FINAL REPORT

Swine USA Anaerobic Digester Performance Analysis

Natural Resources Conservation Service
Iowa State University
Cooperative Agreement
68-6114-9-217

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April 5, 2004

PART I
DIGESTER NUTRIENT SAMPLING AND ENERGY PRODUCTION

INTRODUCTION

Swine USA operates a 5000 sow gestation-farrowing facility in Southern Iowa, approximately 6 miles south of Thayer. The facility uses shallow pull plug gutters that drain to a reception pit. Raw manure is pumped from the pit to a 76' X 65' X 16' (16 sq ft/sow) concrete, heated, complete mix anaerobic digester. The digester started operating in August, 1999. Methane from the digester was burned in a Caterpillar engine to drive an 80 Kw generator. The electricity was used on the farm. This paper is the final report on a monitoring project to evaluate the digester, and test the digested manure for plant production characteristics as compared to the raw manure.

FACILITY LAYOUT

The digester was designed by RCMdigesters, Inc. as part of the AG Star program. Total construction cost was approximately $500,000, or $100 per sow. Government cost sharing for the project was provided by the Iowa Department of Natural Resources (IDNR), and the Natural Resources Conservation Service (NRCS) for approximately half of the total cost. The general facility layout is shown in figure 1. The digester is a Completely Stirred Tank Reactor (CSTR).

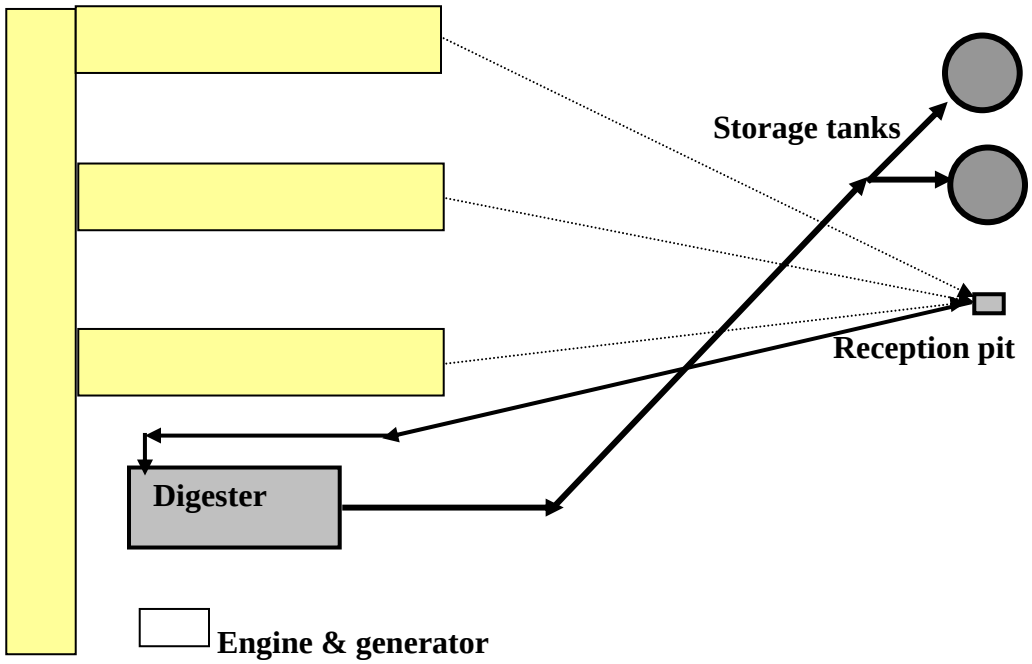

Figure 1. Plan view of Swine USA and digester (not to scale).

OPERATING RESULTS

The digester system was initially capable of providing approximately 35% of the farm's energy needs. When excess methane was produced (more than the engine could use) it was flared off to the atmosphere. The digester started operation August, 1999. ISU monitored the digester and storage system by sampling at 4 locations since from October 8, 1999 through May 9, 2001.

SAMPLING PROTOCOLS

Samples were taken at several locations to characterize the manure nutrients before and after digestion. Samples were initially taken at two week intervals, and then monthly, and finally intermittently until sampling ceased. Samples were immediately refrigerated upon collection until delivery to the lab for analysis.

Sample locations were as follows:

1. Reception/transfer pit Raw manure was sampled here by probing with a 1.5" diameter PVC pipe and check valve on the bottom. Each sample was a vertical profile sample of the manure contained in the transfer pit.

2. Outlet of the digester Digested manure was sampled leaving the digester by collecting a bottle of the liquid effluent overflowing the weir outlet. A bottle was held by hand and swept along the length of the weir allowing it to fill.

3. North and south storage tanks These storage tanks were sampled with the same 1.5" diameter probe used for the transfer pit. The 14'-probe was not quite long enough to reach the bottom of the tanks, so some sample error may have resulted. Liquid depth was determined by measuring down from the top edge of the 16' deep tanks.

DIGESTER SOLIDS AND NUTRIENT DATA

Total and volatile solids

Loading rate averaged 1.46 Kg/M^3-day of COD, or 1.23 Kg/M^3-day of VS (90 lb VS/1000 ft^3). This loading rate is approximately 15-20 times the typical loading rate for an anaerobic lagoon in Iowa (4-6 lb VS/1000 ft^3), and is typical of other mixed anaerobic digesters. Figure 2 shows the mean concentrations of Total Solids (TS) (dark bars), Volatile Solids (VS) (light bars), with the VS/TS percentage written above the bar. The VS percentage should decline as the manure moves through the digester and the VS are digested and liquefied to organic acids. The increase in VS percentage, along with the decrease in TS indicates the likelihood of some settling occurring within the digester.

Chemical Oxygen Demand provides a gauge of how complete the digestion process is. COD leaving the digester has averaged 37.7% of the incoming COD, indicating a COD reduction of approximately 62%. COD averaged 48,487 mg/l in and 19,495 mg/l out indicating that it had been stabilized significantly.

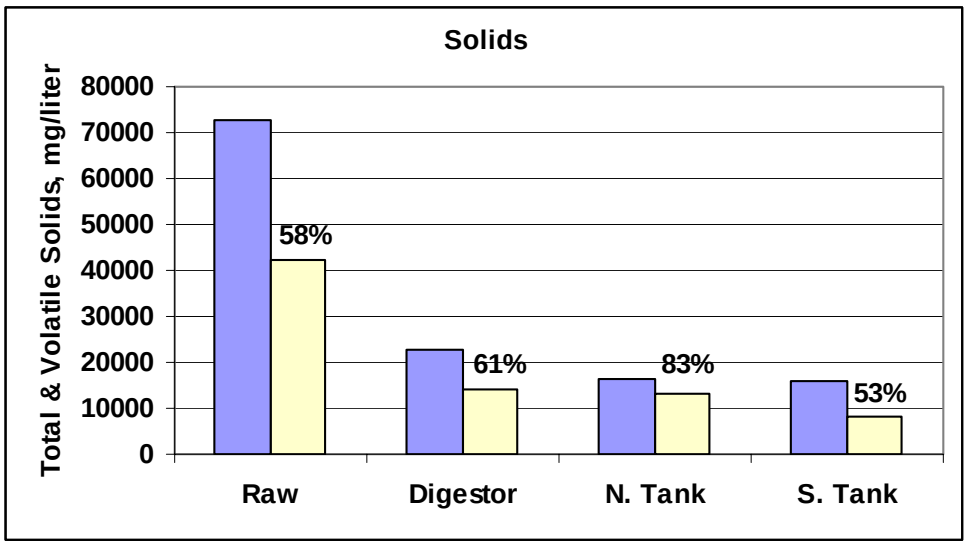

Figure 2. Solids concentrations at four locations

Nitrogen: Influent Total Kjeldahl nitrogen (TKN) concentrations averaged 3312 mg/l over the monitoring period. Influent ammonia (NH_3-N) concentrations averaged 2517 mg/l. Both are typical of raw swine sow manure. Concentrations leaving the digester were TKN = 2996, and NH_3-N = 2626 mg/l. NH_3-N expressed as a percentage of TKN increased from 75% to 86% as the manure was digested from the organic form to NH_3-N, figure 3. TKN concentrations decreased 10% through the digester. The lower concentrations shown in figure 3 are due to dilution from precipitation, and sampling error due to the depth (16 ft) of the tanks.

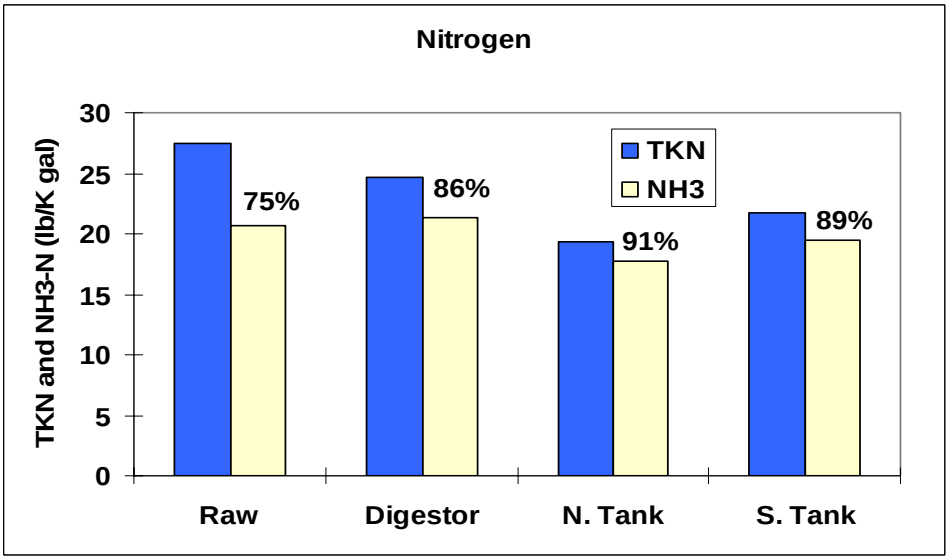

Figure 3. Nitrogen concentrations at four locations

Odors Odors and gases from digested and undigested manure were tested. Figure 4 shows H_2S and odor concentrations in the air and liquid. Samples were collected and transported to the ISU manure testing laboratory where 3 replications were placed in PVC cylinders. They were allowed to incubate and the liquid and headspace gases were periodically tested. Headspace H_2S was tested using a Jerome meter, and odors were tested in the ISU olfactometry lab. Both odors and hydrogen sulfide (H_2S) from the digested manure were significantly lower (85%) than those from the undigested manure gases.

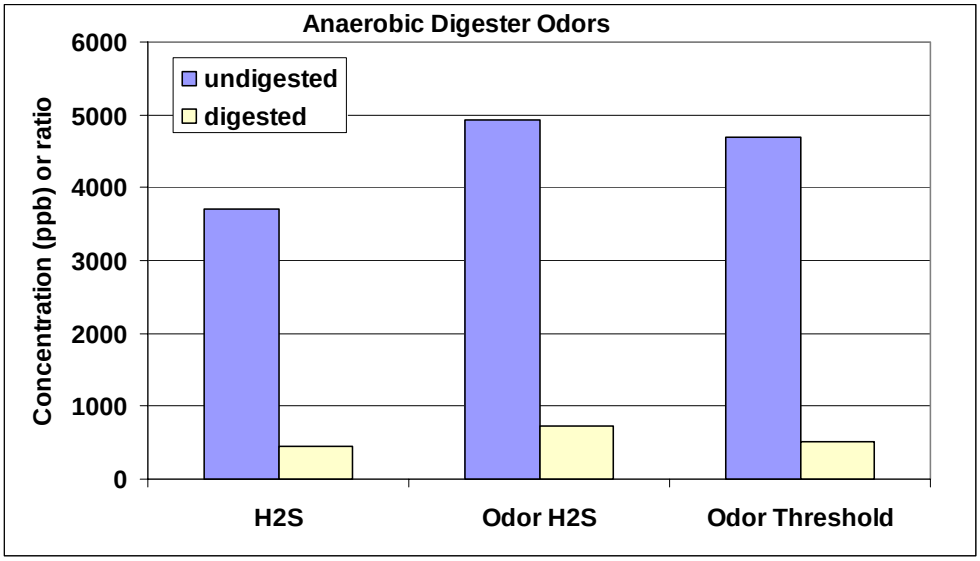

Figure 4. Hydrogen sulfide and odor threshold in gases from digested and undigested manure.

Phosphorus Phosphorus (P) should remain essentially unchanged through the digester because there is essentially no P in the gas, so it remains in the liquid and solid portion of the manure. Phosphorus concentration averaged 2850 mg/l in the influent. P concentration leaving the digester averaged 1313 mg/l, 46% of the influent.

Potassium Potassium (K) is primary soluble, and like P, is expected to pass through the digester in the liquid phase without loss of mass. Manure influent and effluent concentrations were 1336 and 1339 mg/l, respectively.

Manure Mass The volume of manure used by the sows that ultimately must be stored and land applied is an important consideration in designing swine facilities. Holding tanks must be large enough to hold all manure between pump out periods. The mass of manure accumulated was measured by monitoring the round holding tanks. Typically one tank was used to receive digester effluent until the tank was full, then the second one was filled. Figure 5 shows manure depth in the North tank. The digested manure accumulated at the rate of 3.62 gal/sow-day.

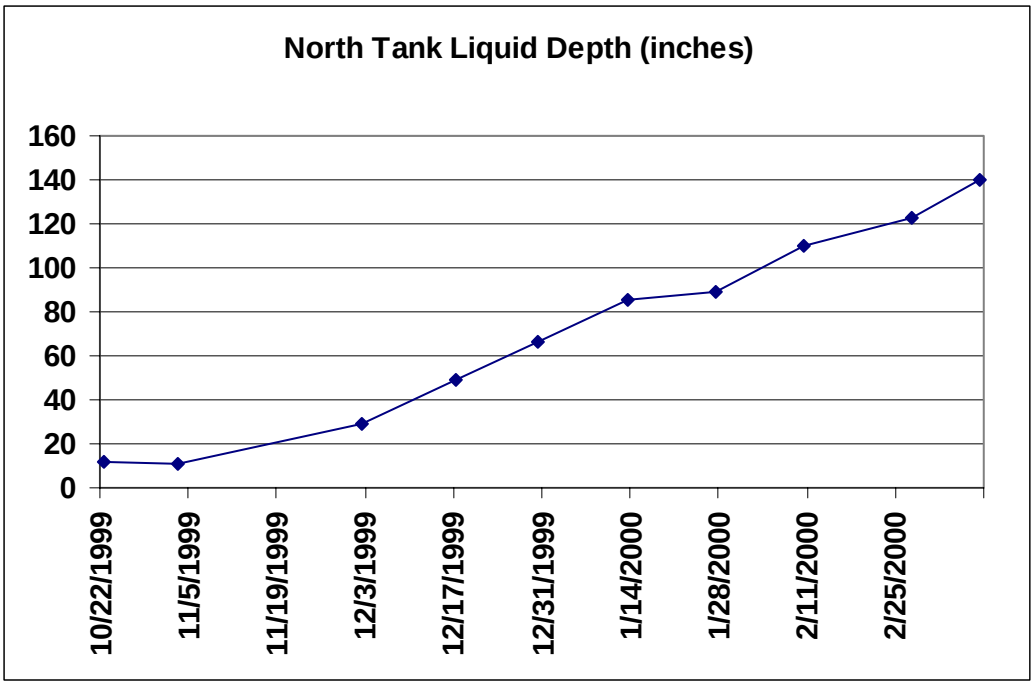

Figure 5. Depth of manure in North manure storage tank at Swine USA sow farm

pH The average pH of the digested manure was more basic (7.92) than the incoming raw manure (7.23) as shown in Figure 6.

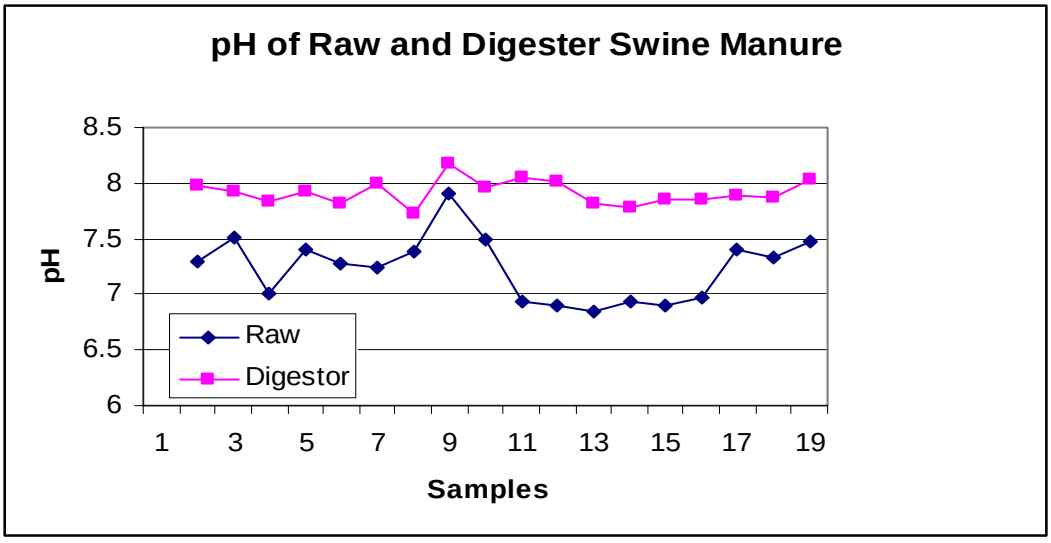

Figure 6. pH of raw and digested swine sow manure

OPERATIONAL DATA SUMMARY

Average gallons fed daily	14,730 gallons/day
Overall generator run time since startup	~84%
Biogas production: ~950,000 ft^3/mo =	190 ft^3/sow-mo (6.3 ft^3/sow-day)
CO_2 measured concentration	26%
Methane production (assumes 74%) =	140 ft^3/sow-mo (4.7 ft^3/sow-day)
Electricity . Produced	
Per sow	11.5 watt
Per day	1375 Kw-hr/day
Per month	42,290 Kw-hr/mo
Per sow per month	8.5 Kw-hr/sow-mo
Value ($0.066/Kw-hr)	$2790/mo

The digester ran well initially, but experienced a number of mechanical problems and other problems that caused gas production to dwindle, and ultimately stop. Figure 7 shows daily biogas production from startup through the first year of operation. Gas production appeared to be slowly decreasing by September, 2000. The reduced gas production in January, 2000 was due to mechanical malfunctions requiring the system to be shutdown temporarily. The digester was operated for another two years as gas production dwindled. It was ultimately shut down when company executives refused to purchase LP to heat it up to operational temperature following a shutdown for repairs.

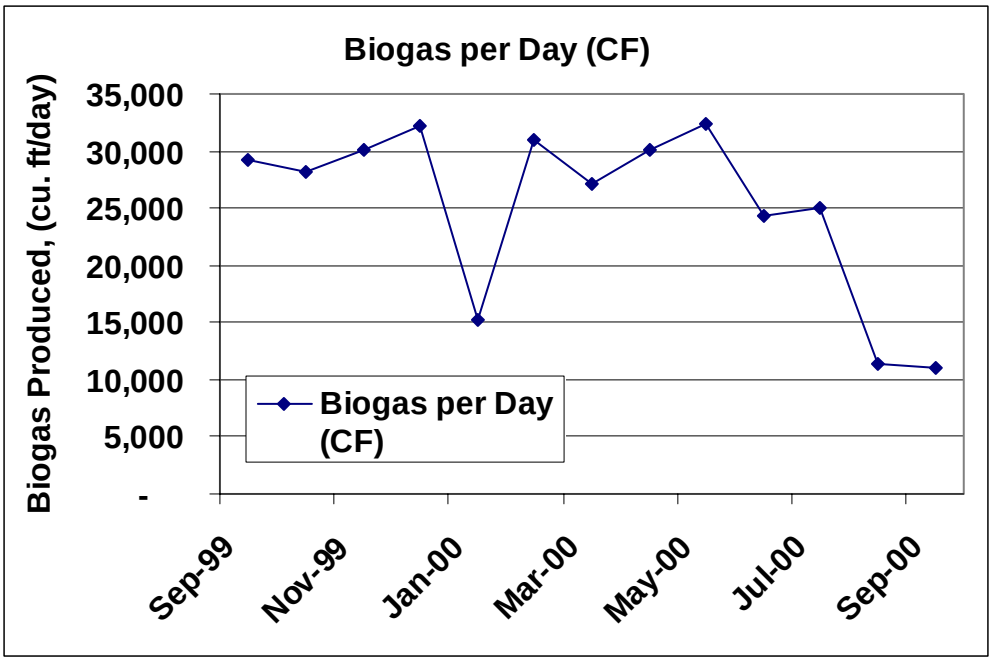

Figure 7. Biogas production per day for year one of digester operation.

CHRONOLOGICAL EVENTS REGARDING ENERGY HARVESTING

1. The engine failed shortly after startup. It was corrected by the providing company.
2. Large fuse blew out. It took 2 weeks to get replacement fuse. Digester had to be reheated to restart.
3. Elbow separated inside the digester resulting in a manure spill. It was stopped before reaching waters of the state.
4. Crews inside farrowing house washed down pits to remove accumulating solids. Unwanted dilution reduced gas production temporarily.
5. The entire crew was fired and replaced with a new crew. A new manager with no digester knowledge or experience took over operation of the digester.
6. By the end of year 1, gas production started to decrease
7. Second elbow separation and manure spill
8. Facility was sold to Bell Farms. New crew took over management, including the digester manager (third manager since startup).
9. Numerous small leaks around the edge of the cover were thought to be the cause of the lack of gas production to run the generator. The cover was ultimately replaced
10. During the course of replacing the cover solids were observed to have built up significantly throughout the digester. They were not, however, removed while the cover was off (due to the inexperience of the crew).
11. Gas production was still not enough to keep the engine running and the digester was shut down. It remains shutdown as of 12/31/2003.

SUMMARY

A mixed, concrete “soft top” anaerobic digester was constructed on a 5000 head sow farrowing and gestation facility in south central Iowa. An internal combustion engine and an 80 Kw generator were installed to operate using the captured methane gas. The digester operated well for two years, generating an average of 8.5 Kwh per sow per month. Significant odor reduction of the digested manure resulted from the process. The digester, however, experienced numerous mechanical difficulties, both major and minor. In addition, the facility had a complete crew change once, and was later sold. New untrained operators became responsible for day to day operation of the digester each time. Energy harvesting eventually declined and subsequently stopped. The digester is currently not in operation.

This project showed that
1) A properly operating digester can capture a significant amount of energy in the form of methane gas that can be converted to electricity and/or heat.
2) Digesters are complex living organisms that require knowledgeable, trained, and motivated operators if they are to operate successfully.
3) Digesters do not significantly change either the volume of manure to be land applied, nor the nutrient quantity or quality of the manure

Anaerobic Digester Chemical Results

	TKN - mg/l as N				Total P - mg/l as P			
	Raw	**Digestor**	**N. Tank**	**S. Tank**	**Raw**	**Digestor**	**N. Tank**	**S. Tank**
10/08/'99	2940	2690		2020	2010	747		486
10/22/'99	2670	3440	1820	3570	961	838	412	1420
11/04/'99	3430	2990		2710	2950	1220		1060
12/02/'99	2730	2750	2340	2190	5810	2070	686	580
12/20/'99	2720	2330	4110	2380	3590	2220	5830	1330
12/30/'99	2900	4120	2630	4340	1270	2690	902	4380
1/14/2000	2510	2300	2610	2510	2840	820	1000	1600
1/27/2000	2690	2990	2690	3450	972	1200	649	2440
2/10/2000	2979	3208	2225	2271	2324	2192	619	638
2/24/2000	3830	3710	2650	2230	972	1750	539	431
3/9/2000	2880	2550	2270	2100	5950	1000	640	523
3/23/2000	3450	3010	2580	2650	4450	1020	566	542
4/20/2000	6360	4110	3340	3560	1820	1100	493	495
5/22/2000	4930	3680	2590	2520	3970	1390	770	540
6/18/2000	3384	2298	1796	2304	5970	804	505	511
8/1/2000	2100	2080	128	1860	1223	519	469	440
9/2/2000	3588	2150	1026	1738	3250	617	581	447
1/4/2001	2762	3225	2278	2478	405	2010	462	400
5/9/2001	4080	3300	2370	1830	3412	748	451	331

	TKN - mg/l as N				Total P - mg/l as P			
	Raw	**Digestor**	**N. Tank**	**S. Tank**	**Raw**	**Digestor**	**N. Tank**	**S. Tank**
average	3312.3	2996.4	2320.8	2563.7	2849.9	1313.4	916.1	978.6
max, mg/l	6360	4120	4110	4340	5970	2690	5830	4380
min, mg/l	2100	2080	128	1738	405	519	412	331
avg lb/Kgal	27.6	25.0	19.4	21.4	23.8	11.0	7.6	8.2
max, lb/Kgal	53.0	34.4	34.3	36.2	49.8	22.4	48.6	36.5
min, lb/Kgal	17.5	17.3	1.1	14.5	3.4	4.3	3.4	2.8

Loading Rates	conc mg/L mg/L	Feed Vol L/day	Load gm/day	Dig Vol. cu meters	**Loading Rate Kg/M^3-day**	
COD -	50027	83106.45	4157566	2854.656	**1.456416**	**COD**
VS -	42325	83106.45	3517480	2854.656	**1.232191**	**VS**

Anaerobic Digester Chemical Results

Ammonia - mg/l as N				*Total Solids - mg/l*			
Raw	*Digestor*	*N. Tank*	*S. Tank*	*Raw*	*Digestor*	*N. Tank*	*S. Tank*
2610	2870		2300	34470	13450		8620
1950	2790	1530	2650	27540	15160	15420	24570
2690	2170		2040	46600	22400	17100	1.71%
2400	2070	2050	2390	100960	39520	12450	11790
2630	2640	3070	2400	73620	28290	81500	20180
2400	2990	2420	3380	21780	58980	15270	60580
2180	2720	2790	2670	62150	14540	16570	23720
2270	2530	2360	2690	18800	20600	11800	33600
2647	2753	2211	2532	46870	40940	12110	11520
2720	2470	2230	1640	19460	33180	10600	11670
2120	2670	2210	2160	118100	10240	11880	10230
1920	2280	2120	2380	96440	15210	10680	10220
4710	4070	3010	2510	121800	16800	9288	9295
2220	2170	1790	2000	80190	23980	13350	10180
2285	2247	1764	2306	104300	12810	9472	9004
2090	2060	1120	1850	200090	8370	8550	7028
2290	1915	1275	1655	62940	9562	8801	6812
2725	3270	2220	2188	8298	29660	8156	7246
2970	3210	2330	1900	53770	12250	7846	5850

Ammonia - mg/l as N				*Total Solids - mg/l*			
Raw	*Digestor*	*N. Tank*	*S. Tank*	*Raw*	*Digestor*	*N. Tank*	*S. Tank*
2517.2	2626.1	2147.1	2296.9	68325.2	22418.0	15602.4	14848.2
4710	4070	3070	3380	200090	58980	81500	60580
1920	1915	1120	1640	8298	8370	7846	0.0171
21.0	21.9	17.9	19.2	569.8	187.0	130.1	123.8
39.3	33.9	25.6	28.2	1668.8	491.9	679.7	505.2
16.0	16.0	9.3	13.7	69.2	69.8	65.4	0.0

Anaerobic Digester Chemical Results

Vol Solids - mg/l				*Potassium - mg/l as K*			
Raw	***Digestor***	***N. Tank***	***S. Tank***	***Raw***	***Digestor***	***N. Tank***	***S. Tank***
23140	*7380*		*4120*	*1340*	*1510*		*1310*
17820	*8200*	*4010*	*12840*	*1070*	*1460*	*1410*	*1480*
29320	*16620*		*8955*	*1680*	*1610*		*1660*
68760	*26030*	*6212*	*5337*	*1120*	*1220*	*1240*	*1440*
51590	*14500*	*46070*	*10450*	*1760*	*1660*	*1780*	*1760*
12267	*40810*	*81230*	*32020*	*1380*	*1480*	*1380*	*1660*
43730	*8093*	*8790*	*12070*	*1280*	*1380*	*1510*	*1670*
11200	*12100*	*5950*	*17500*	*1340*	*1530*	*1700*	*1870*
32080	*26490*	*6266*	*5642*	*1590*	*1560*	*1460*	*1670*
11460	*21190*	*5280*	*4280*	*1820*	*1500*	*1410*	*1370*
84150	*8258*	*6286*	*4992*	*1270*	*1380*	*1370*	*1460*
71260	*8030*	*5501*	*5066*	*970*	*1280*	*1400*	*1440*
82200	*9220*	*4600*	*4509*	*1520*	*1160*	*1340*	*1320*
56420	*14780*	*6740*	*4720*	*1450*	*1140*	*1450*	*1400*
70720	*7074*	*4510*	*4382*	*1080*	*1040*	*1330*	*1280*
12020	*4100*	*3258*	*2794*	*1080*	*1027*	*1580*	*1300*
41390	*4994*	*3682*	*2930*	*1090*	*972*	*1440*	*1070*
3976	*17050*	*3691*	*3250*	*1106*	*1248*	*1024*	*930*
33890	*6078*	*3438*	*2426*	*1430*	*1290*	*1150*	*960*

Vol Solids - mg/l				*Potassium - mg/l as K*			
Raw	***Digestor***	***N. Tank***	***S. Tank***	***Raw***	***Digestor***	***N. Tank***	***S. Tank***
39862.8	*13736.7*	*12089.1*	*7804.4*	*1335.6*	*1339.3*	*1410.2*	*1423.7*
84150	*40810*	*81230*	*32020*	*1820*	*1660*	*1780*	*1870*
3976	*4100*	*3258*	*2426*	*970*	*972*	*1024*	*930*
332.5	*114.6*	*100.8*	*65.1*	*11.1*	*11.2*	*11.8*	*11.9*
701.8	*340.4*	*677.5*	*267.0*	*15.2*	*13.8*	*14.8*	*15.6*
33.2	*34.2*	*27.2*	*20.2*	*8.1*	*8.1*	*8.5*	*7.8*

Anaerobic Digester Chemical Results

COD - mgO2/l				PH			
Raw	**Digestor**	**N. Tank**	**S. Tank**	**Raw**	**Digestor**	**N. Tank**	**S. Tank**
41600	14900		7010				
28400	14	17	21	7.3	7.97	8.01	7.91
38800	24000		15200	7.51	7.92		7.97
60650	30390	10570	9610	7	7.84	7.98	8.04
51400	18700	58700	16500	7.4	7.93	7.83	7.94
53200	37000	20100	47800	7.28	7.82	7.87	7.6
42000	13500	15500	18700	7.24	8	8.02	7.9
24900	19400	10800	29900	7.39	7.73	8.04	7.8
67750	33030	9980	8760	7.9	8.18	8.2	8.14
27200	23000	9260	6790	7.5	7.96	7.94	7.89
64700	13200	9780	7820	6.93	8.05	8.14	8.08
67200	12700	9400	8830	6.9	8.02	8.11	8.09
79700	15700	8300	7630	6.85	7.81	8.06	8
67500	40500	14000	10800	6.93	7.78	7.93	7.87
50900	10000	6950	6760	6.9	7.85	8.1	8.03
30460	6920	5730	4850	6.98	7.85	8.16	8.1
54100	7750	6310	4810	7.4	7.88	8.17	8.07
11600	23700	7520	6710	7.33	7.87	8.15	8.08
59200	26000	6910	5190	7.48	8.04	8.07	8.12

COD - mgO2/l				PH			
Raw	**Digestor**	**N. Tank**	**S. Tank**	**Raw**	**Digestor**	**N. Tank**	**S. Tank**
48487.4	19494.9	12342.8	11773.2	7.2	7.9	8.0	8.0
79700	40500	58700	47800	7.9	8.18	8.2	8.14
11600	14	17	21	6.85	7.73	7.83	7.6
404.4	162.6	102.9	98.2				
664.7	337.8	489.6	398.7	0.1	0.1	0.1	0.1
96.7	0.1	0.1	0.2	0.1	0.1	0.1	0.1