-5000**	
COMPANY:	**TRITON SYSTEMS, LLC**	
ADDRESS:	**5355 ROYAL VALE LANE DEARBORN, MI 48126**	**PHONE: (313) 336-4154 FAX: (313) 963-1707**

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 solid bowl centrifuge for separating solids from flushed swine waste. This verification statement summarizes the test results for the Triton Systems, LLC, Solid Bowl Centrifuge, Model TS-5000. 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 more 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 Triton Systems, LLC Solid Bowl Centrifuge Model TS-5000 (TS-5000) was provided by the vendor and does not represent verified information.

The TS-5000 is designed to remove solids from swine wastewater-wash systems. The TS-5000 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 separation process relies on an imperforate bowl basket centrifuge operating at up to a maximum of 1,300 times the force of gravity. The high "G" force provides rapid separation of suspended solids from the wastewater. The TS-5000 can process between 25 and 75 gpm, depending on solids loadings and required separation performance.

The centrifuge is designed to operate continuously under automatic control, although manual operation is possible. The centrifuge operation consists of several sequences. Wastewater is pumped to the unit once it is operating at a preset feed speed. Solids begin to accumulate along the wall of the centrifuge during the feeding operation. When the accumulated solids contact a sensor, feed is discontinued and the skimming operation begins. Skimming, the process of removing thin, watery material accumulated along the inside of the bowl, is performed at the same bowl speed as the feeding operation. Skimming is accomplished by moving the end of a rigid tube into the watery layer after it builds up along the inside of the centrifuge bowl. The tube mechanism is attached to translucent tubing so the operator can visually determine when the solids content of the skimmed material increases. The skimmed material contains significant solid material but is still classified as liquid. Returning the skimmed material to the feed tank during normal operation is intended to optimize the removal of solids and further reduces the moisture content in the accumulated solids. When skimming is complete, the centrifuge slows to a preset plow speed. During the plowing operation, a plow blade removes the solids from the unit by scraping them away from the centrifuge wall and allowing them to fall out the bottom of the unit. A preset limit switch prevents the plow blade from contacting the centrifuge wall. Once plowing is complete, the bowl speed increases back to the preset feed speed, feed water flow resumes, and the process is repeated.

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 onsite lagoon. Flushed waste then flows back to the anaerobic 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. 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.

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 pumped from the influent mixing tank to the test unit. Liquids discharged from the test unit were collected in effluent and skimming tanks, and the separated solids were collected on the adjacent concrete pad.

Methods and Procedures

Verification testing began on Monday, May 20, 2002. Technology evaluation and sampling procedures were carried out three days per week (Monday, Wednesday, and Friday) for four weeks, for a total of 12 testing events.

After the safety status of the unit was assured, the centrifuge was started. As the bowl began to spin, some of the solid material that had remained in the unit from previous tests dropped out of the unit. In an effort to quantify this material for the mass balance, an initial plow sequence, that was not part of the normal operating procedures as defined in the operations manual, was performed on each test day. The mass of material removed during this pre-plow operation was recorded in addition to the material that had fallen out since the last test day. After the material was removed from below the unit, wastewater flow was started.

Wastewater from the swine unit was collected and mixed in the influent mixing tank to equally distribute solids throughout the tank. Wastewater was typically held in the mixing tank for less than five minutes, but never more than thirty minutes. Wastewater was then pumped to the centrifuge at a nominal flow rate of 35 gallons per minute while the centrifuge unit was operating at the preset feed speed (1,200 rpm).

Under normal operating conditions, the TS-5000 is run continuously, and skimming and plowing operations are initiated automatically based on the depth of accumulated solids in the bowl. Batch processing is specified by the *ETV Test Plan for the Verification of Technologies for Separation of Manure Solids from Flushed Swine Waste* for all solids separation technologies undergoing verification testing to ensure that sufficient wastewater is provided to the technology on test dates. It also allows accurate calculation of mass in and mass out of the technology being verified and ensures consistency between verification tests. The batch processing approach required that automatic operation be suspended and that skimming and plowing operations be activated manually during this verification test. To compensate for the longer time the unit would spin in a field installation, the feed pump was turned off and the unit maintained the same feed speed for one hour prior to skimming. Skimming was performed at the same bowl speed as the feeding operation and was initiated manually by actuating the skimmer advance switch on the control panel. Under normal operating conditions, the skimmed liquid would be returned to the wastewater storage unit or the feed tank to be sent through the separator again. Under the batch processing used in this verification test, this skimming liquid was collected in a tank separate from the effluent, was quantified and analyzed separately, and was ultimately disposed in the lagoon. The skimming operation continued until solids were observed leaving the system with the skimming liquid. Following skimming, a manual switch was turned that slowed the centrifuge bowl to the preset plow speed. A control panel light indicated when this speed was reached, and the plowing was then initiated manually. The plow blade moved through its normal range of motion and automatically retracted. The plow procedure was then repeated. Solids removed during the plowing process dropped out of the bottom of the unit. Once all effluent and solids were removed from the discharge points, the unit was shut down.

Measurements made each test day included volume of wastewater entering the unit, volume of the skimming stream, volume of the effluent stream, weight of solids removed (plowed) from the unit, and concentrations of quality parameters in each of the sampled components (influent, effluent, solids, and skimming liquid). The influent, effluent, and skimming liquid 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. The analyses performed included solids (total, suspended, and volatile), total organic carbon (TOC), nutrients, metals, pH, conductivity, and bulk density. The mean daily values were summed over the test period and converted to mass in order to complete the mass balance.

At the end of the test period, the centrifuge was accelerated to 100 rpm and eight plow cuts were performed to remove built up solids and obtain full plow blade travel. Any solid residue that did not fall out of the centrifuge during this final plowing process was removed manually after the system was completely powered down. The mass of this material was recorded for inclusion in the mass balance.

Performance Verification

System Performance

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 1. The skimming liquid contained less than 1.4 percent of any of the parameters and is therefore not included as a separate column in Table 1. For each parameter, the total mass recovered from the centrifuge (effluent, skimming liquid, solids) is shown in Table 1 as the percent of the mass in the influent.

Table 1. Partitioning and Recovery of Parameters from Influent

Parameter	Percent In: Recovered Solids	Percent In: Liquid Effluent	Percent In: Total (Solids, Effluent, Skimming)
Dry matter / suspended solids	55	29	84
Total nitrogen	20	69	90
Total phosphorus	42	40	82
Potassium	3.2	89	94
Copper	22	51	74
Zinc	30	48	78
Chloride	1.6	93	96

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

While the recoveries from the mass balance would ideally be within ± 10 percent of 100 for this type of work, lower recoveries are common due to the complex nature of both the wastewater and separated solids. The flushed swine waste entering the treatment unit included colloidal and suspended solids, as well as larger aggregates of organic waste, microbial biomass, and undigested feed. Mixing of the influent, as was done during the verification test, increases the opportunities to obtain consistent samples but cannot overcome the inherent heterogeneity of the wastewater. Sampling anomalies may have occurred, resulting in some of the influent samples, collected in triplicate, containing larger amounts of solids than were consistent with the rest of the influent.

Recovery of some parameters is also influenced by the additional sample preparation required for solid samples and the lower precision of quantifying solids compared to liquids. This is a practical consideration that is inherent in this type of analysis and not an artifact of the laboratory or the equipment being evaluated. The data quality indicators demonstrate that the analytical procedures performed within expected limits.

The characteristics of the liquid effluent and the recovered solids are shown in Tables 2 and 3, respectively. All values presented in the tables reflect means calculated over the test period.

Over the entire test period, 1,750 lb of dry solids were recovered by the TS-5000, representing 55 percent on a mass basis of the 3,200 lb of suspended solids in the influent. The recovered solids contained 26 percent dry matter (74 percent moisture).

Most of the remaining solids were released with the effluent stream (29 percent), which had a suspended solids concentration of 3,680 mg/L. The solids not contained in the recovered material or in the effluent were in the skimming liquid. This material would be returned to the feed tank in normal continuous operation. Centrifuges are generally expected to be less efficient when used for batch processing, due to the lower bowl speeds during the start up and shutdown phases.

Table 2. Influent/Effluent Characteristics

Parameter	Units	Influent	Effluent
Total solids	mg/L	12,900	6,340
Volatile solids	mg/L	9,420	4,030
Suspended solids	mg/L	11,700	3,680
Total Kjeldahl nitrogen	mg/L	1,060	792
Ammonia nitrogen	mg/L	454	420
Total phosphorus	mg/L	423	182
Ortho phosphorus	mg/L	179	88
Potassium	mg/L	534	516
Chloride	mg/L	271	272
Copper	mg/L	9.2	5.0
Zinc	mg/L	15.3	7.9
N:P:K ratio		2.51:1.00:1.26	4.35:1.00:2.84
pH		7.23	7.51
Conductivity	µmhos/cm	4820	4760
Total coliform	MPN/100mL	1.3×10^{10}	2.0×10^{10}
E. coli	MPN/100mL	8.1×10^{9}	1.5×10^{10}

Note: The data in Table 2 are based on 12 samples, with the exception of the *E. coli* data, which are based on eight samples.

Operation and Maintenance Results

Operational Observations

Several types of operational problems were seen with the TS-5000. First, the bowl speed during the plow or pre-plow sequence did not maintain the 100 rpm design speed, but varied between 30 and 140 rpm throughout the verification test. Although the vendor explained this as normal operation while the drive motor and centrifuge bowl match speeds, the situation caused the system to be shut down on three occasions due to either an out-of-balance condition or operator-perceived instability of the structure. Second, on three occasions, the bowl speed began to increase after the plow sequence rather than to shut down. The manual "Cycle Stop" control did not interrupt this sequence and the operator had to use the "Control Power" switch to disconnect power at the control panel. Finally, the nature of the centrifuge operation introduced a significant amount of air into the liquid effluent, as evidenced by foaming that occurred whenever the centrifuge was operated. Generally this foam dissipated within 24 to 48 h of shutting off the unit. Additional operational observations are described in the verification report.

Table 3. Recovered Solids Characteristics

Parameter	Units	Concentration
Dry matter	percent by weight	26.2
Volatile solids	percent by weight	22.3
Total nitrogen	percent by weight	0.86
Total phosphorus	µg/g	7,280
Potassium	µg/g	714
Chloride	µg/g	179
Copper	µg/g	83.0
Zinc	µg/g	185
Bulk density	g/mL	0.736
Total coliform	MPN/g	6.1×10^{10}
E. coli	MPN/g	3.5×10^{10}
N:P:K ratio		1.18:1.00:0.098

Note: The data in Table 3 are based on 12 samples, with the exception of the *E. coli* data, which are based on eight samples.

<u>*Maintenance Observations*</u>

The skimming volume was low on test days seven, eight, and nine (approximately 15 gal compared to typical values of 50 gal). The system also chattered harshly during the plow sequence of test nine. Because of these observations, the NCSU staff opened the access hatch of the TS-5000 and inspected the bowl at the end of test nine. Hair and debris had accumulated on the leading edge of the plow blade. After consultation with the vendor, the unit was cleaned, as this type of maintenance would be expected in a commercial application. The hair and solids were removed from the blade with a shovel (an effort of about 15 min).

<u>*Electrical Requirements*</u>

The standard electrical installation of the TS-5000 is three-phase, but the system can be installed on 240 V single-phase power, as it was for the verification test. Current and voltage were measured during every test day, allowing the calculation of total, peak, and mean power. The peak power usually occurred at the start of the feed cycle and was never maintained for more than one ten-second reading. The manual operation procedures described previously included an hour of operation at full feed speed without any wastewater entering the system. This operation consumed power at a lower rate than during the feeding operation. The mean power consumed during the feeding operation, more representative of continuous operation, was generally less than 20 kW with a mean peak of 30 kW.

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 the NSF QA Management Program and accompanied NSF during audits of the NCSU facilities.

Original signed by *Lee A. Mulkey*	*09/30/03*	*Original signed by* *Gordon E. Bellen*	*10/02/03*
Lee A. Mulkey	Date	Gordon E. Bellen	Date

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Acting Director
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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.

September 2003

Environmental Technology Verification Report

Separation of Manure Solids from Flushed Swine Waste

Triton Systems, LLC
Solid Bowl Centrifuge, Model TS-5000

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

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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.

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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
g	Acceleration due to gravity (32.2 ft/sec^2)
gal	Gallons
gpm	Gallons per minute
h	Hour
K	Potassium
lb	Pound
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 Brian Phillips 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:

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

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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. Jamie Tutor and Ms. Kelly Ackles provided substantial support during set up and testing.

The manufacturer of the solids separation technology was:

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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) 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 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.

NSF International (NSF), in cooperation with EPA, operates the ETV Water Quality Protection Center. This Center oversaw the verification testing of the Triton Systems, LLC (Triton) Solid Bowl Centrifuge, Model TS-5000 (TS-5000), which is a solid bowl basket centrifuge with associated control systems designed to separate solids from liquid swine waste. The potential market for this equipment includes swine producers who could benefit from having 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 TS-5000 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
Triton Systems, LLC	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:

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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
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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, skimming liquid, effluent, and solids 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:

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1.2.4 Triton Systems, LLC – Vendor

Triton 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. Triton's technical representatives in North Carolina, Kyte Centrifuge Sales and Consulting, assisted with equipment installation at the test site and provided technical input as needed during the testing process. Triton'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.

Triton's contacts for this project were:

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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 corn. 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 and 2 percent 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 solids in the wastewater. The organic load from the solids requires a larger treatment system (lagoon), first to break down the solids to soluble components, and then to treat the added organic matter. Another problem is that the solids that settle in the bottom of the system remain there for long periods of time and require additional capacity in the treatment system. Finally, the 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 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 back 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 TS-5000 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 disposed in the lagoon. In addition to the effluent, skimming liquid from the unit was collected in a separate tank. Figure 1-1 is a schematic diagram of the testing facility.

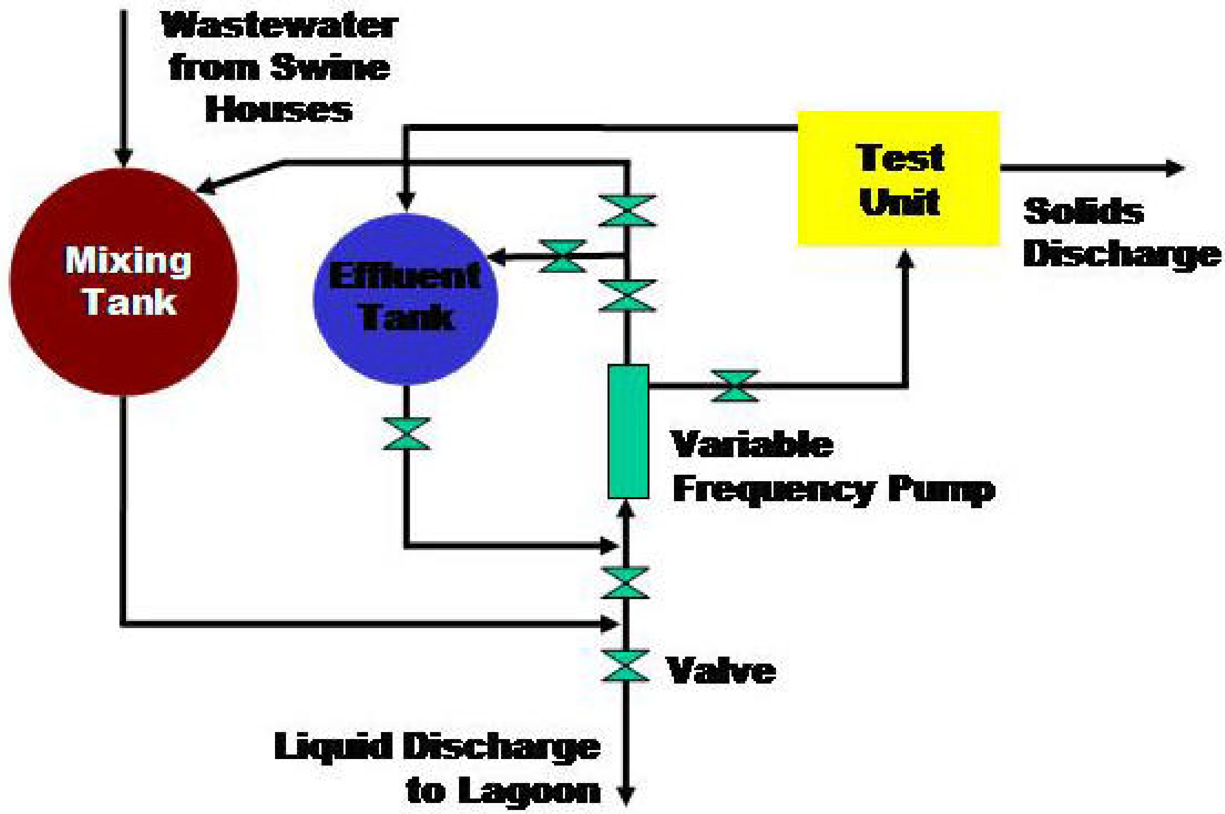

Figure 1-1. Test site schematic at NCSU Lake Wheeler Road Field Laboratory.

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 pumped from the influent mixing tank to the test unit. Liquids discharged from the test unit were collected in effluent and skimming tanks, 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 TS-5000 is designed to remove solids from flushed swine waste and other animal waste slurries (Figure 2-1). The TS-5000 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. Ancillary equipment provides the ability for chemical addition to aid in the capture of small diameter, neutrally buoyant solids. Recent research conducted by the vendor suggests that chemical addition is not needed for most applications. Similarly, an optional oxygen delivery system is available to saturate (and/or supersaturate) the liquid fraction of the discharge for both odor control and improved biological oxidation/organic reduction. Neither the chemical addition system nor the oxygen addition system was installed for this verification test.

Figure 2-1. TS-5000 during final assembly.

According to vendor claims, the TS-5000 can process between 25 and 75 gpm, depending on solids loadings and required separation performance, and provides a solid material that exceeds 25 percent solids. The verification test was conducted at a nominal flow rate of 35 gpm.

The following is a summary of the characteristics of the TS-5000:

Size:	48" Diameter x 30" Deep
Maximum RPM:	1400
Maximum "G"s:	1300
Bowl Capacity:	16 ft^3
Air Pressure:	80-100 psi (1 cfm required with an instantaneous surge of 20 cfm for 2 seconds to operate controls)
Type:	Bottom Discharge
Weight (with drive motor):	7700 to 9560 lb

The TS-5000 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 Engineering and Scientific Concepts of the Equipment

The TS-5000 solids separation process relies on an imperforate bowl basket centrifuge operating at up to a maximum of 1300 times the force of gravity. The high "G" force provides rapid separation of suspended solids from the wastewater or slurry. Polymer coagulants may be used with the TS-5000 to improve its efficiency, however, they add to the operating costs and the vendor only recommends chemical addition when there are substantial constraints on the quality of the discharged liquid. Consequently, no coagulants were used during this test.

2.3 Basic Operation of the Centrifuge

The centrifuge is designed to operate continuously under automatic control, although manual operation is possible. The centrifuge operation consists of several sequences. Wastewater is pumped to the unit once it is operating at a preset feed speed. Solids begin to accumulate along the wall of the centrifuge during the feeding operation. When the accumulated solids contact a sensor, feed is discontinued and the skimming operation begins. Skimming, the process of removing thin, watery material accumulated along the inside of the bowl, is performed at the same bowl speed as the feeding operation. Skimming is accomplished by moving the end of a rigid tube into the watery layer after it builds up along the inside of the centrifuge bowl. The tube mechanism is attached to translucent tubing so the operator may visually determine when the solids content of the skimmed material increases, although under automatic operating conditions, "skimmer dwell time" is preset. The skimmed material contains significant solid material but is still classified as liquid. Returning the skimmed material to the feed tank in normal operation is intended to optimize the removal of solids and further reduces the moisture content in the accumulated solids.

The centrifuge for this verification test was manually operated in order to conform to the requirements in the generic ETV *Test Plan for the Verification of Technologies for Separation of*

Manure Solids from Flushed Swine Waste. The test plan specifies that wastewater be fed to the unit being tested on a batch basis, (1) to ensure that sufficient wastewater is provided to the technology on test dates, (2) to allow for accurate calculation of mass in and mass out, and (3) to ensure consistency between verification tests. In addition, if run in automatic mode during the verification test, the solids would not have accumulated in the bowl to a depth at which skimming and plowing (described below) would have been automatically triggered, due to the volume of available wastewater and the size of the centrifuge in comparison to the feed rate selected for this evaluation. As a result, the skimming liquid was not returned to the centrifuge, as it would be under normal operation. Rather, it was collected in a skimming tank separate from the effluent. The skimming liquid was quantified and analyzed separately and was ultimately disposed in the lagoon. Because the unit never became full of solids, verification of the automatic operation of skimming and plowing was not possible.

When the unit is operated under automatic control, the centrifuge bowl slows to a preset plow speed once skimming is complete. The plowing operation consists of removing the solids from the unit by scraping them away from the centrifuge wall with the plow blade and allowing them to fall out the bottom of the unit. A preset limit switch prevents the plow blade from contacting the centrifuge wall. Once plowing is complete; (1) the bowl speed increases back to the preset feed speed, (2) the feed water flow resumes, and (3) the process is repeated.

Chapter 3
Verification Procedures and Methods

3.1 Verification Objectives

Although the primary purpose of this equipment is to recover and remove solid material, use of the 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 TS-5000 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 TS-5000 with regard to the mass of solids;
2. Characterize the separated solids and resulting liquid stream with respect to nutrients, metals, and pathogen indicators; and
3. Gather qualitative operation and maintenance requirements of the system.

To meet these objectives, a VTP was prepared and approved for verification of the TS-5000 and is attached to this report as Appendix A. The 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 sections below. 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 TS-5000 arrived at the Lake Wheeler Road Field Laboratory Swine Educational Unit on May 6, 2002. Plumbing and electricity were connected, and on May 7th the unit was started for shakedown testing. Over the first few days of operation, the flow rate was adjusted and samples were taken for total and suspended solids analyses. Testing continued through the week of May 13-17, 2002, while the vendor adjusted operating conditions and final changes were made to the VTP under which the unit would be tested. Changes to the VTP were needed to include the skimming operation that was not disclosed in the original description of the technology. The flow rate of wastewater into the unit was also adjusted according to results of tests during the week of equipment set up. Final adjustments were made to the equipment and final changes were made to the VTP by May 17th. Testing began on Monday, May 20th. Figure 3-1 shows the TS-5000 installed at the test site. Figure 3-2 shows details of the control panel. Figures 3-3 to 3-5 show details of the interior mechanisms of the unit.

Figure 3-1. TS-5000 during set up at test site.

3.3 Verification Testing Procedures

The test period for verification of the TS-5000 was 28 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 samples of influent and effluent were collected, one set on each of the twelve testing events during the verification period. There were no delays due to invalid operation. For safety considerations, at least two NC State personnel were present during each testing operation.

Figure 3-2. TS-5000 control panel.

Figure 3-3. Internal view of TS-5000 showing feed tube at the bottom of the bowl.

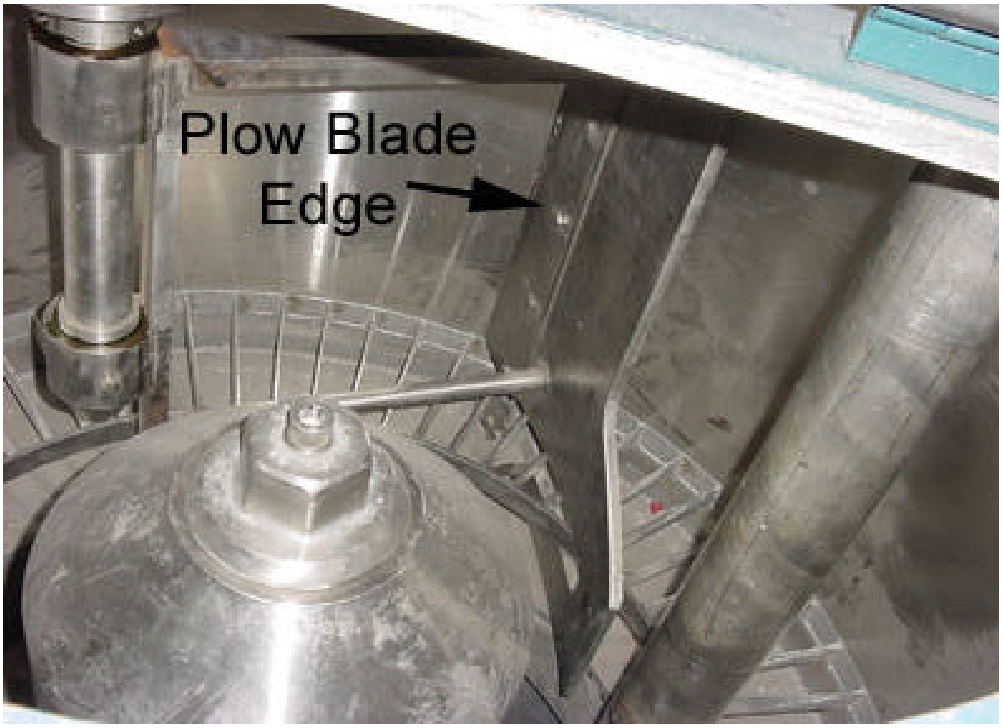

Figure 3-4. Internal view of TS-5000 showing the plow blade.

Figure 3-5. Internal view of TS-5000 showing the skimming tube at the top of the bowl.

3.3.1 Daily Operation

Daily operation of the verification test was consistent to the greatest extent possible. Testing took place in the morning hours to ensure samples were transferred to the lab for timely processing. The centrifuge was inspected according to the daily schedule listed in Table 3-1, and the status of the unit relative to those inspections was recorded on the daily log sheet. The TS-5000 operated safely (within all safety parameters) during the entire 28-day verification period.

After the safety status of the unit was determined according to the inspection and maintenance checks specified in Table 3-1, the centrifuge was started. Because the operational speed of the centrifuge bowl is preset in the control panel, no further adjustments were necessary. A panel light indicated when the unit was at the proper speed to begin wastewater feed. The motor speed was verified by checking the motor speed indicator each time the speed changed for the next function. As the bowl began to spin, some of the solid material that had remained in the unit from previous tests would drop out of the unit. In an effort to quantify this material for the mass balance, an initial plow sequence that was not part of the normal operating procedures as defined in the operations manual was added each day of testing. The mass of material removed during this pre-plow operation, in addition to the material that had fallen out since the last test day, was recorded. After this material was removed from below the unit, wastewater flow was started.

Table 3-1. Inspection and Maintenance Checks

Inspection and Maintenance Checks	Frequency *
Check speed setting in control panel	Daily
Drain filter reservoir on the "Lubri-Air Control Unit"	Daily
Check air pressure reading	Daily
Check for air leaks at connections	Daily
Adjust lubricator oil feed adjustment screw	Initially
Check alarms/limit switches/meter relays/air pressure cutoffs	Initially

* The term "daily" refers to the days of the week during which technology operation and verification testing took place.

Wastewater from the swine unit was collected in the influent mixing tank. Floating solids were excluded 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. Wastewater was typically held in the mixing tank for less than five minutes, but never more than thirty minutes. Wastewater was then pumped to the centrifuge at a nominal flow rate of 35 gpm while the centrifuge unit was operating at the preset feed speed (1,200 rpm).

Under normal operating conditions, the TS-5000 is run continuously, and skimming and plowing operations are initiated automatically based on the depth of accumulated solids in the bowl. However, as discussed in 2.3, the batch operation of this verification test required that the automatic operation be suspended and that the skimming and plowing operations be activated manually, because the accumulated solids would not contact the sensor to initiate skimming and plowing. To compensate for the longer time the unit would spin in a field installation, the feed pump was turned off and the unit maintained the same feed speed for one hour prior to skimming. Skimming was performed at the same bowl speed as the feeding operation and was initiated manually by briefly actuating the skimmer advance switch on the control panel. This action incrementally moved the skimmer mechanism into the wall of accumulated material inside the centrifuge. Under normal operating conditions, the skimmed liquid would be returned to the wastewater storage unit or the feed tank to be sent through the separator again. Under the batch processing used in this verification test, the skimming liquid was collected in a tank separate from the effluent, was quantified and analyzed separately, and was ultimately disposed in the lagoon. The skimming operation continued until solids were observed leaving the system with the skimming liquid. Following skimming, a manual switch was turned that slowed the centrifuge bowl to the preset plow speed. A control panel light indicated when this speed was reached, and the plowing was then initiated manually. The plow blade moved through its normal range of motion and then retracted automatically. The plow procedure was then repeated. Solids removed during the plowing process dropped out of the bottom of the unit (Figure 3-6).

Figure 3-6. Solids recovered from TS-5000.

Once all effluent and solids were removed from the discharge points, the unit was shut down by turning the main switch to the "off" position. The times at which the unit was started and reached operating/skimming speed and plow speed were recorded.

Measurements made each test day included volume of wastewater entering the unit, volume of the skimming stream, volume of the effluent stream, weight of solids removed (plowed) from the unit, and concentrations of quality parameters (as listed in Table 3-2) in each of the sampled components. The influent, effluent, and skimming 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 3-2 lists the constituents that were measured in the influent, effluent, and solid samples. It also lists the analytical methods and preservation/holding times for each parameter.

At the end of the test period, following the last day of testing, the TS-5000 was accelerated to100 rpm and eight plow cuts were performed to remove built-up solids and obtain full plow blade travel. Any solid residue that did not fall out of the centrifuge during this final plowing process was removed manually after the system was completely powered down. The mass of this material was recorded for inclusion in the mass balance.

3.3.2 Sampling Methods

Triplicate samples from the mixing tank were taken for influent samples just prior to pumping to the TS-5000 Separator. Once centrifuge operation was complete, the liquid effluent was mixed for ten minutes by pumping it through an internal recycle loop and triplicate samples were taken for analysis. The liquid in the skimming tank was more homogeneous and required less mixing before triplicate samples were taken. Representative samples from the solids removed following the plowing process 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. Triplicate samples of at least 50 g each were taken with a shovel, one from each of three different locations within the stacked solids and were combined into a single sample.

Each replicate was analyzed as an independent sample and the results averaged. 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. 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.

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 3-2, no preservation methods 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 QA/QC checks were completed by the laboratory manager. All analyses met QA/QC standards so none of the samples had to be re-analyzed.

Table 3-2. 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	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[2]	Refrigerate	7 d
Chloride	SM 4500-Cl^- E	Methods of Soil Analysis (1982) 84-2 as modified[2]	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[3]	Refrigerate	48 h
Copper	SM 3111 B	Methods of Soil Analysis (1982) 78-4.2.1[3]	HNO_3 to pH<2	6 mo
Zinc	SM 3111 B	Methods of Soil Analysis (1982) 78-4.2.1[3]	HNO_3 to pH<2	6 mo
Potassium	SM 3111 B	Methods of Soil Analysis (1982) 78-4.2.1[3]	HNO_3 to pH<2	6 mo
Bulk density		Methods of Soil Analysis (1982) 30-2.1	None	None

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

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

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

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, skimming liquid, and solids), and the 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.

3.4 Analytical Protocols

The Environmental Analysis Laboratory of the Biological and Agricultural Engineering Department at NCSU performed all analyses except pH and measurement of the 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 *Standard Methods for the Examination of Water and Wastewater (19th edition)*, 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 3-2. 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 for the Examination of Water and Wastewater (19th edition)* 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^{o}C; the bulk density was determined as is. A plastic 50 mL beaker previously had the top cut down to the 50 mL marker. This beaker 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 divided by 50 mL. The determination was made three times and the mean 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 provided total flow and total mass of the different components of the waste stream. Because the pre-plow solids (recovered before each day's test) were not analyzed separately for the various parameters, a daily mass balance on the unit was not possible, but an overall mass balance 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 overall concentration in the daily recovered solids while equation (4-2) shows the calculation for the three liquid phases (influent, effluent, and skimming liquid). The average concentration of each parameter in the recovered solids was multiplied by the total mass of pre-plow solids (recovered before each day's test) to obtain the mass of each parameter in the pre-plow solids. The mass of each parameter was added to the mass determined from analysis of daily solids to get the total mass recovered in the solid phase.

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

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

Where:

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

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

$\overline{C}_{i,\,j,\,d}$ = 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, skimming liquid

This total mass was then used in calculations of mass removal and parameter concentration in the recovered solids and liquid effluent. 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 the solids and liquids, respectively. The final parameter concentrations in the recovered solids were adjusted to account for the mass of each parameter recovered in the solids collected at the start of each testing day.

$$R_{solids,i} = \frac{\text{total mass of parameter } i \text{ recovered in solids}}{\text{total mass of parameter } i \text{ in influent}} \tag{4-3}$$

$$R_{liquid effluent,i} = \frac{\text{total mass of parameter } i \text{ recovered in liquid effluent}}{\text{total mass of parameter } i \text{ in influent}} \tag{4-4}$$

Where:
R = Mass recovery of parameter *i* in solids or liquid effluent

These mass balance calculations were carried out for the following parameters: suspended solids/dry matter, 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 characterizing the recovered solids and liquid effluent.

The following sections discuss the performance of the TS-5000 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 Section 5.

4.1 Mass Balance Results and Characterization

The mass balance approach allowed testers to determine 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. The skimming liquid contained less than 1.4 percent of any of the parameters and is therefore omitted from Table 4-1. It is, however, included in Appendix C with the rest of the complete results of the analyses. For each parameter of interest, the total mass recovered from the centrifuge (effluent, skimming liquid, and solids) is shown in Table 4-1 as a percent of the mass in the influent. As shown in the table, 55 percent of the mass of solids in the influent was recovered by the TS-5000. Overall, the suspended solids *concentration* in the TS-5000 effluent was reduced by 68 percent compared to that of the influent.

Nutrients and metals were recovered in different proportions in the solids and liquid effluent from the TS-5000, as shown in Table 4-1. The largest proportion of most nutrients was found in the liquid effluent with potassium and nitrogen having the greatest proportion of the mass in the effluent (89 percent and 69 percent, respectively). While the solids contained a significant proportion of phosphorus (42 percent), almost as much was found in the liquid effluent (40 percent).

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

Parameter	Percent In: Recovered Solids	Liquid Effluent	Total (Solids, Effluent, Skimming)
Dry Matter / Suspended Solids	55	29	84
Total Nitrogen	20	69	90
Total Phosphorus	42	40	82
Potassium	3.2	89	94
Copper	22	51	74
Zinc	30	48	78
Chloride	1.6	93	96

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 disposal 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 slightly higher than expected at 1.2 percent (11,700 mg/L), indicating that the operational scheme of removing waste three times per week during testing of technologies under the ETV VTP was effective at increasing the suspended solids load in the wastewater. Over the entire test period, 1,750 lb of dry solids were recovered by the TS-5000 centrifuge, representing 55 percent of the 3,200 lb of suspended solids in the influent. The recovered solids contained 26 percent dry matter (the solids contained 74 percent moisture). Most of the remaining solids were released with the effluent stream (29 percent) having a suspended solids concentration of 3,680 mg/L. The solids not contained in the recovered material or in the effluent were in the skimming liquid. This material would be returned to the feed tank in normal continuous operation. An important measurement is the ratio of nitrogen, phosphorus, and potassium (N:P:K ratio). The N:P :K ratio indicates that the effluent is enriched in both nitrogen and potassium relative to phosphorus when compared with the influent, reflecting the partitioning shown above. The ratio of the solids nearly balances nitrogen and phosphorus with very little potassium.

Table 4-2. Influent / Liquid Effluent Characteristics

Parameter	Units	Influent	Effluent
Total solids	mg/L	12,900	6,340
Volatile solids	mg/L	9,420	4,030
Suspended solids	mg/L	11,700	3,680
Total organic carbon	mg/L	1,630	1,390
Total nitrogen	mg/L	1,060	792
Ammonia nitrogen	mg/L	454	420
Total phosphorus	mg/L	423	182
Ortho phosphorus	mg/L	179	88
Potassium	mg/L	534	516
Chloride	mg/L	271	272
Copper	mg/L	9.17	5.02
Zinc	mg/L	15.3	7.86
N:P:K ratio		2.51: 1.00:1.26	4.35:1.00:2.84
PH		7.23	7.51
Conductivity	μmhos/cm	4820	4760

Table 4-3. Recovered Solids Characteristics

Parameter	Units	Concentration
Dry matter	percent by weight	26.2
Volatile solids	percent by weight	22.3
Total carbon	percent by weight	10.8
Total nitrogen	percent by weight	0.86
Total phosphorus	μg/g	7,280
Potassium	μg/g	714
Chloride	μg/g	179
Copper	μg/g	83.0
Zinc	μg/g	185
Bulk density	g/mL	0.736
N:P:K ratio		1.18:1.00:0.098

4.2 Results of Pathogen Indicator Tests

Because of a scheduling problem at the start of the verification test, the pathogen indicator tests did not begin until the fifth day of testing, May 29, 2002. Samples were tested for total coliform bacteria and *E. coli* 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 averages of the MPN results from the tests of influent, effluent, and solid samples.

Table 4-4. Pathogen Indicator Test Results

	Influent (MPN/100 mL)	**Effluent** (MPN/100 mL)	**Solids** (MPN/g)
Total coliforms	1.3×10^{10}	2.0×10^{10}	6.1×10^{10}
E. coli	8.1×10^{9}	1.5×10^{10}	3.5×10^{10}

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

Several types of operational problems were seen with the TS-5000. First, the bowl speed during the plow or pre-plow sequence did not maintain the 100 rpm design speed, but varied between 30 and 140 rpm throughout the verification test. Although the vendor explained this as normal operation while the drive motor and centrifuge bowl match speeds, the situation caused the system to be shut down on three occasions due to either an out-of-balance condition or operator perceived instability of the structure. Second, on three occasions, the bowl speed began to increase after the plow sequence rather than to shut down. The manual “Cycle Stop” control did not interrupt this sequence and the operator had to use the “Control Power” switch to disconnect power at the control panel. Finally, the nature of the centrifuge operation introduced a significant amount of air into the liquid effluent, as evidenced by foaming that occurred whenever the centrifuge was operated. Figure 4-1 shows the foam that the system produced. Generally this foam dissipated within 24 to 48 h of shutting off the unit.

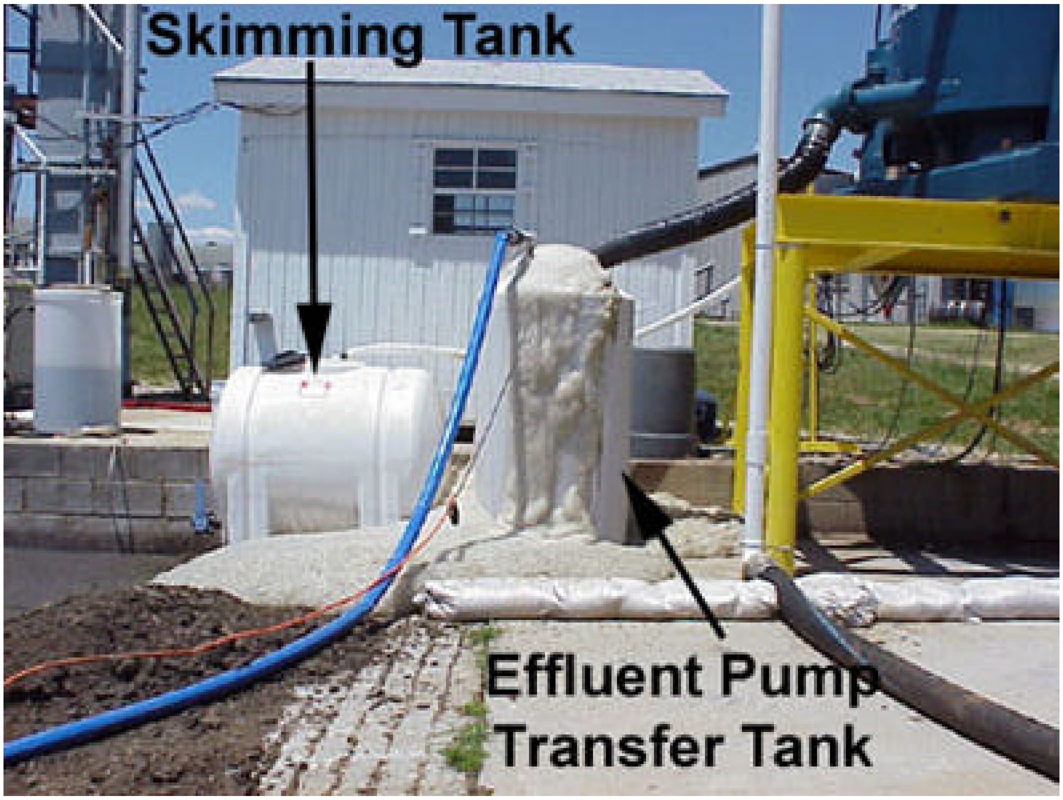

Figure 4-1. Foam produced with the TS-5000 effluent.

On two occasions the system safety controls shut down the system during the pre-plow operation due to the unloader limit failure alarm on the plow mechanism. This limit switch was adjusted and the operation continued.

The centrifuge went out of balance on three occasions after the pre-plow sequence while the bowl speed increased to the feed speed. Per the vendor's suggestion, a small amount (25 gal) of wastewater was pumped into the bowl immediately. This was successful in correcting the out of balance condition and allowed the testing procedure to continue.

The skimming volume was low on test days seven, eight, and nine (approximately 15 gal compared to typical values of 50 gal). The system also chattered harshly during the plow sequence of test nine. Because of these observations, the NCSU staff opened the access hatch of the TS-5000 and inspected the bowl at the end of test nine. Hair and debris had accumulated on the leading edge of the plow blade (see Figure 4-2). After consultation with the vendor, the unit was cleaned, as this type of maintenance would be expected in a commercial application. The hair and solids were removed from the blade with a shovel (an effort of about 15 minutes) and operation resumed.

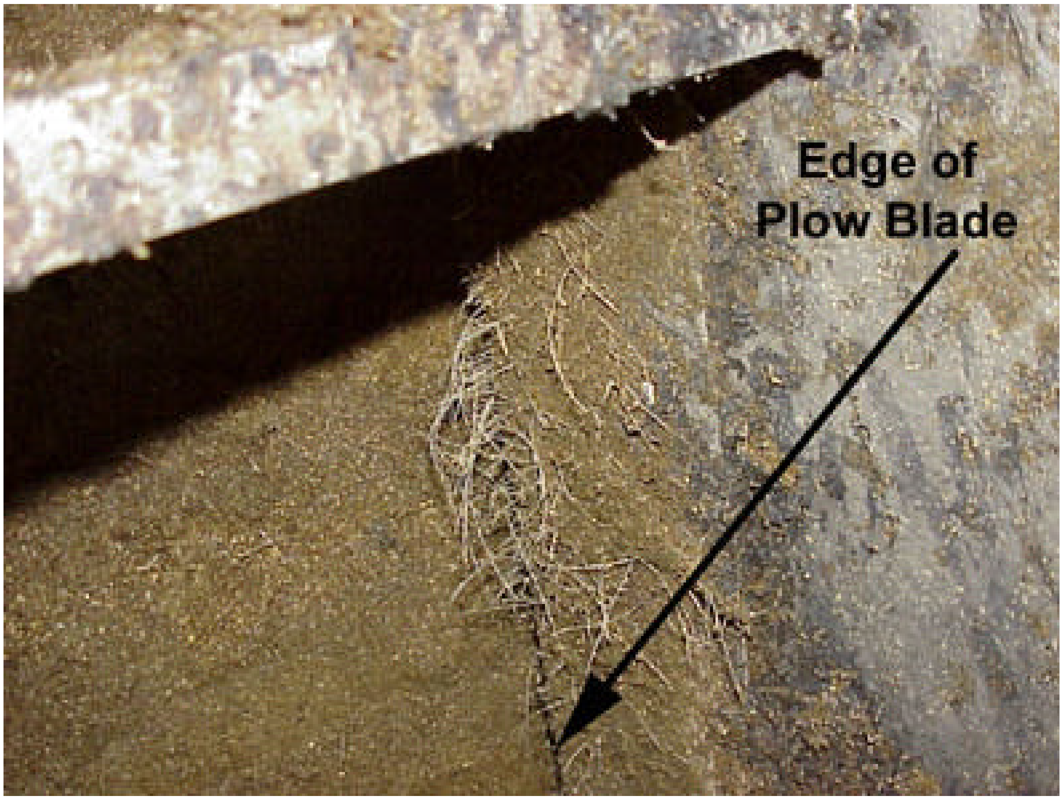

Figure 4-2. Plow blade with build up of hair and debris.

During test ten, the NCSU farm crew doing repair work to a nearby service panel interrupted electrical power to the system. This outage occurred during the feed sequence and was anticipated by the NCSU testing team. The power was off for 18 minutes. All safety alarms and equipment associated with the operation of the TS-5000 worked properly. After power was restored, the TS-5000 was inspected, brought up to feed speed and the test procedure was completed. The plowing operation was much smoother during this test, after the cleaning operation of test nine.

4.3.2 Operation and Maintenance Manual Evaluation

The Operation and Maintenance Manual submitted by Triton (refer to the VTP in Appendix A) provided a good overview of the system function, controls and operation. Also covered in sufficient detail were the requirements for routine maintenance and the possible fault conditions that could lead to error codes. The manual however, provided limited insight into what to do once an error code was encountered.

A section on troubleshooting and system adjustments to correct error conditions would be helpful. For instance, during the testing period an unloader motion alarm condition was annunciated and it took significant time and a phone call to the manufacturer to determine that the cause was a limit switch adjusting screw that had vibrated loose rather than an actual problem with the unloader.

4.4 Power Requirements

The standard electrical installation of the TS-5000 is three-phase, but the system can be installed on 240 V single-phase power. Although the test site has access to three-phase power, the vendor asked, and NCSU staff agreed, to convert to single-phase power. This was done to demonstrate how to convert and operate the TS-5000 with single-phase power, which is more commonly found in agricultural settings. It is recognized that this installation is less efficient than the standard installation, but this is the only option for sites that do not have access to three-phase power.

An Extech, Model 380940 clamp-on power data logger measured current and voltage. Calculated values of kilowatts were recorded every ten seconds. This power data is summarized in Table 4-5. The values from the first test day are not available due to a computer failure. The peak power usually occurred at the start of the feed cycle, and it was never maintained for more than one ten-second reading. The manual operational procedures described previously included an hour of operation at full feed speed without any wastewater entering the system. This operation consumed power at a lower rate than during the feeding operation. The average power consumed during the feeding operation, more representative of continuous operation, was generally less than 20 kW with an average peak of 30 kW.

Table 4-5. Power Consumption

Test #	Peak Power (kW)	Average Power (kW)	Total Test Duration (h)	Average Feed Cycle Power (kW)	Feed Cycle Duration (h)
1	No Data	No Data	No Data	No Data	No Data
2	28.40	17.03	0.92	19.13	0.86
3	33.69	12.80	2.44	18.70	1.02
4	28.34	12.80	2.21	18.20	1.45
5	32.00	12.37	2.42	17.88	1.06
6	26.98	11.83	2.56	17.96	1.09
7	29.32	13.36	2.18	18.63	0.99
8	29.76	11.38	2.65	18.56	0.98
9	20.60	12.38	2.28	18.28	1.00
10	29.74	12.40	2.50	16.83	1.06
11	31.34	12.27	2.47	17.16	1.19
12	31.80	12.58	2.47	17.33	1.17
Average	29.27	12.84	2.28	18.06	1.08

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 every day of the verification test. Duplicate samples were analyzed to verify the precision of the analyses. Spiked samples were analyzed to verify the accuracy of those analyses and to determine the presence of effects due to the matrix sample. Duplicate and spiked samples were run after every ten samples. Data completeness refers to the proportion of valid, acceptable data generated using each method. 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. All 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 completeness of the data set was affected primarily by the lack of pathogen testing on the first four days of sample collection. There were also two test days during which the pH of the skimming samples and the trip blank were not taken. The data completeness parameter was calculated as described in the test plan and was 97 percent.

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	102	0.97	99	4.3
Ammonia nitrogen	100	0.30	N/A	N/A
Total phosphorus	102	2.4	102	1.2
Ortho phosphorus	106	1.1	101	0.7
Potassium	99	8.2	103	13
Chloride	103	0.55	103	1.5
Copper	98	7.7	99	11
Zinc	100	8.6	99	5.9

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, in the liquid effluent, and in the skimming liquid. The system performance is measured by the completeness of the mass balance – whether all of the mass of each parameter going into the centrifuge is what comes out of the centrifuge. The recovery is different for each quality parameter as previously shown in Table 4-1.

The recovery of most parameters was acceptable at near 90 percent or above. However the recovery of phosphorus was less than expected. As with the other analyses, the phosphorus analysis was always within control limits, duplicates were within acceptable limits, and spiked samples showed no matrix effects. As mentioned earlier, the partitioning of phosphorus between solids and liquids was approximately equal.

Chloride recovery was above 95 percent with most of that (93 percent) found in the liquid effluent. This indicates that the mass balance approach was quite acceptable, especially for those parameters found mostly in the liquid phase.

Copper and zinc had the lowest recoveries at 74 percent and 78 percent, respectively. As with the other analyses, the metal analyses were always within control limits, duplicates were within acceptable limits, and spiked samples showed no matrix effects in either the solid or liquid phase.

While the recoveries from the mass balance would ideally be within ± 10 percent of 100 for this type of work, lower recoveries are common due to the complex nature of both the wastewater and separated solids. The flushed swine waste entering the treatment unit included colloidal and suspended solids as well as larger aggregates of organic waste, microbial biomass, and undigested feed. Mixing of the influent, as was done during the verification test, increases the opportunities to obtain consistent samples but cannot overcome the inherent heterogeneity of the wastewater. Sampling anomalies may have occurred, resulting in some of the influent samples, collected in triplicate, containing larger amounts of solids than were consistent with the rest of the influent.

Recovery of some parameters is also influenced by the additional sample preparation required for solid samples and the lower precision of quantifying solids compared to liquids. This is a practical consideration that is inherent in this type of analysis and not an artifact of the laboratory or the equipment being evaluated. The data quality indicators demonstrate the analytical procedures performed within expected limits.

Chapter 6
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) 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.

4) 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.

5) 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 TS-5000
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 (mean) of a number of measurements to the true value, and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Comparability - a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

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 verification of environmental technologies and issue Verification Statements and Verification Reports.

Verification report - a written document that details 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 Verification Test Plan(s) 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 QA/QC requirements relevant to the specific technology as installed at the test site.

Watershed Protection Stakeholder Advisory Group - a group of individuals, established by the VO, consisting of any or all of the following: buyers and users of solids separators and other technologies, developers and vendors, consulting engineers, the finance and export communities, and permit writers and regulators.