

**ENVIRONMENTALLY SUPERIOR
TECHNOLOGY**

ORBIT/HSAD

“On-campus Report”

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Executive Summary

The objective of this study was to evaluate the effectiveness of the innovative high solids anaerobic digestion (HSAD) technology in treating swine waste. This technology is distinctive from other anaerobic processes in that relatively high solid concentrations, viz., greater than 30 percent, can be digested. The digestion is accomplished by thermophilic anaerobic bacteria. The evaluation was made at the ORBIT facility in Sampson County, NC. Swine waste was provided by the SuperSoil Systems (SSS) facility at Goshen Farm in Duplin County, NC.

The following analyses were conducted on the swine waste prior to and following anaerobic digestion during a 70-day test period: 1) Solids percentage; 2) Total nitrogen (N); 3) Ammonia (NH₃); 4) Phosphorus (P); 5) Copper (Cu); and 6) Zinc (Zn). Biogas production was measured by the technology provider. Pathogens were identified and assessed by the OPEN team. The solids content of the original swine waste feedstock was approximately 15%, about one-half of the content required to meet the high solids criterion of at least 30%. The solids content of the processed feedstock was approximately 11%. However, the total quantity of solids before and after processing was about the same.

Total N diminished by approximately 50% during processing. Ammonia decreased by about 72%. Reductions in P, Cu, and Zn were 26%, 46%, and 32%, respectively. The technology provider reported the production of large amounts, up to 81,500 liters per day, of methane. The OPEN team reported the destruction of almost all the harmful pathogens. These results indicate that this system quantitatively eliminates unaccounted-for discharges of critical elements and compounds into the environment.

Several factors limited the evaluation of the technology: 1) Inadequate quantities of swine waste to utilize the full capacity of the system; 2) Variable composition of the swine waste feedstock; 3) Brevity of the evaluation period, 70 days. Despite these limitations, the evaluation indicates that the HSAD system is a promising innovative technology.

ORBIT High Solids Anaerobic Digestion (HSAD) Technology General Description

This innovative technology utilizes thermophilic anaerobic digestion and bacteria adapted to these conditions (54.4°C as goal) to digest the solids in swine waste, recover energy in the form of biogas, and eliminate pathogenic organisms. This system is distinctive from most other anaerobic processes in that relatively high solid concentrations, e.g., >30% (35-40% preferred), can be digested. The effectiveness of HSAD is based on the theory of film transfer of digestive products between anaerobic microbes in a high-solids environment. The synergistic interaction of thermophilic organisms and high solid concentrations should reduce the construction and operating costs of the HSAD system when compared to conventional mesophilic (34°C) systems.

A schematic diagram of the HSAD flow process for treatment of swine waste is shown in Figure 1. A logistical layout of the facility as actually constructed in Sampson County, NC is depicted in Figure 2.

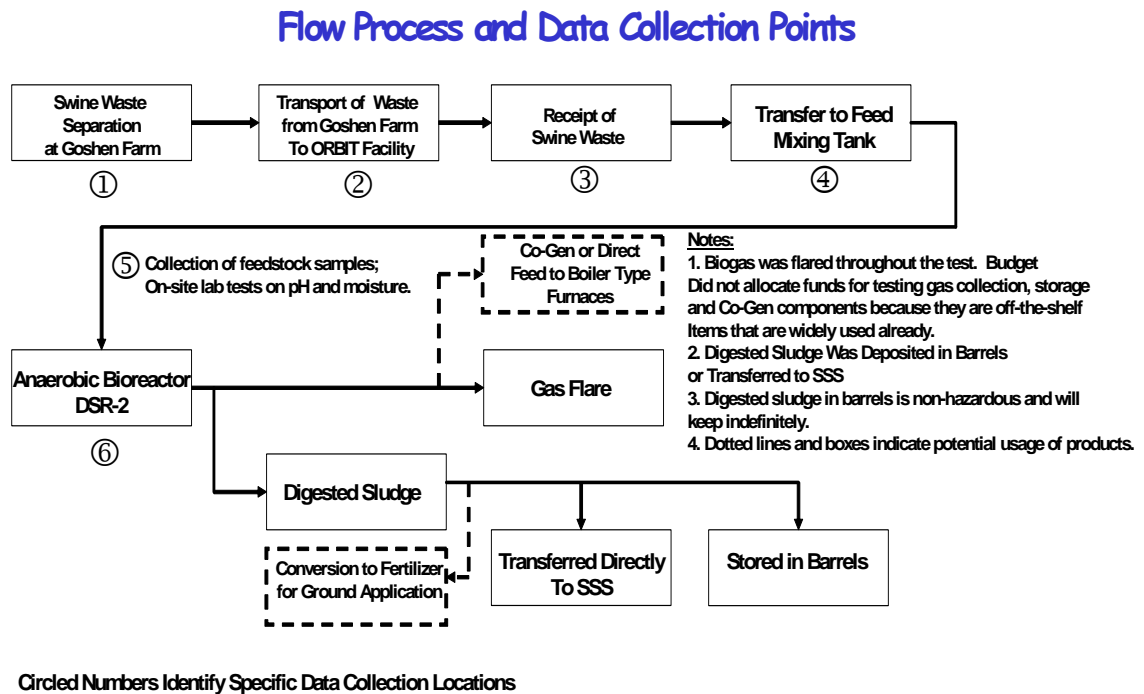


Figure 1. Flow Process for HSAD Treatment of Swine Waste

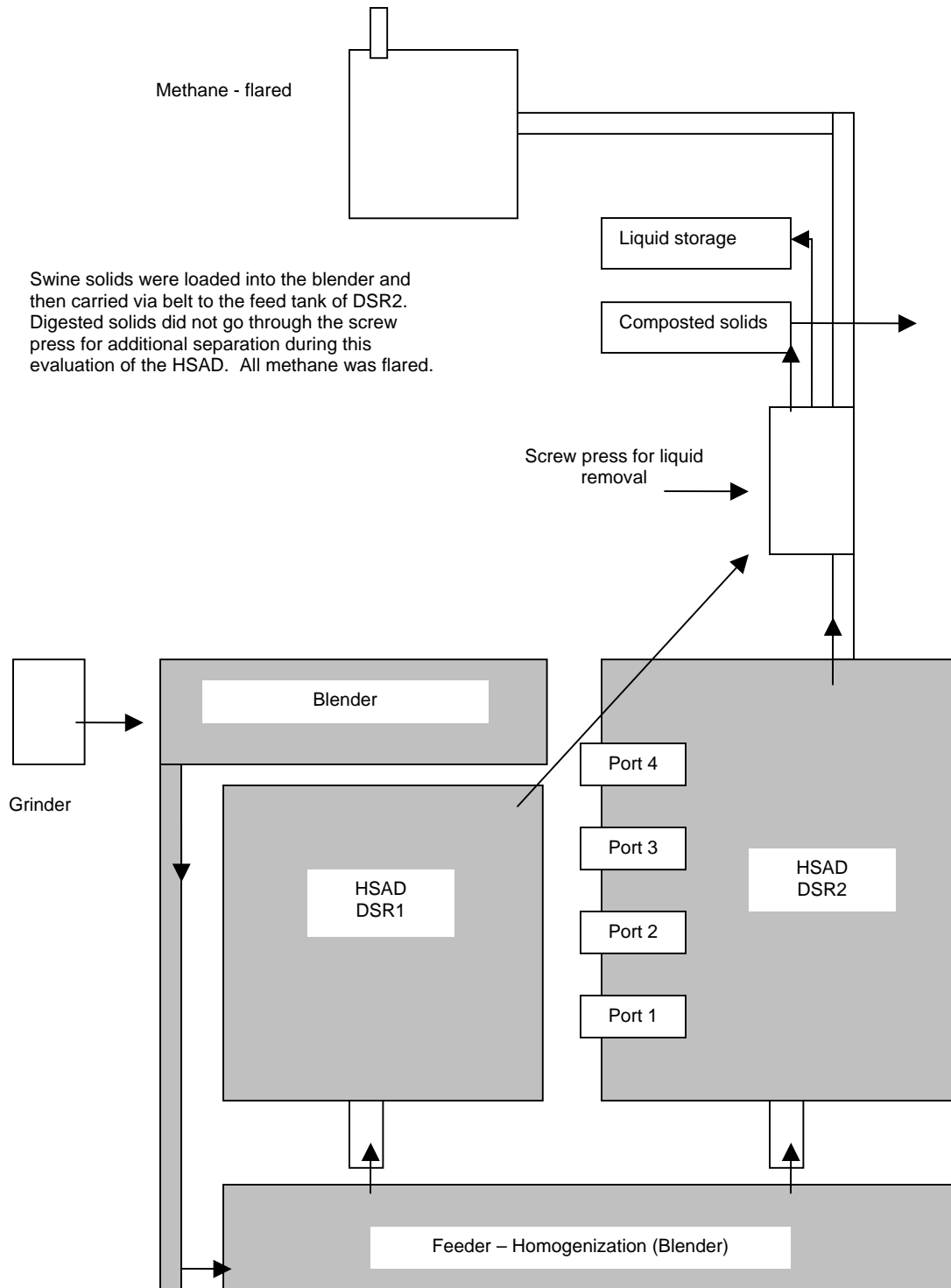


Figure 2. Spatial Arrangement of ORBIT Site, Showing Two HSAD Units, Feedstock Flow and Location of Sampling Ports in Test Digestion System (HSAD DSR2), Liquid/Solid Separation Unit (not used) with Flow of Separated Solids and Liquid, and Biogas (Methane) Collection/Flaring Unit

Swine waste was collected at the SuperSoil Systems (SSS) facility at Goshen Farm in Duplin County, NC. (By contract, this was the sole source of material to be used in the evaluation. Prior to this evaluation, food preparation and dining hall waste was processed in the digestion units as part of a contract with the US Army and was used as the initial charge of feedstock to the DSR2 unit.) The swine waste received from SSS had been treated with chemical additions to remove nutrients. The description of that process can be found in the report on the SSS system. Swine waste was transported to the ORBIT facility in Sampson County and emptied into a large rotary ribbon blender for mixing. ORBIT personnel (hereafter referred to as “technology provider”) weighed the feedstock daily and checked it for moisture content, pH and toxicity. The feedstock was then fed via screw conveyors to a 4-ton capacity surge bin, where precise rates for application of it to the digester were determined. The feedstock was transferred to the digester via a pneumatically retractable and heated screw conveyor, with target temperature of the feedstock to be 54.4°C at the time of introduction into the digester. This process required from two to five hours, at which time the digester was sealed until the next feeding period (approximately 24 hours).

The digester was heated to 54.4°C by means of thermostatically controlled heaters in integral contact with the vessel walls. The contents were gently stirred to release the continual development of biogas, which was removed from the digester, measured (volume) and disposed of by flaring. The preferred commercial fate for the biogas is as an energy source with value recovered to help support the operation of the system. Daily digestate samples were collected from four ports evenly spaced along the length of the digester.

The schematic diagram indicates that there is provision for separation of the liquid and solid fractions of the digestate exiting the unit for subsequent value-added product development, e.g., liquid fertilizer, compost. That step was not employed in this testing program due to financial constraints. In addition, the biogas produced during this test was flared rather than being used as a recoverable energy source. In a full-scale production application of HSAD, it is expected that liquid and solid products would be produced and that the collected biogas would be used as an energy source to provide revenue streams. Without data, however, this report cannot address those components.

Performance Parameters Covered in this Report

The focus of this report is to describe the fate (destruction or recovery with containment) of the following materials and nutrients associated with the feedstock entering the digester and digestate exiting the digester: a.) solids; b.) total nitrogen; c.) feedstock and digestate ammonia (NH₃); d.) phosphorus; e.) copper; f.) zinc. All of these components were measured according to the requirements of the Agreements, indicating that a third party collected, secured, transported and analyzed the samples. Numerous other data were gathered during the project by the technology provider. Some of those, especially the methane production that is central to anaerobic digestion, are included among the Appendices to this report. They are designated in each case as being “Collected by the Technology Provider” in each case for clarity. This report emphasizes

the specific components noted above and it also includes a discussion of system operational requirements, considerations and recommendations.

The design and purpose of the total containment ORBIT/HSAD system, as noted above, is to process high-solids (35-40 % solids) biomass at thermophilic anaerobic conditions (54.4°C) with extraction of recoverable and usable energy as methane, elimination of odor producing compounds, expected elimination of pathogens by virtue of the temperature used, and recovery and control of nitrogen forms and mineral elements (especially phosphorus, copper and zinc). A documented advantage of the thermophilic digestion process is the elevated rate of reaction and therefore theoretically reduced process (retention) time. By virtue of the total containment and quantitative collection of exiting material, protection of groundwater and the surrounding environment is assured. Theoretically, any non-volatile element added to a single-vessel component system should be quantitatively recovered and, thus, can serve as the basis for calculation of mass-balance. Because of the sealed nature of the system and the fact that it was sited at a location which had no animal production, the only emissions that would be expected (ammonia, odors) would be those associated with the handling of the feedstock prior to introduction into the system, and the subsequent handling of the digestate exiting from the system. The extent of those possible events (emissions) would be dictated by the nature of the material and the operational procedures employed by the technology provider.

Prior to swine solids being introduced, material from testing done previously using food residue material was put into the unit to “seed” the thermophilic anaerobic digestion process. Swine waste feedstock was introduced into the unit from August 19-29, from October 24-November 4, and from November 6-29, 2003 (Appendix Table 4). Due to the interrupted feeding schedule and variable quantities of feedstock introduced as a result of variable availability, “steady state operation” was never achieved during this test. The expected retention time of material in the digestion unit was anticipated to be from 7-21 days, depending on loading rate. Due to the variable and interrupted loading rate, it is not possible to calculate an average retention time. Consequently, data are presented in this report based on three different estimated retention times. The fact that the feeding rate was never more than about 20 percent of the capacity of 5,400kg/day (technology provider estimate) would suggest that the retention time was longer than would be observed under full-operating, steady-state conditions. Also, nutrient recovery evaluation would require collection of digestate for an extended time after cessation of feeding of the material. The total period for collecting data was September 11 through November 29, 2003. This period coincided with the availability of swine waste feedstock and the monitoring of ammonia emissions, odors and pathogens by the OPEN team. The test ended ahead of schedule due to operational and financial difficulties. That made this evaluation more difficult to conduct than originally intended.

As noted earlier, the digestate was not processed to separate liquid and solid fractions. Thus, there are no data on the distribution of nutrients between those components. The digestate was collected in 55-gallon barrels, which were sealed and stored for future use. All biogas produced was flared.

Tables of Primary Data and Calculations

All of the critical data required for this evaluation are summarized in Tables 1 and 2 below. The sampling schedule and a complete dataset for all of the analyses are found in Appendix Tables 1 and 2. These data are based on the quantities introduced into and removed from the digestion unit, and the analysis of samples taken by the On-Campus team, with all subsequent chemical analyses conducted by the Division of Agronomic Services of the North Carolina Department of Agriculture and Consumer Services.

During the test period, eight samples of the material being introduced into the digestion unit were taken and analyzed. Because the performance is based on the difference between what is introduced and what is recovered from the material introduced, and to assure that previously processed food-waste material was totally cleared, only five samples of the material exiting the digestion unit were analyzed. This is based on the originally estimated retention time of 21 days provided by the technology provider (not actually measured-see below). All material introduced into the digestion unit was weighed daily by the technology provider, and all material collected from the digestion unit was weighed by On-Campus team members. The digestion unit is equipped with four sampling ports as described above and shown in Figure 2. Ports 1-3 were used as indicators of internal change in composition during processing. Port 4 was at the point of discharge from the unit. The results of all of those analyses are found in Appendix Table 2. The port 4 sample analyses were used as indicative of the composition of the discharge material resulting from the processing of swine waste by the unit, although a review of the data from ports 1-3 suggest that the majority of digestive activity was completed in the first portion of the digestion unit. The results shown in Table 1 are calculated based on 7, 14 and 21 day estimated retention times due to the variable feedstock addition schedule and the relatively low feeding rate (related to capacity). The difference between each of these calculations is the fact that digestate weight was included from those periods (7, 14, 21 days) after the last feeding to accommodate those three retention time estimates.

Table 1. Processing / Recovery Of Swine Waste Solids / Nutrients By ORBIT / HSAD

Parameter	Quantity In	Quantity Out	Loss/(Gain)	Loss/(Gain)	Recovery
--	kg	kg	kg	%	%
		<u>7-day Estimated Retention Time</u>			
Total Weight	30,706	30,976	(270)	(0.9)	100.9
Solids	4,636	3,314	1,321	29	72
Total Nitrogen	1,424	621	803	56	44
Ammonia	87	25	62	71	29
Phosphorus	683	507	176	26	74
Copper	69	37	32	46	54
Zinc	45	31	14	31	69

Table 1. Processing / Recovery Of Swine Waste Solids / Nutrients By ORBIT / HSAD (continued)

<u>Parameter</u>	<u>Quantity In</u>	<u>Quantity Out</u>	<u>Loss/(Gain)</u>	<u>Loss/(Gain)</u>	<u>Recovery</u>
--	kg	kg	kg	%	%
<u>14-day Estimated Retention Time</u>					
Total Weight	30,706	34,347	(3,641)	(84)	108
Solids	4,636	3,675	961	21	79
Total Nitrogen	1,424	689	735	51	49
Ammonia	87	28	59	68	32
Phosphorus	683	562	121	18	82
Copper	69	42	27	39	61
Zinc	45	34	11	24	76
<u>21-day Estimated Retention Time</u>					
Total Weight	30,706	40,054	(9,348)	(30)	130
Solids	4,636	4,285	350	8	92
Total Nitrogen	1,424	804	620	44	56
Ammonia	87	32	55	63	37
Phosphorus	683	656	27	4	96
Copper	69	49	20	29	71
Zinc	45	40	5	11	89

Notes on Table 1 data:

- a. Analytical data are found in Table 2. Complete analyses are found in Appendix Table 2.
- b. Values in () represent gain in weight.

Table 2. Composition Of Digestion Input And Output Used In Table 1 Computations

<u>Sample Source</u>	<u>n</u>	<u>Solids</u>	<u>TotalN</u>	<u>NH3</u>	<u>P</u>	<u>Cu</u>	<u>Zn</u>
--	--	%	ppm	ppm	ppm	ppm	ppm
Input Material	8	15.1	40637	2841	22242	2252	1472
Std. Dev.		3.1	14873	2636	6803	955	527
Output Material	5	10.7	20063	808	16379	1212	996
Std. Dev.		.64	4837	1039	4504	549	267

Notes on Table 2 data:

- a. Nutrients in Parts Per Million (ppm) as-received basis (1 ppm = 1 mg/1000g).
- b. Input material at 15.1 percent solids from supplier was at less than 50% of system performance design and recommended specifications (35-40%).
- c. Output material is collected from port 4 of the digestion unit. All data for all samples shown in Appendix Table 2.

Weight Differences

The fact that the weight of material added to the digestion unit was less than that removed for each of the Estimated Retention Times is baffling. A partial explanation may be that there was a lower solids content in the removed material than that added. With extension of the digestate collection period to accommodate the longer Estimated Retention Times, the weight difference increased. Since weight is not a critical parameter *per se*, and since there are concerns about the irregular feeding patterns and unknown retention times, no further discussion of the wet weight data will be made.

Solids Decomposition and Methane Production

The primary interest in solids disappearance is related to the production of biogas (methane and carbon dioxide) as a method for extraction of useful energy from the system in a form that has added value. Data collected by the technology provider (see Appendix Table 3) indicated that the swine waste solids contained 79% of volatile solids (VS), and that the conversion of those VS to biogas was predicted to be 51% based on theoretical calculations. This should have resulted in a **reduction** in solids passing through the digestion unit of about 40%. That reduction was not achieved under any of the Estimated Retention Times. The data on estimated and measured methane production (Appendix Figure 1, provided by technology provider) show variable production rates during the time of actual measurement (10/31-11/27/03). The range in daily methane yield is from 0-81,500l/day. In some cases the yields reported were above theoretical estimates, and in other cases they were below. We believe that the variable flow created by the feeding pattern noted above is responsible for these variations.

Accountability for Nitrogen

Ability to account for, contain and manage nitrogen within a waste processing system is an important performance parameter. In a component and sealed system such as ORBIT/HSAD, the tracking of nutrients should be relatively easier than in more complex, multi-component systems with numerous transfers and partitioning functions.

The nitrogen analysis data from the samples taken of input and output material are found in Table 2 above. Total nitrogen balance (all forms) across the digestion system during the 70-day test interval is shown in Table 1. Only 44-56% of the nitrogen introduced into the system can be accounted for. The specific percentage depends on the Estimated Retention Time used. That recovery is disappointing. We attribute these differences to a combination of uncertainties associated with the weights obtained, the small number of digestate samples (5) that were collected and analyzed, the lack of steady-state operation, and uncertain retention time. These erratic findings point to the need for steady-state operation with an extended sampling period in future evaluations. The unaccounted-for nitrogen, other than that due to analytical and sampling causes, could be partly due to a small amount exiting with the produced biogas. This is not considered a major loss avenue due to the pH of the digestion mixture (7.5-8.3).

Accountability for Ammonia

The concentrations of ammonia in the input and output samples are shown in Table 2 above. There is a concentration decrease of nearly 75% between input and output. The balance of ammonia calculated from those data indicates that from 63-71% was lost during the process, depending on the Estimated Retention Time used. The same uncertainties can be assigned to these data as are noted above, including the possibility that some ammonia was lost in the biogas stream. The report of the OPEN team evaluations of this site (see OPEN team report) suggests that ammonia emission at this site was not high. Ammonia was detectable around the digestion site, and that may have been due to the combination of some emissions from the feedstock, the digestate, and the fact that there was an operating composting facility on the same site located “upwind” from the ORBIT facility.

Accountability for Phosphorus

The recovery data for phosphorus are shown in Table 1. Concentrations of total phosphorus in samples of input and output materials to the digestion unit are found in Table 2. The balance of phosphorus calculated from those data and the weights of materials resulted in our being unable to account for from 3.9-26% of the input phosphorus, for the three Estimated Retention Times. In a closed system such as this, the expected theoretical recovery is 100% for a non-volatile mineral such as phosphorus under extended steady-state conditions. It is anticipated that a full recovery of phosphorus would occur if tests were conducted under steady-state conditions created by a more nearly constant feeding protocol.

A common practice in many analytical procedures is the use of a non-volatile element as an internal marker that allows adjustment of all data to an assumed 100 percent recovery of that marker. That probably would have been useful in this evaluation. While phosphorus may not be the element of choice, an extensive and statistically-based evaluation of all of the non-volatile mineral elements included in the analyses conducted as part of this project could yield candidates for consideration in future testing. A review of the data in Table 1 suggests that the true retention time for the system under the conditions employed would be slightly longer than 21 days to achieve 100% recovery of phosphorus. The same projections could be made using other non-volatile elements.

Accountability for Copper

The balance of copper through the system is shown in Table 1. As a point of interest, the animals from which the waste was collected prior to pre-processing (Super Soil, USA) in this study were managed to the exclusion of sub-therapeutic use of antibiotics in production, but with elevated levels of dietary copper as an alternative. For that reason, copper concentration in the material processed here was notably high (Table 2). Based on those data, the unaccountability for copper during the test period ranged from 29-46% of that put into the system, for the three Estimated Retention Times. One

could use the same approach here as for phosphorus, and estimate that under the conditions used, exiting digestate collection would have needed to be measured and sampled for longer than the 21-day period used at the end of the test period to achieve full copper recovery.

Accountability for Zinc

The balance of zinc through the system is shown in Table 1. Zinc concentrations in material put into and collected from the digestion unit are shown in Table 2. Based on those data, the unaccountability of zinc during the test period ranged from 11-31% of the amount introduced. As with the results for phosphorus and copper balances noted above, a quantitative recovery of zinc should be expected during steady-state operation for an extended time, and these data suggest that to be the case, with a retention time that is longer than that used in this test.

Operating Considerations

The ORBIT/HSAD system is designed to operate with a feedstock solids content of 35-40 percent for optimal biogas production and value-added product output. The solids content of the feedstock used in this study averaged 15.1 percent during the 70-day evaluation period. Thus, optimal performance of the high solids feature of the system was probably not realized. It is difficult to ascertain from this brief study if a high solids content of feedstock is essential for the system to qualify as an effective new technology option. Obviously, the description of the high solids aspect of the system would need to be modified in the event that the solids content of the feedstock does not reach the levels for which the system was designed.

It is notable that the OPEN team evaluation (to be found elsewhere) indicated that the HSAD system performed extremely well in pathogen destruction.

The system requires an adequate and consistent supply of feedstock to attain maximum efficiency. In addition to the low solids content noted above, the swine waste solids provided for the operation of the system were deficient in quantity and variable in composition. The potential capacity of the system is approximately 6,000 kg per day. The average feeding rate during the 70-day trial was 270 kg per day. Large variations in the amounts of nitrogen, ammonia, phosphorus, copper, and zinc in the feedstock were noted earlier in this report. These deficiencies limited the function of the system and, hence, any evaluation of the system.

Large amounts of solid digestate were produced by the digestion process. A utilization plan for these solids needs to be developed. A conceivable use is as a soil amendment. Storage of the byproducts in 55-gallon barrels, the current practice, is an inadequate long-term solution.

Large amounts of biogas high in methane were produced by the operation. The disposition and/or utilization of this gas need to be addressed. The disposal of the methane-rich material by flaring may pose an environmental concern. The large amounts of methane (up to 80,000 liters/day) can be viewed positively as a source of energy when properly utilized.

The system requires at least one skilled operator. Additional personnel are likely required if the system is adopted as a regional collection facility. The operator must have a high school education as a minimum. The operator needs to receive adequate training that includes detailed information on equipment, its operation and maintenance, identification and reporting of malfunctions, and troubleshooting. The training should also include health and safety requirements, and record keeping.

Attention needs to be given to biosecurity. It appears that there are no compliance measures for personnel entering and leaving the property.

Discussion

The ORBIT/HSAD system represents a single vessel component for waste management, unlike the more comprehensive and multi-component or multi-compartmental systems. For that reason, the entire performance evaluation is based on a single set of input and output samples taken across the digestion unit. The transit time of material through the digestion system was projected by the technology provider to be between 7-21 days. It is based on continual feedstock introduction and modest mixing of the feedstock during that transit. These processing actions should cause the samples of effluent to reflect the composition of influent 7-21 days earlier plus the influence of internal mixing during transit. If the system operated with a constant feeding rate (which was not possible due to erratic feedstock supply and periods of interrupted feeding), and if the composition of the feedstock was relatively constant, a mass balance could be calculated that would represent the true operational capability of the system.

Steady state operation is a definite requirement for any system of this type in order to achieve reliable estimates of mass balance of any of the critical nutrients associated with this performance verification program. Since that condition was not achieved, as discussed in this report, these data are limited in their interpretation within the context of the conditions of this test period.

These data suggest strongly that in order for a truly functionally and economically representative test of the ORBIT/HSAD system to take place the following would have been needed:

- a. Feedstock availability daily at a quantity consistent with the capacity of the system (**not achieved in this test and a serious disadvantage**);
- b. Feedstock composition of either low variability or accompanied by daily aliquot sampling for analysis (**not achieved in this test**);
- c. Daily representative sampling of effluent discharged from the digestion unit for analysis (**not achieved in this test**).

Prior to the initiation of the swine waste solids tests upon which this report is based, a very successful test was conducted by ORBIT/HSAD using food waste under contract with the U. S. Army (Fort Bragg, NC). That test was reviewed and certified by the U. S. Army, and there are significant data contained therein that demonstrate the effectiveness of the HSAD process when operated at an appropriate feeding rate. The Executive Summary of that report is found in the Appendix of this report.

APPENDICES

Appendix Table 1. Sample Collection Schedule for HSAD System During Test Period

Date	Feed tank	Port 1	Port 2	Port 3	Port 4
8/20/03	X	N/A	N/A	N/A	N/A
8/27/03	X	X	N/A	N/A	N/A
9/3/03	X	X	X	N/A	N/A
9/17/03	X	X	X	X	N/A
9/22/03	X	X	X	X	X
9/29/03	X	X	X	X	X
10/13/03	--	X	X	X	X
10/20/03	X	X	X	X	X
11/12/03	X	X	X	X	X

Notes: a. N/A indicates dates when no sample were taken based on expected transit time for material through digestion unit.

b. No sample was available on 10/13/03

Appendix Table 2. Analyses of Feedstock and Sampling Port Samples from HSAD System During Test Period, as Reported by NCDA and CS Agronomic Laboratory (all in ppm, wet basis except DM, %)

Date	Sample	Code	N (total)	IN-N	NH4	NO3	OR-N	Urea	P	Zn	Cu	%DM
*8/20/2003	feedstock	O1	51142	656	649	7.45	50486	1.86	15301	1159	1639	21.29
8/27/2003	feedstock	O1	37701	1125	709	416	35876	22.1	17610	1485	2605	17.46
9/3/2003	feedstock	O1	53233	6897	6772	125	46337	23.9	31288	1958	3157	11.9
9/17/2003	feedstock	O1	17792	965	925	40	16827	12.6	14885	761	973	12.87
9/22/2003	feedstock	O1	45459	3725	3431	320	42708	359	22518	1803	2902	13.96
9/29/2003	feedstock	O1	17958	45.3	35.2	10.1	17913	0.55	18326	959	994	12.09
10/13/2003	feedstock	O1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
10/20/2003	feedstock	O1	50482	6118	6021	97	44364	20.9	31405	2292	3447	15.58
11/12/2003	feedstock	O1	51330	4309	4191	118	47021	39	26602	1359	2299	15.29
		Mean	40637.13	2980.04	2841.65	141.69	37691.50	59.99	22241.88	1472.00	2252.00	15.06
		Std dev	14872.70	2646.45	2635.73	149.07	13228.67	121.46	6803.04	520.68	955.48	3.16
8/27/2003	Port 1	O2	14235	1417	1016	401	12818	11.3	8257	422	448	9.79
9/3/2003	Port 1	O2	14173	907	816	90.1	13267	7.27	12761	538	577	11.9
9/17/2003	Port 1	O2	12594	319	298	21	12275	5.12	12496	563	622	12.28
9/22/2003	Port 1	O2	20283	1006	756	250	19277	152	11356	749	856	11.52
9/29/2003	Port 1	O2	15897	35.6	26.3	9.33	15861	0.73	14665	752	782	10.86
10/13/2003	Port 1	O2	15262	57.3	44.7	12.5	15205	0.98	14301	987	927	9.87
10/20/2003	Port 1	O2	28714	2964	2735	229	25750	12.3	20634	1293	1829	12.31
11/12/2003	Port 1	O2	19099	1525	971	554	17574	19.6	16857	836	1231	11.41
		Mean	17532.13	1028.86	832.88	195.87	16503.38	26.16	13915.88	767.50	909.00	11.24
		Std dev	5201.97	970.37	864.77	201.62	4446.07	51.23	3711.34	278.64	443.12	0.99

Date	Sample	Code	N (total)	IN-N	NH4	NO3	OR-N	Urea	P	Zn	Cu	%DM
9/3/2003	Port 2	O3	11157	609	542	67	10549	7.8	12300	523	528	12.02
9/17/2003	Port 2	O3	12655	370	329	41.4	12275	0	10182	473	540	10.57
9/22/2003	Port 2	O3	16842	820	580	239	16023	22.7	10609	656	725	11.3
9/29/2003	Port 2	O3	16860	40.4	31.6	8.85	16819	0.78	16853	914	829	10.87
10/13/2003	Port 2	O3	15660	45.5	34	11.5	15615	0.65	13694	890	819	10.82
10/20/2003	Port 2	O3	28208	2812	2710	102	25396	13.7	21791	1319	2062	13.09
11/12/2003	Port 2	O3	15705	818	730	87.6	14888	24.1	16542	833	1234	10.76
		Mean	16726.71	787.84	708.09	79.62	15937.86	9.96	14567.29	801.14	962.43	11.35
		Std dev	5502.02	950.04	922.66	78.78	4724.10	10.42	4125.29	287.50	539.25	0.91
9/17/2003	Port 3	O4	13295	425	343	81.4	12870	5.65	11693	509	549	11.64
9/22/2003	Port 3	O4	19301	903	622	281	18398	11.8	9869	692	781	11.41
9/29/2003	Port 3	O4	27603	55.1	46.1	9	27547	0.81	22364	1384	1507	10.27
10/13/2003	Port 3	O4	19097	46.5	35.5	11	19051	0.87	13631	979	918	8.7
10/20/2003	Port 3	O4	29021	3583	3475	109	25438	27	23672	1362	2097	12.55
11/12/2003	Port 3	O4	17218	942	874	67.3	16276	25.3	18339	901	1335	11.55
		Mean	20922.50	992.43	899.27	93.12	19930.00	11.91	16594.67	971.17	1197.83	11.02
		Std dev	6133.17	1327.93	1303.48	100.17	5561.87	11.76	5735.17	352.05	564.97	1.35
9/22/2003	Port 4	O5	17626	791	569	222	16835	8.81	11116	735	828	10.95
9/29/2003	Port 4	O5	18061	49.4	34.7	14.6	18012	0.55	16950	958	912	10.63
10/13/2003	Port 4	O5	17651	45.2	33.7	11.6	17606	0.7	13518	933	839	10.66
10/20/2003	Port 4	O5	28702	2680	2557	123	26022	15.5	23019	1448	2108	11.24
11/12/2003	Port 4	O5	18273	949	846	103	17324	23.7	17295	908	1376	9.56
		Mean	20062.60	902.92	808.08	94.84	19159.80	9.85	16379.60	996.40	1212.60	10.61
		Std dev	4837.38	1076.67	1038.64	87.17	3859.93	9.94	4503.86	267.20	549.16	0.64

Appendix Table 3. Technology Provider's Daily Operation Log - Biogas Production Data

Day	Date	Comments	Ave. Temp C°	Biogas (CH4) measured L/day	Theoretical CH4 prod L/day
Friday	01-Aug-03	(Technology supplier's daily operation log)	29		
Saturday	02-Aug-03		34		
Sunday	03-Aug-03		37		
Monday	04-Aug-03		38		
Tuesday	05-Aug-03		38		
Wednesday	06-Aug-03		39		
Thursday	07-Aug-03		39		
Friday	08-Aug-03	Got heat going to DSR2.	29		
Saturday	09-Aug-03		39		
Sunday	10-Aug-03		43		
Monday	11-Aug-03		29		
Tuesday	12-Aug-03		39		
Wednesday	13-Aug-03		44		
Thursday	14-Aug-03		39		
Friday	15-Aug-03		43		
Saturday	16-Aug-03		46		
Sunday	17-Aug-03		48		
Monday	18-Aug-03		50		
Tuesday	19-Aug-03	Fed pig waste from SSS for the first time.	49		0
Wednesday	20-Aug-03	Opened hot water pump wide open yesterday.	49		0
Thursday	21-Aug-03		50		15347
Friday	22-Aug-03	Opened DSR1 heater to DSR2 at 10:00 am. Explosion.	53		15046
Saturday	23-Aug-03		51		8090
Sunday	24-Aug-03		48		8090
Monday	25-Aug-03	Turned heaters back on with door open.	45		8090
Tuesday	26-Aug-03		48		8090
Wednesday	27-Aug-03	Heater breaker failed - switched breakers - found skint wire.	50		8090

Day	Date	Comments	Ave. Temp C°	Biogas (CH4) measured L/day	Theoretical CH4 prod L/day
Thursday	28-Aug-03	(Technology supplier's daily operation log)	51		8090
Friday	29-Aug-03		57		14800
Saturday	30-Aug-03		59		0
Sunday	31-Aug-03		58		0
Monday	01-Sep-03		57		0
Tuesday	02-Sep-03		56		0
Wednesday	03-Sep-03		55		0
Thursday	04-Sep-03		55		0
Friday	05-Sep-03		54		0
Saturday	06-Sep-03		55		0
Sunday	07-Sep-03		55		0
Monday	08-Sep-03		55		0
Tuesday	09-Sep-03		54		0
Wednesday	10-Sep-03		55		0
Thursday	11-Sep-03		55		14800
Friday	12-Sep-03	Not gassing except for slight bubbling.	56		14800
Saturday	13-Sep-03	Feeding	56		14800
Sunday	14-Sep-03	Feeding	56		14800
Monday	15-Sep-03	Waiting for Hurricane Isabella - mminor gassing.	56		14800
Tuesday	16-Sep-03	Discharging 5 drums - gassing very well thru sample port.	56		14800
Wednesday	17-Sep-03		56		14602
Thursday	18-Sep-03	Isabella due in this AM.	55		14602
Friday	19-Sep-03		55		34532
Saturday	20-Sep-03		54		34532
Sunday	21-Sep-03		54		34532
Monday	22-Sep-03	OPEN team evaluation	55		34532
Tuesday	23-Sep-03		54		34532
Wednesday	24-Sep-03		54		24074
Thursday	25-Sep-03		55		24074

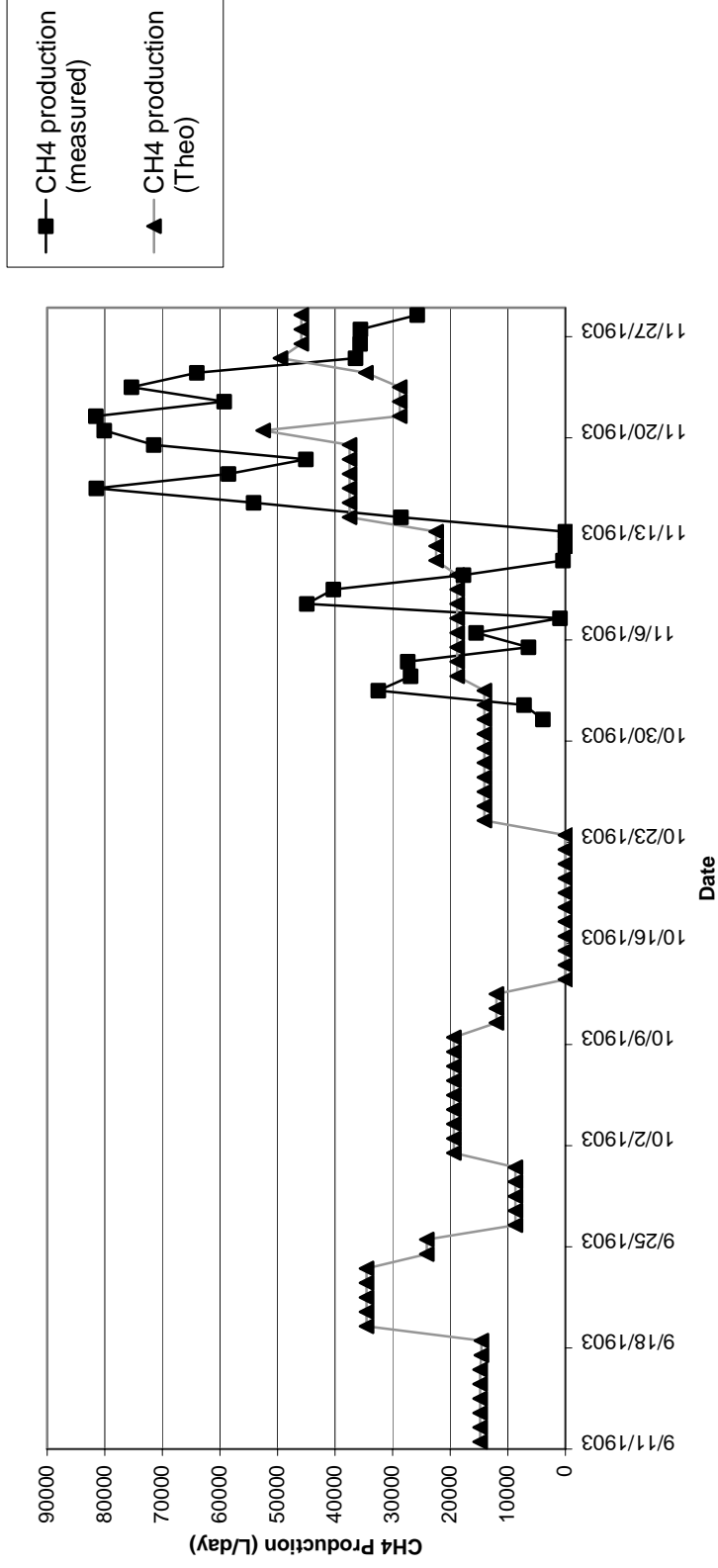
Day	Date	Comments (Technology supplier's daily operation log)	Ave. Temp C°	Biogas (CH4) measured L/day	Theoretical CH4 prod L/day
Friday	26-Sep-03		55		8682
Saturday	27-Sep-03		54		8682
Sunday	28-Sep-03		54		8682
Monday	29-Sep-03		53		8682
Tuesday	30-Sep-03		53		8682
Wednesday	01-Oct-03		55		19387
Thursday	02-Oct-03		64		19387
Friday	03-Oct-03		64		19387
Saturday	04-Oct-03		-		19387
Sunday	05-Oct-03		-		19387
Monday	06-Oct-03		62		19387
Tuesday	07-Oct-03		62		19387
Wednesday	08-Oct-03		-		19387
Thursday	09-Oct-03		61		19387
Friday	10-Oct-03		61		11988
Saturday	11-Oct-03		59		11988
Sunday	12-Oct-03		57		11988
Monday	13-Oct-03	Began reducing volume in DSR2 to enhance gas production.	54		0
Tuesday	14-Oct-03	Reducing volume (by discharging)	53		0
Wednesday	15-Oct-03	Reducing volume	50		0
Thursday	16-Oct-03	Reducing volume	51		0
Friday	17-Oct-03	Reducing volume	54		0
Saturday	18-Oct-03	Reducing volume	56		0
Sunday	19-Oct-03	Reducing volume	60		0
Monday	20-Oct-03	Reducing volume - OPEN team evaluation	60		0
Tuesday	21-Oct-03	Put boxes on heater coils.	59		0
Wednesday	22-Oct-03	Last of mass discharges will take place this weekend - normal feeding next week.	57		0
Thursday	23-Oct-03	Called FCI about DSR2 meter - will send out technician.	55		0
Friday	24-Oct-03	Feeding again	54		14060

Day	Date	Comments (Technology supplier's daily operation log)	Ave. Temp C°	Biogas (CH4) measured L/day	Theoretical CH4 prod L/day
Saturday	25-Oct-03		52		14060
Sunday	26-Oct-03		52		14060
Monday	27-Oct-03		52		14060
Tuesday	28-Oct-03		53		14060
Wednesday	29-Oct-03		52		14060
Thursday	30-Oct-03		51		14060
Friday	31-Oct-03	New DSR2 meter installed	52	3893	14060
Saturday	01-Nov-03		54	7182	14060
Sunday	02-Nov-03		58	32492	14060
Monday	03-Nov-03		60	26883	18795
Tuesday	04-Nov-03		62	27361	18795
Wednesday	05-Nov-03		62	6400	18795
Thursday	06-Nov-03		61	15503	18795
Friday	07-Nov-03		60	936	18795
Saturday	08-Nov-03		59	44906	18795
Sunday	09-Nov-03		59	40274	18795
Monday	10-Nov-03		59	17708	18795
Tuesday	11-Nov-03		59	412	22446
Wednesday	12-Nov-03		58	0	22446
Thursday	13-Nov-03		58	0	22446
Friday	14-Nov-03		57	28548	37492
Saturday	15-Nov-03		58	54132	37492
Sunday	16-Nov-03		58	81449	37492
Monday	17-Nov-03		58	58517	37492
Tuesday	18-Nov-03		58	45058	37492
Wednesday	19-Nov-03		56	71478	37492
Thursday	20-Nov-03		58	80086	52489
Friday	21-Nov-03		57	81547	28777
Saturday	22-Nov-03		58	59244	28777

Day	Date	Comments (Technology supplier's daily operation log)	Ave. Temp C°	Biogas (CH4) measured L/day	Theoretical CH4 prod L/day
Sunday	23-Nov-03		57	75359	28777
Monday	24-Nov-03		58	63995	34647
Tuesday	25-Nov-03		57	36439	49496
Wednesday	26-Nov-03		57	35638	45879
Thursday	27-Nov-03		57	35596	45879
Friday	28-Nov-03		56	25734	45879
Saturday	29-Nov-03		55	6	45879
Sunday	30-Nov-03		55	0	0
Monday	01-Dec-03		57	0	0
Tuesday	02-Dec-03		56	0	0
Wednesday	03-Dec-03		56	0	0
Thursday	04-Dec-03		57	110	0
Friday	05-Dec-03		55	458	45879
Saturday	06-Dec-03		55	384	0
Sunday	07-Dec-03		55	162	0
Monday	08-Dec-03		55	154	0
Tuesday	09-Dec-03		55	0	0
Wednesday	10-Dec-03		55	49	0
Thursday	11-Dec-03		55	1	0
Friday	12-Dec-03		56	4	0
Saturday	13-Dec-03		56	262	0
Sunday	14-Dec-03		55	844	0
Monday	15-Dec-03		55	438	0
Tuesday	16-Dec-03		53	186	0
Wednesday	17-Dec-03		53	16	0
Thursday	18-Dec-03		53	0	0
Friday	19-Dec-03		52	0	0
Saturday	20-Dec-03	No more swine waste available.	53	0	0
Sunday	21-Dec-03		53	0	0

Day	Date	Comments (Technology supplier's daily operation log)	Ave. Temp C°	Biogas (CH4) measured L/day	Theoretical CH4 prod L/day
Monday	22-Dec-03		52	0	0
Tuesday	23-Dec-03		52	0	0
Wednesday	24-Dec-03		53	147	0
Thursday	25-Dec-03		54	0	0
Friday	26-Dec-03		56	663	0
Saturday	27-Dec-03		57	686	0
Sunday	28-Dec-03		56	179	0
Monday	29-Dec-03		57	768	0
Tuesday	30-Dec-03		58	381	0
Wednesday	31-Dec-03		58	120	0
Thursday	01-Jan-04		59	953	0

CH4 Production - ORBIT (HSAD)



Appendix Figure 1. ORBIT Methane Production, Theoretical And Actual, As Determined By Technology Provider

Appendix Table 4. Technology Provider's Daily Operation Log – Feedstock Addition and Digestate Discharge Data

Date	Comments	Feedstock		Discharge		Mean	
		lbs	kg	lbs	kg	lbs	kg
Friday	01-Aug-03						
Saturday	02-Aug-03						
Sunday	03-Aug-03						
Monday	04-Aug-03						
Tuesday	05-Aug-03						
Wednesday	06-Aug-03						
Thursday	07-Aug-03						
Friday	08-Aug-03						
Saturday	09-Aug-03						
Sunday	10-Aug-03						
Monday	11-Aug-03						
Tuesday	12-Aug-03						
Wednesday	13-Aug-03						
Thursday	14-Aug-03						
Friday	15-Aug-03						
Saturday	16-Aug-03						
Sunday	17-Aug-03						
Monday	18-Aug-03						
Tuesday	19-Aug-03			660	300		
Wednesday	20-Aug-03			660	300		
Thursday	21-Aug-03			673	306		
Friday	22-Aug-03			660	300		
Saturday	23-Aug-03			660	300		
Sunday	24-Aug-03			660	300		
Monday	25-Aug-03			660	300		
Tuesday	26-Aug-03			660	300		
Wednesday	27-Aug-03			660	300		

Day	Date	Comments (Technology supplier's daily operation log)	As reported by tech supplier		NCSU APWMC		Mean	
			Feedstock lbs	kg	Discharge lbs	kg	lbs	kg
Thursday	28-Aug-03		660	300				
Friday	29-Aug-03		660	300				
Saturday	30-Aug-03		0	0				
Sunday	31-Aug-03		0	0				
Monday	01-Sep-03		0	0				
Tuesday	02-Sep-03		0	0				
Wednesday	03-Sep-03		0	0				
Thursday	04-Sep-03		0	0				
Friday	05-Sep-03		0	0				
Saturday	06-Sep-03		0	0				
Sunday	07-Sep-03		0	0				
Monday	08-Sep-03		0	0				
Tuesday	09-Sep-03		0	0				
Wednesday	10-Sep-03		0	0				
Thursday	11-Sep-03		660	300				
Friday	12-Sep-03	Not gassing except for slight bubbling.	660	300				
Saturday	13-Sep-03	Feeding	660	300				
Sunday	14-Sep-03	Feeding	660	300				
Monday	15-Sep-03	Waiting for Hurricane Isabella - mminor gassing.	660	300				
Tuesday	16-Sep-03	Discharging 5 drums - gassing very well thru sample port.	660	300				
Wednesday	17-Sep-03		660	300				
Thursday	18-Sep-03	Isabella due in this AM.	660	300				
Friday	19-Sep-03		660	300				
Saturday	20-Sep-03		660	300				
Sunday	21-Sep-03		660	300				
Monday	22-Sep-03	OPEN team evaluation start	660	300				
Tuesday	23-Sep-03		660	300	674.3	307		
Wednesday	24-Sep-03		660	300		0		
Thursday	25-Sep-03		660	300	578.0	263		

Day	Date	Comments (Technology supplier's daily operation log)	As reported by tech supplier		NCSU APWMC		Mean	
			Feedstock lbs	kg	Discharge lbs	kg	lbs	kg
Friday	26-Sep-03		660	300	274.7	125		
Saturday	27-Sep-03		660	300		0		
Sunday	28-Sep-03		660	300	247.2	112		
Monday	29-Sep-03		660	300	312.3	142		
Tuesday	30-Sep-03		660	300	611.7	278		
Wednesday	01-Oct-03		660	300	599.0	272		
Thursday	02-Oct-03		660	300		0		
Friday	03-Oct-03		660	300		0		
Saturday	04-Oct-03		660	300		0		
Sunday	05-Oct-03		660	300		0		
Monday	06-Oct-03		660	300	287.8	131		
Tuesday	07-Oct-03		660	300		0		
Wednesday	08-Oct-03		660	300	276.2	126		
Thursday	09-Oct-03		660	300	523.1	238		
Friday	10-Oct-03		660	300	886.7	403		
Saturday	11-Oct-03		660	300		0		
Sunday	12-Oct-03		660	300		0		
Monday	13-Oct-03	Began reducing volume in DSR2 to enhance gas production.	0	0	2573.1	1,170		
Tuesday	14-Oct-03	Reducing volume (by discharging)	0	0	4932.8	2,242		
Wednesday	15-Oct-03	Reducing volume	0	0	752.4	342		
Thursday	16-Oct-03	Reducing volume	0	0	6455.6	2,934		
Friday	17-Oct-03	Reducing volume	0	0	686.7	312		
Saturday	18-Oct-03	Reducing volume	0	0	3990.9	1,814		
Sunday	19-Oct-03	Reducing volume	0	0		0		
Monday	20-Oct-03	Reducing volume - OPEN team evaluation start	0	0	1007.6	458		
Tuesday	21-Oct-03	Put boxes on heater coils.	0	0	2084.7	948		
Wednesday	22-Oct-03	Last of mass discharges will take place this weekend - normal feeding next week.	0	0	1810.7	823		
Thursday	23-Oct-03	Called FCI about DSR2 meter - will send out technician.	0	0	1277.3	581		
Friday	24-Oct-03	Feeding again	660	300	478.6	218		

Day	Date	Comments (Technology supplier's daily operation log)	As reported by tech supplier			NCSU APWMC		Mean	
			lbs	kg	kg	lbs	kg	lbs	kg
Saturday	25-Oct-03		660	300	313.7	143			
Sunday	26-Oct-03		660	300		0			
Monday	27-Oct-03		660	300		0			
Tuesday	28-Oct-03		660	300	507.7	231			
Wednesday	29-Oct-03		660	300	676.5	307			
Thursday	30-Oct-03		660	300	649.3	295			
Friday	31-Oct-03		660	300	348.1	158			
Saturday	01-Nov-03		660	300	371.7	169			
Sunday	02-Nov-03		660	300		0			
Monday	03-Nov-03		660	300	343.5	156			
Tuesday	04-Nov-03		660	300	726.0	330			
Wednesday	05-Nov-03		660	300	495.5	225			
Thursday	06-Nov-03		660	300	2444.7	1,111			
Friday	07-Nov-03		660	300	2220.4	1,009			
Saturday	08-Nov-03		660	300	1666.5	758			
Sunday	09-Nov-03		660	300	610.4	277			
Monday	10-Nov-03		660	300	1433.0	651			
Tuesday	11-Nov-03		660	300	1158.7	527			
Wednesday	12-Nov-03		660	300	753.5	343			
Thursday	13-Nov-03		660	300	370.6	168			
Friday	14-Nov-03		1,100	500	1472.9	670			
Saturday	15-Nov-03		1,100	500	2315.7	1,053			
Sunday	16-Nov-03		1,100	500	1153.8	524			
Monday	17-Nov-03		1,100	500	812	369			
Tuesday	18-Nov-03		1,100	500	611.3	278			
Wednesday	19-Nov-03		1,100	500	843.6	383			
Thursday	20-Nov-03		1,540	700	1474.0	670			
Friday	21-Nov-03		1,540	700	2693.9	1,225			
Saturday	22-Nov-03		1,540	700		0			

Day	Date	Comments (Technology supplier's daily operation log)	As reported by tech supplier		Feedstock		NCSU APWMC		Mean	
			lbs	kg	lbs	kg	lbs	kg	lbs	kg
Sunday	23-Nov-03		1,540	700	387.8	176				
Monday	24-Nov-03		1,540	700	1174.5	534				
Tuesday	25-Nov-03		2,200	1,000	1104.8	502				
Wednesday	26-Nov-03		2,200	1,000	2223.5	1,011				
Thursday	27-Nov-03		2,200	1,000	440.7	200				
Friday	28-Nov-03		2,200	1,000	833.6	379				
Saturday	29-Nov-03		2,200	1,000		0	67,553	30,706		
Sunday	30-Nov-03		0	0		0				
Monday	01-Dec-03		0	0		0				
Tuesday	02-Dec-03		0	0	1309.7	595				
Wednesday	03-Dec-03		0	0	295.1	134				
Thursday	04-Dec-03		0	0		0				
Friday	05-Dec-03				669.0	304				
Saturday	06-Dec-03				1919.0	872	68146.1	30,976		
Sunday	07-Dec-03				426.8	194				
Monday	08-Dec-03				2447.8	1,113				
Tuesday	09-Dec-03				2157.6	981				
Wednesday	10-Dec-03				1163.7	529				
Thursday	11-Dec-03				847.0	385				
Friday	12-Dec-03				373.3	170				
Saturday	13-Dec-03					0	75562.3	34,347		
Sunday	14-Dec-03				3144.0	1,429				
Monday	15-Dec-03				2627.2	1,194				
Tuesday	16-Dec-03				3263.3	1,483				
Wednesday	17-Dec-03				2426.0	1,103				
Thursday	18-Dec-03				1095.6	498	88118.4	40,054		
Friday	19-Dec-03									
Saturday	20-Dec-03	No more swine waste available.								
Sunday	21-Dec-03									