CHARACTERIZATION OF SULFUR FLOWS IN FARM DIGESTERS at RIDGELINE FARMS

Prepared for

THE NEW YORK STATE
ENERGY RESEARCH AND DEVELOPMENT AUTHORITY
17 Columbia Circle
Albany, NY 12203

Tom Fiesinger, Project Manager

Prepared by

DLTECH, INC.
PO Box 3910
Ithaca, NY 14852

David C. Ludington, Ph.D.
DLtech, Inc.

And

Stanley Weeks, Ph.D.
Stanley A Weeks, LLC
4 Ashor Drive
Middle Grove, NY 12850

9443-1 September 2, 2008

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

Section 1

DESCRIPTION

Ridgeline Farm is located on Legters Road near Clymer, NY. A schematic of the layout of the reception pits, digester and engine/generator building can be found in the Appendix, Figure A-1. At the time of this study the milking herd consisted of 360 Holstein and 103 Jersey cows plus 90 dry cows for a total of 553 head. There are three pits next to each other on the end of the digester, manure (influent) [16 ft x 18 ft], food waste [16 ft x 18 ft] and effluent. The digester at Ridgeline Farm is U-shaped formed by a center wall. There are two soft covers joined at the center wall. Three mixers operate periodically.

Manure from the animals is continually scraped by alley scrapers to cross gutters and then flows by gravity to the raw manure (influent) pit. Food waste is delivered to the farm in tank trucks and is emptied into the food waste pit next to the manure pit on the end of the digester. Effluent from the digester overflows the dam directly into the effluent pit. The effluent flowed by gravity to a long term storage lagoon.

The digester is feed eight times per day (every three hrs). The cycle begins with the influent pump, located in the “raw” manure pit, starting. This pump had an ON time of 11 minutes 4x per day, 12 minutes for 3x per day and a 13 minute time 1x per day. When the influent pump stops the food waste pump starts for a few minutes and pumps food waste into the raw manure (influent) pit. A mixer in the raw manure/influent pit mixes the food waste and manure prior to the next cycle.

The biogas pipe from the digester has a wyed (Y) shortly after leaving the digester, one pipe goes to the engine/generator building and the other goes to the flare. One pipe goes to a main Roots meter in the engine/generator building. Here the gas line is Teed (T) with one line going to the engine and the other line going to a boiler that provides hot water for the milking center. Thus the biogas for the engine is the difference between the main meter and the boiler enter. See Figure A-1.

Two series of tests were conducted during this study, a 24 hr and a 30 day test. These tests were intended to develop sufficient data so that the flow of sulfur could be evaluated.

Section 2

RESULTS – 24 HOUR TEST, JANUARY 22-23, 2007

Five times during the 24 hr test the biogas was tested for carbon dioxide and hydrogen sulfide. The tests were conducted using *Gastec* gas tubes for carbon dioxide and hydrogen sulfide and a *Bacharach* unit also for carbon dioxide. The values measured are given in Table 2-1. All the values are corrected for a dry gas.

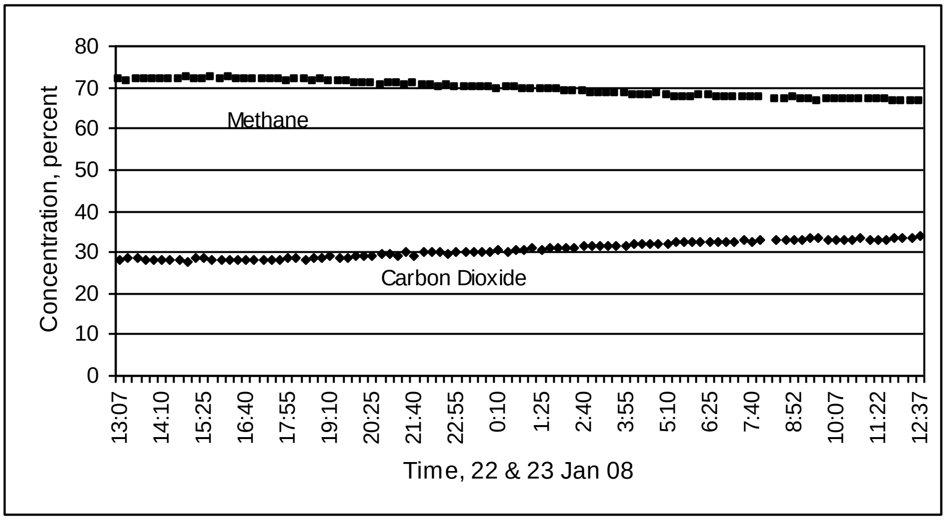
Table 2-1. Concentration of Carbon Dioxide and Hydrogen Sulfide.

Test Number	CO_2		H_2S
	Tubes, %	Bacharach, %	ppm
No. 1, 1:30 pm	24.5	25	650
	26	26	650
No. 2, 4:00 pm	26	25.5	650
	25	25	650
No. 3, 8:16 am	30	30	800
	30	31	900
No. 4, 10:16 am	30	30	900
	30	30	950
No. 5, 12:20 pm	31	27	1000
	30	28	1000
	31	27	
Average	28.5	27.7	815
Standard Dev.	2.54	2.24	153
Confidence Int ±	1.5	1.3	95

The average carbon dioxide concentration measured by the gas tubes was 28.5%. With a confidence interval of ± 1.5 (5%), the range would be 27 to 30%. The results from the *Bacharach* unit had a similar confidence interval ± 0.52. This would yield a range of 26.4 to 29.0% which is inside the range for the *Gastec* tubes. All values are for a dry biogas.

During the 24 hr test the carbon dioxide and methane were monitored with a *GEM2000* instrument. Samples were taken every 15 minutes. The values for carbon dioxide are plotted in Figure 2-1.

Figure 2-1. Carbon Dioxide and Methane Concentration in Dry Biogas (*GEM 2000*).



A problem was encountered with measuring the CH_4. There apparently was some interference with the hydrogen sulfide. This was not a problem with an earlier GEM 2000 unit. The company suggested that because these values are for a dry gas and that there is few trace gases such as hydrogen sulfide the concentration of methane could be calculated by difference. There was a definite change in the concentration of carbon dioxide during the 24 hr period. Because the digester is fed every three hours there was no apparent reason why the concentrations should have changed during a 24 hr period.

Table 2-2. Statistical Analysis of Data from *GEM 2000* Unit.

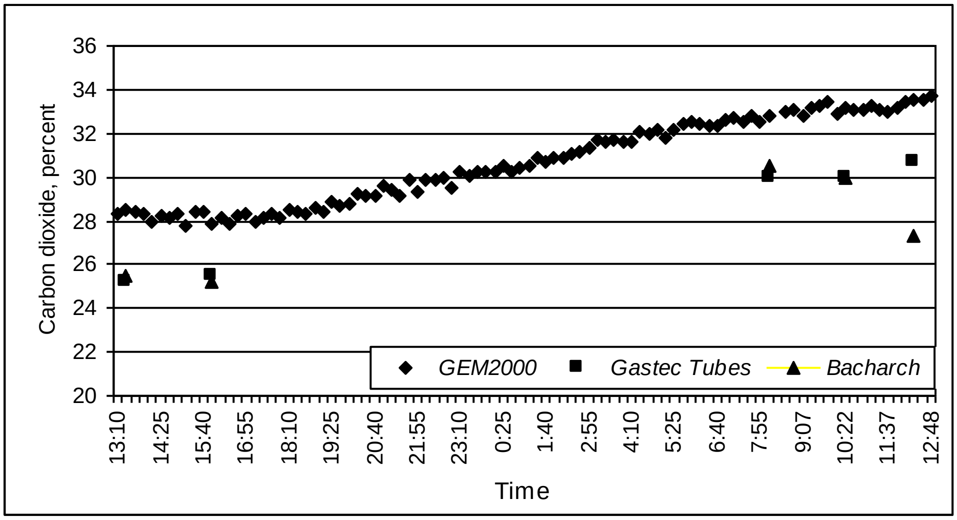
	Avg	Std Dev	Confid Int.	Max	Min
CO_2	30.6	1.9	0.39	33.5	27.8
CH_4	69.4	1.9	0.39	72.2	66.5

The percent CO_2 measured with the Gastec tubes also showed an increased in concentration during the 24 hr period. With conditions of changing concentration, the statistical analysis does not reflect the accuracy or consistency of the measuring unit.

A comparison of the three methods of analyzing for CO_2, GEM2000, gas tubes and Bacharach unit, was made. Because the concentration of carbon dioxide actually changed during the 24 hour period, comparing averages, standard deviations and confidence integrals was not helpful. The data from these three measuring techniques is shown in Figure 2-2. The results raise concern. Why should there be so much difference?

One possible explanation may be connected with the temperature of the biogas at Ridgeline Farms. The average gas temperature at the meter during this 24 hour test was 49.5 ºF. Quoting from the *Bacharach* manual; “Remember, for accurate results the FYRITE must be at temperature equilibrium with its surroundings (ambient temperature) and the incoming gas sample at the same temperature as the FYRITE.” Again, “the gas sample as it enters FYRITE should be cooled (or warmed if sampling cool gases) to same (ambient) temperature as the FYRITE.” The temperature of the FYRITE (red solution in the Bacharach unit) was not 49.5 ºF and the biogas was not warmed.

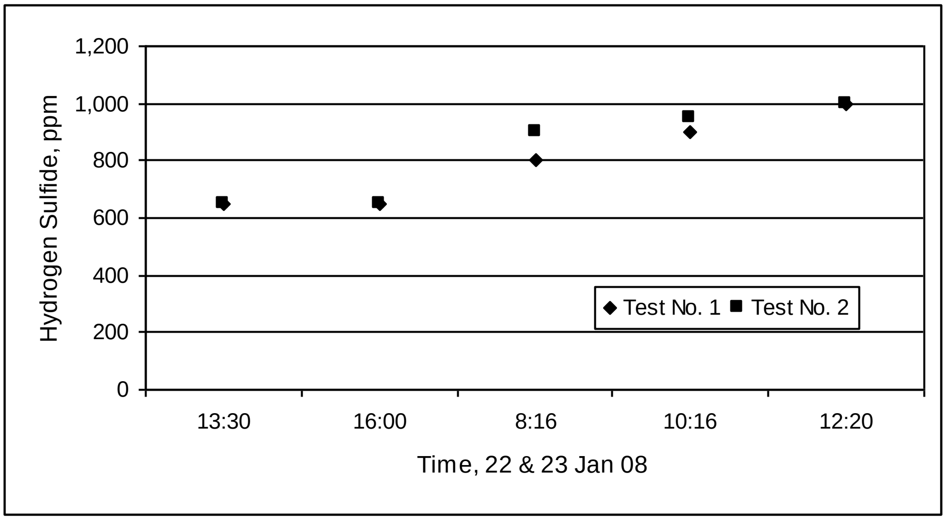
Figure 2-2. Carbon Dioxide Concentration Measured with Three Analyzers (Ridgeline Farms).



The issue of temperature seems less of an issue with the gas tubes. For best results the tube temperature should be at the same temperature as the sampled gas. For biogas which is usually saturated with water vapor, the tubes should be at the same or perhaps a slightly higher temperature to insure that there is no condensation in the tube. This can impact accuracy.

The concentration of hydrogen sulfide also increased over the 24 hour. The concentration of H_2S the afternoon of January 22 was 650 ppm and on the morning of January 23 the average concentration was 925 ppm. The results of the tests for hydrogen sulfide are plotted in Figure 2-3. Again there is no known reason why the H_2S would increase. As stated earlier, the temperature of the biogas was below 50 ºF. Quoting from the *Gastec* Manual, 5th Edition, “When the temperature is lower than 20 ºC (68 ºF):

Figure 2-3. Concentration of Hydrogen Sulfide in Biogas at Ridgeline Farms.



Reaction will slow down and some quantity of the sample will not react in the normal reaction area for 20 ºC (68 ºF) but will sparsely react further into the tube. As a result, a longer layer of pale color change is produced, giving a higher indication." The question now is where do you read the tube, dense color change or into the pale area. Certainly the gas tubes used for the first tests and perhaps the second were cold having been stored in the car overnight.

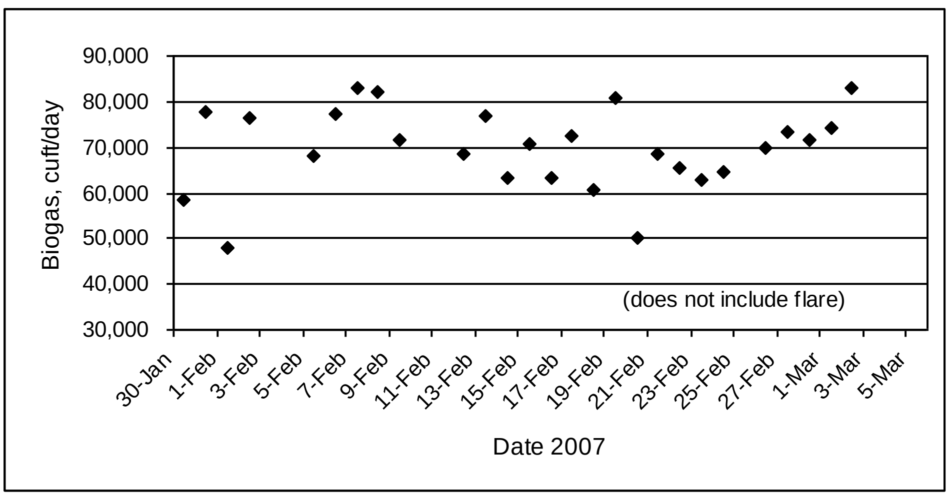
Section 3

RESULTS – 30 DAY TEST, JANUARY 30 – MARCH 5, 2008

During the 30 day test the operator recorded data three times each day. The following data was recorded; biogas temperature and pressure at meter, reading from biogas meters, two samples each for hydrogen sulfide (gas tubes) and carbon dioxide (Bacharach Unit). (A copy of the data collection sheets can be found in the Appendix, Table A-1.)

The biogas recorded by the "main meter" during the "30 day test" averaged 69,700 cubic feet per day with a maximum production of 82,900 and a minimum of 48,000 ft^3/day. The daily use of the biogas recorded by the main meter is shown in Figure 3-1. The boiler used an average of 5,760 ft^3/day.

Figure 3-1. Biogas Consumed at Ridgeline Farms.



At the end of this study a meter was installed in the flare pipe to record gas flow. This data recorded can be found in the Appendix, Table A-2. For the 57 days of data available, an average of 60.3% of the biogas produced was recorded by the main meter (engine plus boiler). Assuming this same value for the 30 day test, the production of biogas would average 115,630 ft^3 per day. During this 57 day period the boiler consumed an average of 5,037 ft3 per day compared to 5,760 ft3 per day during the 30 day test.

Table 3-1. Summary of 30 Day Test at Ridgeline Farms.

	Temp	Press.	Main	Boiler	H2S	CO2
	ºF	(in H20)	cu ft/day		ppm	%
Average	45.2	-0.84	69,724	5,757	1,022	31.8
Standard Deviation	2.0	0.36	9,051	2,093	87.4	3.56
Confidence Interval ±	0.42	0.08	3,414	775	14.7	0.53
# of samples	88	88	27	28	135	176

The temperature of the biogas at the main meter averaged 45 ^{o}F, the lowest biogas temperature of the farms studied. Obviously the time of year had an impact on this temperature but the distance between the digester the engine/generator building and the shallow depth of the pipe also contributed. The daily temperature (average of three readings) is shown in Figure 3-1. This cooling of the biogas caused a significant decrease in the water vapor content of the biogas at the engine, 1.0% at 45 F compared to 4.75% at 90 F.

The level of carbon dioxide in the biogas was measured by the operator with a *Bacharach* unit. There were 176 tests run over the 30 day test. The concentrations of CO_2 in the AM, Noon and PM are plotted in Figure 3-2. There were no distinct differences in concentration with regard to the time of day. The overall average concentration for the 30 days was 31.8%.

The concentration of hydrogen sulfide in the biogas was measured with gas tubes. The average daily concentrations are plotted in Figure 3-3. There were 5 days when the operator did not have gas tubes.

Figure 3-2. Daily Temperature of the Biogas at the Main Meter (average of three readings).

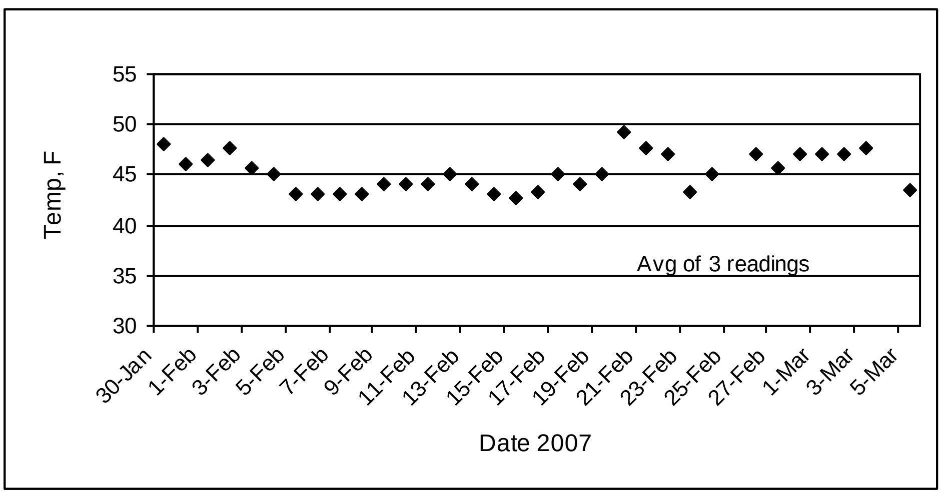


Figure 3-3. Concentration of Carbon Dioxide at Morning, Noon and Evening, 30 Day Test.

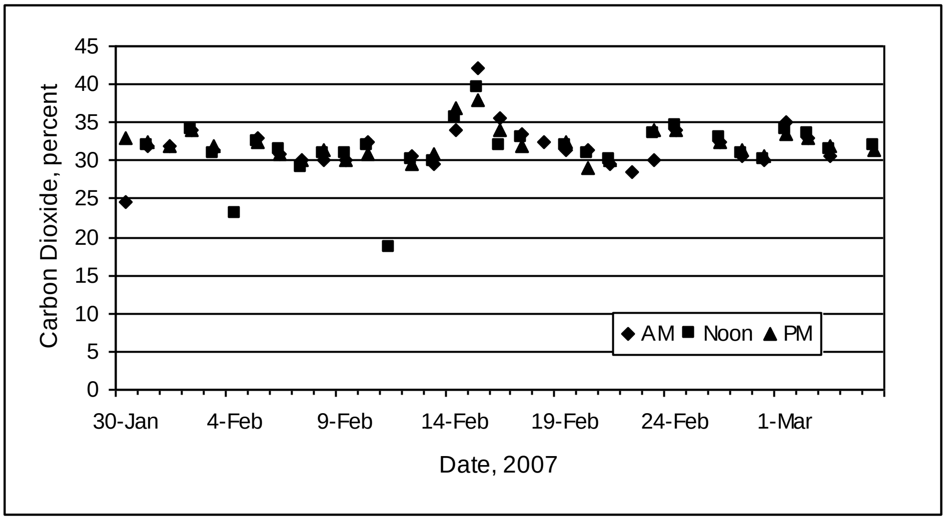
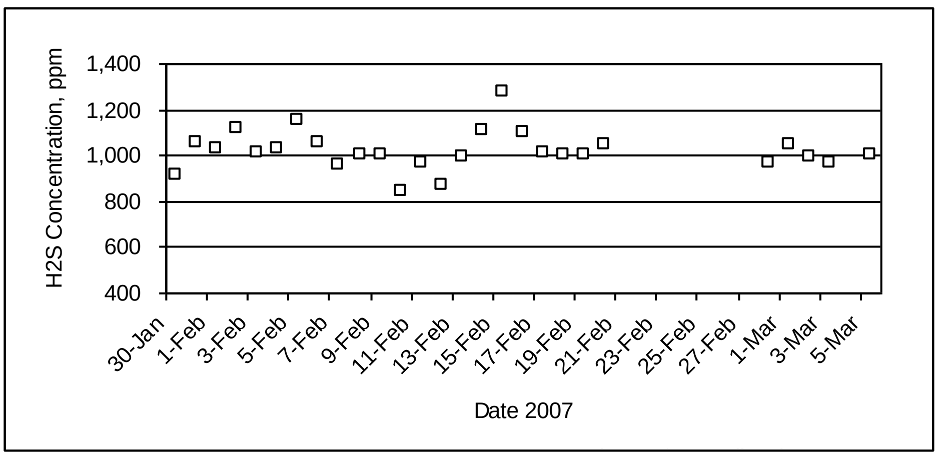


Figure 3-4. Concentration (ppm) of Hydrogen Sulfide in Biogas, average of three readings.



The average concentration of H_2S measured during the 30 day test was 1,000 ppm while the concentration during the 24 hour test averaged 800 ppm. This was lower than any day during the 30 day test. Because food waste, which does vary considerably depending on source, is being fed to the digester along with the dairy manure, a change in the concentration of H_2S should not be surprising. This variation in feedstock may also explain the wide swing in the production during the 30 day test, 48,000 to 82,000 ft^3/day.

Section 4
MASS FLOW OF SULFUR

Samples of the total mixed ration (TMR), drinking water and digester influent and effluent were taken at three different times during the study. The TMR and digester influent and effluent were analyzed for total solids (TS) and sulfur (S) by Dairy One, Inc. in Ithaca, NY. Water samples were analyzed by the Community Science Institute also located in Ithaca, NY.

TOTAL MIXED RATION

There are three groups of cows at the farm, Holstein, Jersey and dry cow. Table 4-1 shows the number of cows in each group and the pounds of TMR fed to the animals each day. This data was provided by the owner. The American Society of Agricultural & Biological Engineers (ASABE) published equations for predicting the production of manure by various farm animals. Using the equations for dairy animals there are 518 equivalent milking cows with regard to manure

Table 4-1. Number of Dairy Cows and TMR Fed at Ridgeline Farms.

	# of cows	lbs TMR/day
Holstein	410	40,650
Jersey	53	6,600
Dry Cow	90	7,160

production. In-other-words, the 90 dry cows are equivalent 55 milking dairy cows. The results of the analysis of the TMR for TS and sulfur are shown in Table 4-2. The total sulfur (S) in the TMR for the whole herd was 47.8 lb S/day.

Table 4-2. Sulfur Content of TMR at Ridgeline Farms.

FEED, TMR				
Holstein				
Date	lbs consumed	Sample	% S (as fed)	lbs S/day
3/30/2007	40,650	RLD Hol 1	0.1	40.7
		RLD Hol 2	0.1	40.7
5/8/2007	40,650	RLD Hol 1	0.1	40.7
		RLD Hol 2	0.1	40.7
6/18/2007	40,650	REF Hol 1	0.08	32.5
		REF Hol 2	0.08	32.5
		REF Hol 3	0.08	32.5
average			0.09	**37.2**
Std Dev			0.01	4.5
Confidence interval ±			0.009	3.56

Jersey				
Date		Sample	% S (as fed)	lbs S/day
3/30/2007	6,600	RLD JER 1	0.05	3.3
		RLD JER 2	0.07	4.6
5/8/2007	6,600	RLD JER 1	0.10	6.6
		RLD JER 2	0.10	6.6
6/18/2007	6,600	REF JER 1	0.07	4.6
		REF JER 2	0.07	4.6
average			0.08	**5.1**
Std Dev			0.02	1.30
Confidence interval ±			0.016	1.04

Dry Cow				
Date		Sample	% S (as fed)	lbs S/day
3/30/2007	7,160	RLD DC 1	0.08	5.7
		RLD DC 2	0.07	5.0
5/8/2007	7,160	RLD DC 1	0.09	6.4
		RLD DC 2	0.07	5.0
6/18/2007	7,160	RLD DC 1	0.09	6.4
		RLD DC 2	0.07	5.0
average			0.08	**5.6**
Std Dev			0.01	0.70
Confidence interval ±			0.008	0.56

Total Sulfur **47.8** lbs/day

DRINKING WATER

The drinking water for the farm comes from well on farm. Analysis of the water samples showed an average concentration of sulfate of 17.8 mg/l. The water consumption was assumed to be 24 gal/cow-day. With 518 cow equivalents, the water consumed by the cows was 12,400 gal/day. This data was used in Table 4-3 to calculate the 0.62 lbs S/day in the drinking water.

Table 4-3. Sulfur in Drinking Water at Ridgeline Farms.

DRINKING WATER			
Date	Sulfate mg/L	Sulfur lbs/1000 gal	lbs S/day
4/7/2007	17.8	0.050	0.62
5/8/2007	16.75	0.047	0.58
	16.5	0.046	0.57
6/18/2007	16.75	0.047	0.58
	21.75	0.061	0.76
average	17.8	0.048	**0.62**
Standard Dev	2.20		
Confid Int ±	1.93		

Note: Conversion factor, sulfate to sulfur = 0.0028
(sulfate, mg/L to sulfur, lbs/1000 gal)

BEDDING

The dairy cows are bedded with sawdust at the rate of 1.5 lb/cow-day with a moisture content of 15%. See Table 4-4. The total solids added to the manure by the bedding was 720 lb TS/day containing less than 1.0 lb of sulfur per day.

Table 4-4. Properties of Bedding Used at Ridgeline Farms.

Type	Cows	Moisture Content, %	Bedding Rate		S*	S
			lb/cow-day	lbs TS/cow-day	% TS	lb/day
Kiln Dried Sawdust	553	15	1.50	1.28	0.1	0.71

* assumed (see Sources)

DIGESTER INFLUENT AND EFFLUENT

The results of the analysis of the digester influent and effluent (percent total solids and sulfur) are given in Table 4-5. The digester influent is a combination of dairy manure and food waste. The average concentrations of TS in the influent and effluent were 11.36% and 6.15%, respectively. The sulfur content was 0.036 and 0.029% S for the influent and effluent.

The mass flow of influent into the digester was measured by monitoring the level of liquid in the influent pit. An ultrasonic instrument was used to monitor the liquid level in the influent and food waste pit. The level was recorded every 0.5 minutes. The data was collected on June 16 – 18, 2007. Data recorded for two – 24 hr periods are shown in Figure 4-1a and 4-1b.

The digester is feed 8 times per day (every 3 hrs). The cycle begins with the influent pump, located in the "raw" manure pit, starting. This pump had an ON time of 11 minutes 4x per day, 12 minutes for 3x per day and a 13 minute time 1x per day for a total operating time of 93 min/day. When the influent pump stops the food waste pump starts and is scheduled to run for 1 minute and pumps food waste into the raw manure (influent pit). The recordings indicate that the pump may operate longer. A mixer in the raw manure/influent pit mixes the food waste and manure prior to the next cycle.

Table 4-5. Properties of the Digester Influent and Effluent at Ridgeline Farms.

	Influent (manure & food waste)			Effluent		
Date	Sample	% TS	% S*	Sample	% TS	% S*
3/30/2007	RL DI 1	7.12	0.025	RL DE 1	6.51	0.030
	RL DI 2	10.87	0.040	RL DE 2	6.51	0.025
	RL DI 3	11.0	0.040	RL DE 3	6.22	0.030
5/8/2007	RL DI 1	11.66	0.035	RL DE 1	5.89	0.030
	RL DI 2	11.41	0.035	RL DE 2	6.03	0.030
6/18/2007	RL DI 1	12.78	0.035	RL DE 1	5.65	0.025
	RL DI 2	13.40	0.040	RL DE 2	5.74	0.030
	RL DI 3	12.62	0.040	RL DE 3	6.68	0.030
average		11.36	0.036		6.15	0.029
Std Dev		1.93	0.005		0.39	0.002
Confidence interval ±		1.34	0.004		0.268	0.002

* As received

Figure 4-1a. Recording of Gallons (depth) of Manure and Food Waste in Influent Pit, June 15-16, 2007.

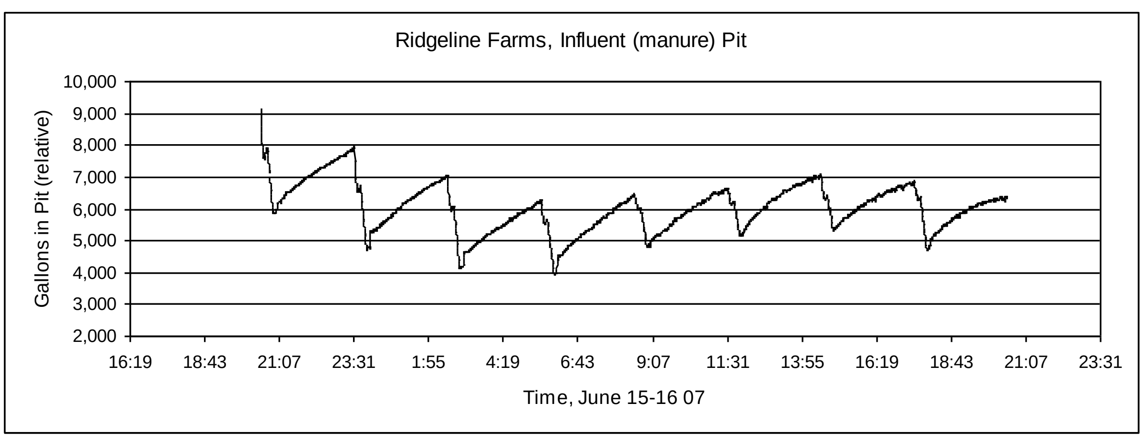
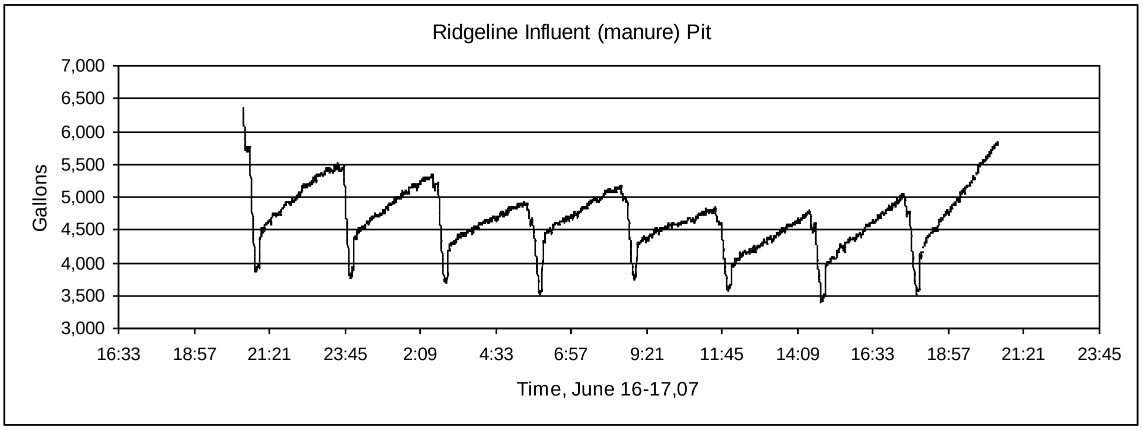
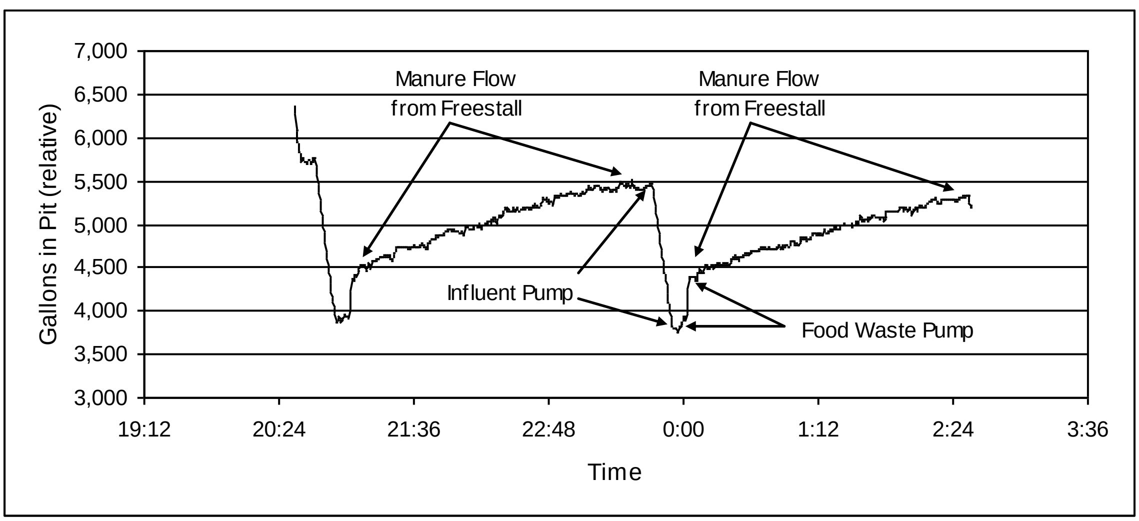


Figure 4-1b. Recording of Gallons (depth) of Manure and Food Waste in Influent Pit, June 16-17, 2007.



The graphs in Figures 4-1a and 4-2b show the eight cycles per day. The various events during a cycle are identified in Figure 4-2. The data was analyzed every 0.5 minute to determine when an event started and ended and the change in volume of the pit during that period. This information was used to determine the mass flow of influent to the digester and the flow of manure from the freestall and the food waste.

Figure 4-2. Events Identified on Ultrasonic Depth Recording (2 cycles).



The times and volume and change in volume based data graphed in Figure 4-1a and 4-2b are shown in Table 4-6.

The analysis of the data showed that over a two day period the influent pump appeared to operate 216 minutes per day as opposed to the 93 min according to the controller. The average flow of manure from the freestall was 7.9 gpm or 11,380 gal/day. While the influent pump was running, the mixture of manure and food waste was removed from the influent pit at a rate of 15,160 gal/day (decrease in liquid level). While this pump was operating (216 min/day) manure was flowing from the freestall at 7.9 gpm [1,710 gal/day]. Therefore, the average influent pumped to the digester was the sum [15,160 + 1,710] =16,870 gal/day or 2,110 gallons for each pump cycle. At 8.5 lb/gal, the mass flow (manure and food waste) was 143,400 lbs per day. The recordings also showed that an average of 607 gallons of food waste was pumped from the food waste pit to the influent pit per cycle or 4,860 gal/day.

Table 4-6. Data from Recordings Made with the Ultrasonic Depth Meter, June 16-18, 200

Influent Pit Operation

	Influent Pump		Gallons			Pump	Food Waste
Time	ON, min	OFF, min	In Pit	Change	Inflow*	gpm	gal/cycle
20:32			9,153				
21:02	30		5,961	3,192	237	114	
23:32		150	7,944				
23:56	24		4,753	3,191	190	141	
0:12			5,323				570
2:32		156	7,010				
3:02	30		4,297	2,713	237	98	
3:12			4,650				353
5:32		150	6,144				
6:02	30		4,160	1,984	237	74	
6:12			4,639				479
8:32		150	6,463				
9:02	30		4,901	1,562	237	60	
11:32		150	6,634				
12:02	30		5,232	1,402	237	55	
14:32		150	6,930				
15:04	30		5,482	1,448	237	56	
17:32		150	6,873				
18:00	28		4,821	2,052	221	81	
20:32		152	6,349				
21:01	29		3,921	2,428	229	92	
21:06			4,479				558
23:32		151	5,448				
23:56	24		3,761	1,687	190	78	
0:11			4,468				707
2:32		156	5,334				
2:59	27		3,693	1,641	213	69	
3:12			4,286				593
5:32		153	4,935				
5:56	26		3,533	1,402	205	62	
6:18			4,514				981
8:32		154	5,175				
8:58	26		3,739	1,436	205	63	
9:14			4,365				626
11:30		154	4,844				
11:56	24		3,579	1,265	190	61	
12:13			4,059				480
14:32		156	4,787				
14:54	22		3,397	1,390	174	71	
15:15			4,080				683
17:32		158	5,038				
17:55	23		3,511	1,527	182	74	
18:06			4,160				649
20:32		157	5,824				
Total	433	2,447		30,320	3,422	average	607

* Inflow of manure while pump is ON

Manure Inflow to Pit

Time	Gallons	Manure Inflow*	
	in Pit	Gallons	gpm
0:12	5323		
2:32	7,010	1,687	12.1
3:12	4,650		
5:32	6,144	1,494	10.7
6:12	4,639		
8:32	6,463	1,824	13.0
21:06	4,479		
23:32	5,443	964	6.6
0:11	4,468		
2:32	5,334	866	6.1
3:12	4,268		
5:32	4,935	667	4.8
6:18	4,514		
8:32	5,175	661	4.9
9:14	4,365		
11:30	4,844	479	3.5
12:13	4,059		
14:32	4,787	728	5.2
15:15	4,080		
17:32	5,038	958	7.0
18:06	4,160		
20:32	5,824	1,664	11.4
21:21	5,380		
23:37	6,896	1,516	11.1
0:20	6,987		
2:33	8,024	1,037	7.8
3:12	7,762		
5:28	8,355	593	4.4
6:16	7,967		
8:41	9,403	1,436	9.9
	Average Inflow, gpm		7.9

* All pumps off.

Manure/food waste pumped	16,871	gal/day
Average pumping rate	78	gpm
at 8.5 lbs/gal	143,404	lb/day
Food Waste average	607	gal/cycle
Cycles/day	8	
	4,857	gal/day

The flow of manure from the freestall barn to the manure/influent pit averaged 7.9 gpm over the two day period. This would equal a manure flow of 11,380 gal/day or 96,700 lb/day at 8.5 lb/gal.

The formulas from ASABE were used to compute the manure produced by the dairy animals. This worksheet can be found in the Appendix, Table A-3. The results showed a production of total solids of 8,560 lb/day. Along with this is the food waste. Using the flow of 4,860 gal/day determined with the ultrasonic instrument, an assumed density of 8.34 lb/day and the average concentration of total solids of 14.8% (Table 4-7), the total solids added in the food waste was 6,000 lb/day.

Table 4-7. Food Waste at Ridgeline Farms.

	Food Waste		
Date	Sample	% TS	% S*
3/30/2007	RL FW 1	16.0	0.02
	RL FW 2	16.5	0.02
5/8/2007	RL FW 1	11.4	0.02
	RL FW 2	13.0	0.02
	RL FW 3	17.1	0.02
average		14.8	0.02
Std Dev		2.47	0.000
Confidence interval ±		1.71	

* As received

The determination of flow of influent to the digester, based on total solids, is summarized in Table 4-8. This procedure predicted a flow of 134,400 lb (wet weight) per day.

Table 4-8. Summary of Flows Into Digester Influent Pit.

Material	Flow gal/day		Flow lb/day		Percent	Lb TS/day
Manure						8,560 (ASABE)
Food Waste	4,860	→	40,800*		14.8	6,000
Bedding			830		85	710
Total			134,400	←	11.36	15,270

* Assume density at 8.4

A third procedure for determining the mass flow rate, influent and effluent, is based on mass balance of total solids and water. The results of this procedure are shown in Table 4-9. The yellow areas indicate the data need to make the calculations. The influent is predicted to be 130,200 lb/day or 15,300 gal/day assuming 8.5 lb/gal. The effluent would be 122,000 lb/day.

Table 4-9. Mass Balance Method of Determining Influent and Effluent.

Vw =	118,863	ft3/day, wet @ 1 atm			
Vo =	117,570	ft3/day, dry			Volume of biogas
CH4 =	0.689				Concentration of methane
CO2 =	0.31				Concentration of carbon dioxide
IPTS =	11.36	%			Percent total solids in influent
EPTS =	6.15	%			Percent total solids in effluent
IPS =	0.036	%			Percent sulfur in influent
EPS =	0.029	%			Percent sulfur in effluent
B =	8,087	lb biogas/day dry			Weight of biogas
T =	45	F			Biogas temperature at meter
bVS =	7,278	90%	[Richards, Brian K.,		Volatile solids consumed
bW =	809	10%	etal]		Mass of water consumed
	1,293	ft3 water vapor/day			Volume of water vapor
Dw =	0.0489	lb water/ft3 biogas			
We =	63.3	lb water/day			Water in saturated biogas
ITS =	0.114	ITW=	0.886		Total solids in influent
ETS =	0.062	ETW=	0.939		Total solids in effluent
ITM =	130,081	lb/day	15,304	gpd	Total mass of influent
ETM =	121,930	lb/day	14,345	gpd	Total mass of effluent
Δ TM =	8,150	lb/day			Change in mass
ITS =	14,777	lb/day			Total solids in influent
ETS =	7,499	lb/day			Total solids in effluent
Δ TS =	7,278	lb/day			Total solids "lost"
Sulfur In	46.8	lb/day			Sulfur in influent
Sulfur Out	35.4	lb/day			Sulfur in effluent
Δ Sulfur	11.5	lb/day			Sulfur "lost"

The “mass balance” method predicted 14,790 lbs of total solids in the influent. This compares favorably with the 15,270 lbs determined by the “total solids” method.

MILK

The concentration of sulfur in the milk is low but with the volume of milk shipped from the farm, sulfur in the milk can not be ignored. Table 4-10 shows the calculation for the sulfur content in the milk.

Table 4-10. Sulfur in Milk.

RHA lbs/cow-yr	lbs/cow day	# of Cow	Sulfur* %	S lbs S/cow day	Total lbs S/day
20,500	56.2	463	0.03	0.017	**7.8**

* based on data from Trace Minerals Research & IFAS at the University of Florida

BIOGAS

The results of analyzing the biogas for sulfur is shown in Table 4-11. Data from the 30 day test [average biogas produced per day, gas temperature and pressure along with the concentration of carbon dioxide] were used. The sulfur in the biogas calculated to be 9.8 lb S per day.

Table 4-11. Analysis of Biogas from Digester.

Based on averages from 30 day test, main meter
Biogas meter, Temp compensated (60 F)

Input Data - yellow area		
Biogas temp @ meter	45.2	F
Pressure in gas line	-0.8	in H_2O
Biogas flow (meter)	115,600	cuft/day
Elevation of meter	1,468	ft
H_2S (dry basis)	1,020	ppm
CO_2 (dry basis)	31.0	%
P_{elev}	13.918	psia
P_m	(0.030)	psig
P_{line}	13.888	psia
Volume of water vapor	1.09	%
Standard Pres.	14.696	psia
Standard Temp.	0	° C
Methane, low heating value	21,518	Btu/lb
Weight CH_4 at 0º C and 1 atm	0.0446	lb/ft^3
Weight CO_2 at 0º C and 1 atm	0.1227	lb/ft^3
Weight H_2S at 0º C and 1 atm	0.0948	lb/ft^3
Biogas to Engine, measured	63,967	cuft/day
Energy available	504	kW

Calculations (assume pressure at 1 atm)				
Biogas flow (wet) at	45.2	F	118,863	cuft/day
Biogas flow (dry) at	45.2	F	117,570	cuft/day
Concentration of methane, CH_4			68.9	%
Volume of CH_4 @	45.2	F	81,003	ft^3/day
Volume of CH_4 @ STP			74,547	ft^3/day
Weight of CH_4			**3,325**	**lb/day**
HEATING VALUE (low)			71,542,805	Btu/day
			2,980,950	Btu/hr
Raw biogas			602	Btu/ft^3
Energy available			873	kW
Volume of H_2S @	45.2	F	119.9	ft^3/day
Volume of H_2S @ STP			110.4	ft^3/day
Weight of H_2S			10.5	lb/day
Weight of Sulfur (S)			**9.8**	**lb/day**
Volume of water vapor	45.2	F	1,294	ft^3/day
Weight of water vapor			0.0489	lb/ft^3
Water			63	lb/day
			7.6	gal/day

A summary of the sources and the disposition of the sulfur are given in Table 4-12.

Table 4-12. Summary of Sulfur Flow, Ridgeline Farms.

Parameter	Value	Comments
Number of Cows	518	ASABE equivalent (553 head)
	Sulfur, lb/day	
TMR	47.8	Measured concentration & mass given
Drinking water	0.62	Measured concentration, assumed volume
Bedding	0.71	Volume given, concentration from reference
Milk	7.8	Volume given, concentration from reference
Raw Manure	41.3	[47.8 + 0.62 + 0.7 – 7.8]
Food Waste	8.2	Volume calculated, concentration measured
Influent	49.5	
Influent	47.2	Mass balance method
Effluent	35.1	Mass balance method
“Lost” in digester	12.1	By difference
Biogas analysis	9.8	Measured mass and concentration

APPENDIX

Figure A-1. Schematic Drawing
Of Ridgeline Farms.

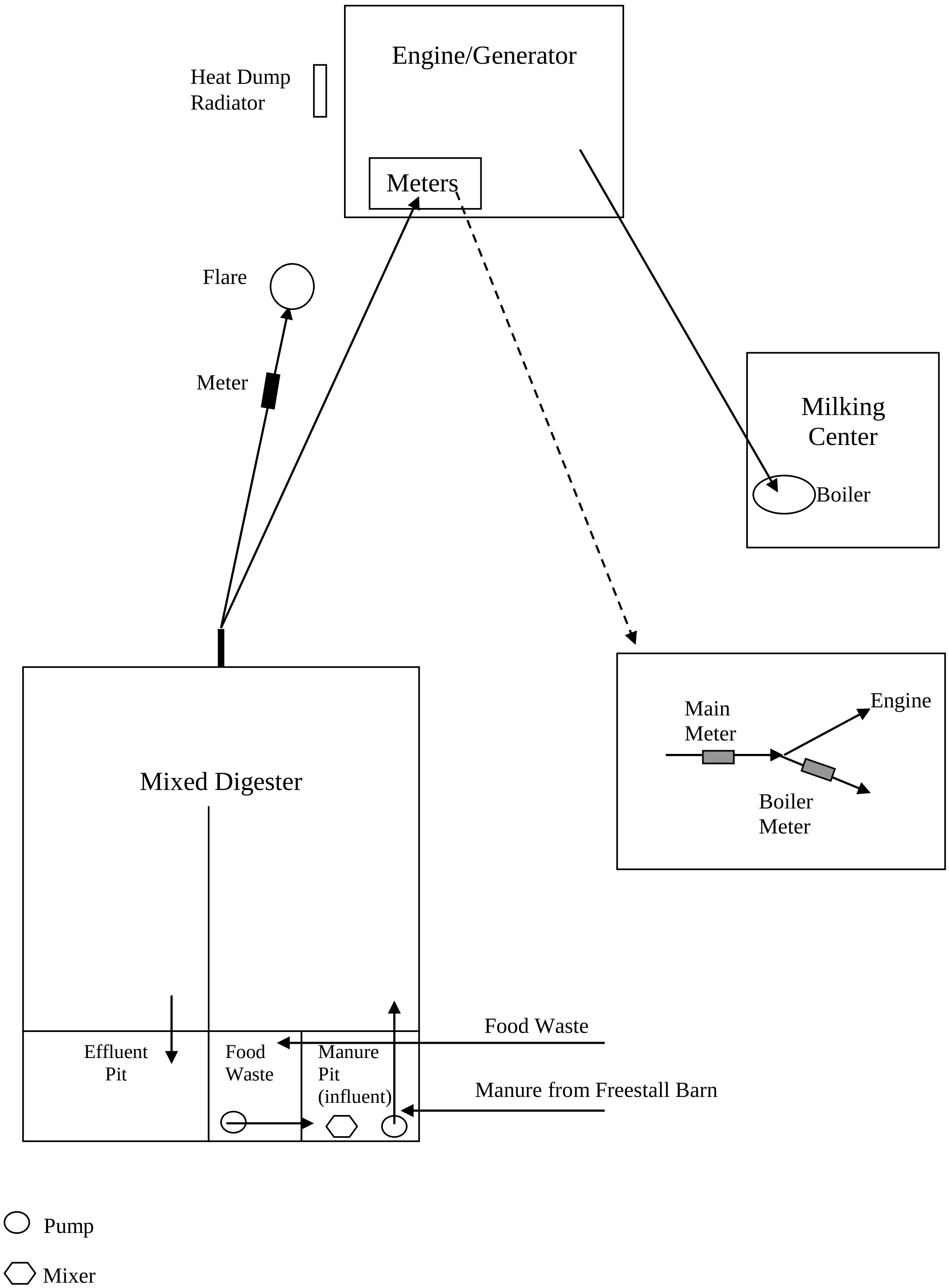


Figure A-2. Mass Flow Diagram of Sulfur, Ridgeline Farms.

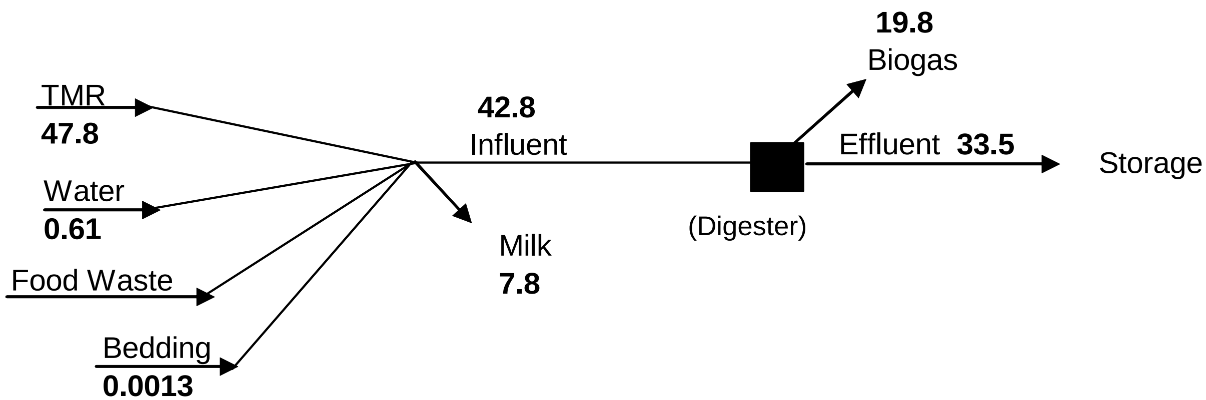


Table A-1. Ridgeline Farms 30 Day Test Data

Day #	Date 2007	Time	Biogas Meters							H2S			CO2			Comments
			Main				Biogas/ day	Boiler	Biogas/ day	ppm/%			ppm/%			
			Temp	Avg	Press	Reading		Reading		#1	#2	Avg	#1	#2	Avg	
1	30-Jan	10:10am	50		0.0	35.0		55,302		820	900		23	26		Third CO2 = 34%
																Engine not running until 3:30pm
		5:00pm	46	48	-0.63	97.0	58,400	55,302	-	920	1,000	910	33	33	29	(oil change & service)
2	31-Jan	10:15am	46		-0.8	619		55,302		1,050	1,050		32	32		Boiler didn't relight from yesterday
		1:30pm	46		-1.1	718		55,303		1,100	1,020		32	32		
		5:15pm	46	46	-1.4	846	77,800	55,312	3,400	1,050	1,050	1,053	33	32	32	
3	1-Feb	10:30am	46		-1.2	1,397		55,336		1,000	1,050		31	33		
																Engine off from 10:30 - 4:30 to
		5:00pm	47	46.5	-1.1	1,419	48,000	55,339	2,600	1,030	1,050	1,033	32	32	32	change exhaust manifold gaskets
4	2-Feb	9:30am	48		-1.2	1,877		55,362		1,100	1,100		34	34		
		1:15pm	48		-1.1	2001		55368		1,150	1,100		34	34		
		5:00pm	47	47.7	-0.9	2131	76,300	55375		1,100	1,175	1,121	34	34	34	
5	3-Feb	10:15am	45		0.7	2,640		55,398	3,500	1,010	1,020		31	32		
		1:15pm	46		-0.6	2,708		55,403		1,000	1,010		30	32		
		4:00pm	46	45.7	-0.75	2,773		55,411		1,020	1,010	1,012	32	32	32	
6	4-Feb								5,100							
		11:50am	45		-0.05	3,298		55,454		1,040	1,010		24	22		Food waste pump not working well
				45								1,025			23	
7	5-Feb	9:00am	42		0.0	3,824		55,482	3,100	1,200	1,100		34	32		
		1:30pm	44		0.0	3,938		55,485		1,150	1,100		33	32		Alley scrapes froze up
		6:00pm	43	43	0.2	5,054	68,000	55,497		1,175	1,200	1,154	33	32	33	Pumped effluent
8	6-Feb	11:00am	43		-1.0	4,504		55,539	6,400	1,075	1,100		31	31		Frozen manure in barns
		2:30pm	43		-0.75	4,627		55,549		1,100	1,000		31	32		Pumped effluent into food waste
		6:00pm	43	43	-0.1	4,734	77,100	55,558		1,000	1,050	1,054	31	31	31	
9	7-Feb	10:15am	43		-0.8	5,275		55,596	5,900	1,000	950		30	30		Frozen manure in barns
		1:30pm	43		-0.6	5,395		55,608		900	1,000		29	29		Pumped effluent into food waste
		5:30pm	43	43	-0.3	5,524	82,800	55,615		1,000	920	962	30	30	30	
10	8-Feb	10:15am	43		-0.75	6,103		55,664	6,700	1,000	1,000		30	30		
		2:00pm	43		-1.1	6,239		55,675		1,000	1,000		30	32		
		5:00pm	43	43	-1.1	6,332	82,300	55,681		1,020	1,000	1,003	32	31	31	
11	9-Feb	10:00am	43		-1.1	6,926		55,729	5,500	1,000	1,000		30	30		
		2:30pm	45		-1.0	7,081		55,730		1,020	1,000		31	31		Boiler down
		5:30pm	44	44	-1.0	7,156	71,600	55,730		1,000	1,000	1,003	30	30	30	

Table A-1. Ridgeline Farms 30 Day Test Data, Cont

Day #	Date 2007	Time	Biogas Meters							H2S			CO2			Comments
			Main				Biogas/ day	Boiler Reading	Biogas/ day	ppm/%			ppm/%			
			Temp	Avg	Press	Reading				#1	#2	Avg	#1	#2	Avg	
12		9:30am	44		-0.9	7,642		55,730		1,000	1,000		33	32		Boiler still down
	10-Feb	2:00pm	44		-0.9	7,790		55,730		1,000	100		32	32		
		4:15pm	44	44	-1.2	7,853		55,730		1,000	975	846	31	31	32	boiler back on at 4:00pm
13																
	11-Feb	11:50am	44		-1.25	8,539		55,795		990	950		17	20		
				44								970			19	
14		9:30am	45		-0.9	9,307		55,867		900	820		30	31		
	12-Feb	1:30pm	45		-1.0	9,413		55,845		820	900		30	30		
		5:30pm	45	45	-0.9	9,529	68,600	55,878	4,000	900	875	869	30	29	30	
15		9:30am	44		-1.1	9,993		55,907		1,000	975		30	29		
	13-Feb	1:30pm	44		-1.1	10,114		55,919		975	1,000		29	30		Broken water line to Digester
		5:30pm	44	44	-1.1	10,226	76,900	55,934	7,900	1,000	1,000	992	31	31	30	
16		10:00am	44		-1.0	10,762		55,986		1,075	1,100		34	34		Bags way down
	14-Feb	1:30pm	42		-0.75	10,855		55,994		1,100	1,100		36	35		Cold weather
		5:00pm	43	43	-0.6	10,957	63,200	56,006	5,100	1,100	1,150	1,104	37	37	36	2 loads of food waste
17		9:30am	43		-1.0	11,394		56,037		1,300	1,250		42	42		
	15-Feb	1:30pm	42		-1.1	11,509		53,047		1,300	1,275		39	40		2 loads of food waste
		5:30pm	43	43	-1.0	11,625	70,900	56,057	5,700	1,275	1,250	1,275	38	38	40	
18		10:30am	43		-0.8	12,103		56,094		1,175	1,200		35	36		
	16-Feb	1:00pm	43		-0.8	12,182		56,102		1,100	1,075		32	32		
		4:30pm	44	43	-0.8	12,285	63,200	56,115	4,600	1,050	1,000	1,100	34	34	34	
19		10:00am	45		-0.7	12,735		56,140		990	1,050		34	33		
	17-Feb	12:30pm	45		-0.9	12,806		56,149		1,000	1,000		33	33		
		4:30pm	45	45	-0.9	12,915	72,400	56,163	8,100	1,000	1,000	1,007	33	31	33	
20		10:30am	44		-0.8	13,459		56,221		1,000	1,000		32	33		
	18-Feb															
				44			60,600		6,400			1,000			33	
21		8:30am	44		-1	14,065		56,285		1,000			32	31		
	19-Feb	2:00pm	45		-0.9	14,230		56,304		1,000			32	32		Ran out of H2S tubes
		5:30pm	46	45	-1	14,319	80,800	56,314	8,300			1,000	33	32	32	
22		9:30am	47		-0.5	14,873		56,368					32	31		
	20-Feb	12:30pm	48		-0.6	14,935		56,375		1,050			31	31		Oil changed
		5:00pm	53	49	-0.5	14,937	50,300	56,376	3,400			1,050	29	29	31	Just restarted engine
23		9:00am	47		-1.1	15,376		56,402					29	30		
	21-Feb	1:30pm	48		-0.9	15,500		56,402					30	30		Boiler off to clean
		5:30pm	48	48	-0.75	15,598	68,400	56,408	6,000				29	31	30	Digester foaming a little
24		10:15am	47		-0.75	16,060		56,462					28	29		
	22-Feb															
				47			65,600		7,600						29	
25		9:15am	43		-0.75	16,716		56,538					30	30		
	23-Feb	2:00pm	43		-0.5	16,840		56,553					33	34		
		5:00pm	44	43	-0.6	16,909	62,900	56,563	7,700				34	34	33	
26		9:00am	43		-0.7	17,345		56,615					34	34		
	24-Feb	2:15pm	46		-0.9	17,489		56,633					35	34		
		5:00pm	46	45	-0.6	17,573	64,650	56,642	7,300				34	34	34	

Table A-1. Ridgeline Farms 30 Day Test Data, Cont.

Day #	Date 2007	Time	Biogas Meters							H2S			CO2			Comments
			Main				Biogas/ day	Boiler Reading	Biogas/ day	ppm/%			ppm/%			
			Temp	Avg	Press	Reading				#1	#2	Avg	#1	#2	Avg	
28	26-Feb	9:00am	47		-0.6	18,638		56,761					32	33		
		2:00pm	47		-0.9	18,791		56,782					33	33		
		5:00pm	47	47	-0.9	18,875	69,700	56,792	7,600				33	32	33	
29	27-Feb	9:00am	47		-0.9	19,335		56,837					31	30		
		1:00pm	45		-1.1	19,450		56,844					31	31		
		5:00pm	45	46	-1	19,573	73,200	56,853	6,000				32	31	31	
30	28-Feb	9:00am	47		-1	20,067		56,897		950	950		30	30		
		1:00pm	47		-1.3	20,200		56,911		950	950		30	30		Got new H2S tubes
		6:00pm	47	47	-1.2	20,362	71,700	56,929	7,800	975	1,000	963	30	31	30	
31	1-Mar	8:00am	47		-1.2	20,784		56,975		1,100	1,100		36	34		
		1:00pm	47		-1.2	20,945		56,990		1,050	1,000		34	34		
		5:27pm	47	47	-1.2	21,090	74,300	57,009	6,500	1,000	1,000	1,042	34	33	34	
32	2-Mar	7:30am	47		-1.2	21,527		57,040		975	1,000		33	33		
		1:00pm	47		-1.2	21,670		57,053		1,000	1,000		34	33		
		5:00pm	47	47	-1.1	21,827	82,900	57,069	9,000	975	1,000	992	33	33	33	
33	3-Mar	9:30am	48		-1.2	22,356		57,130		950	975		30	31		
		1:30pm	48		-1.1	22,487		57,142		975	975		32	31		
		4:00pm	47	48	-1.1	22,563		57,153		950	975	967	32	32	31	
35	5-Mar															
		2:00pm	44		-0.75	23,994		57,311		1,000	1,000		32	32		
		5:30pm	43	44	-0.6	24,078		57,322		1,000	1,000	1,000	31	32	32	

		Temp	Avg	Press	Reading	Biogas/ day	Boiler Reading	Biogas/ day	H2S #1	H2S #2	H2S Avg	CO2 #1	CO2 #2	CO2 Avg
Average		45.2		-0.84		69,724		5,757			1,022			32
Standard Dev.		2.02		0.36		9,051		2,093			87.4			3.56
Confidence Interval ±		0.42		0.08		3,414		775			14.7			0.53
(# of samples)		88		88		27		28			135			176

Table A-2. Production and Use of Biogas, Ridgeline Farms.

Date	Main Roots	Boiler Roots	Flare Meter
1/24	68,623	73,408	36,840
1/25	69,439	73,453	123,438
1/26	70,262	73,492	216,385
1/27			
1/28	71,885	73,580	333,645
1/29	72,707	73,625	391,138
1/30	73,549	73,671	428,952
1/31	74,386	73,722	472,316
2/1	75,204	73,769	494,324
2/2	76,043	73,823	545,076
2/3	76,865	73,869	595,467
2/4	77,687	73,915	645,858
2/5	78,514	73,962	699,335
2/6	79,371	74,010	741,550
2/7	80,024	74,051	798,239
2/8	80,869	74,125	859,769
2/9	81,682	74,182	906,720
2/10			959,866
2/11	83,358	74,276	1,013,048
2/12	84,135	74,329	1,078,356
2/13	84,991	74,374	1,112,602
2/14	85,520	74,415	1,168,151
2/15	85,895	74,443	1,240,492
2/16	86,674	74,494	1,304,422
2/17	87,448	74,539	1,364,635
2/18	88,223	74,583	1,424,849
2/19	89,007	74,632	1,466,237
2/20	89,781	74,682	1,502,198
2/21	90,561	74,736	1,541,075
2/22	91,341	74,790	1,579,952
2/23	92,125	74,843	1,628,409
2/24	92,923	74,895	1,704,129
2/25	93,721	74,948	1,779,848
2/26	94,538	75,008	1,857,297
2/27	95,400	75,063	1,930,297
2/28	96,017	75,104	2,007,777
2/29	96,811	75,155	2,042,155
3/1	97,632	75,206	2,082,665
3/2	98,453	75,265	2,112,598
3/3	99,275	75,331	2,142,530
3/4	100,092	75,392	2,185,202
3/5	100,909	75,453	2,227,873
3/6	101,729	75,513	2,256,396
3/7	102,541	75,567	2,327,496
3/8	103,356	75,615	2,397,000
3/9	104,157	75,661	2,446,834
3/10	104,959	75,708	2,496,667
3/11	105,761	75,755	2,531,899
3/12	106,587	75,809	2,563,332
3/13	107,417	75,868	2,578,592
3/14	108,253	75,929	2,617,865
3/15	109,074	75,984	2,669,484
3/16	109,891	76,036	2,722,964
3/17	110,708	76,087	2,776,443
3/18	111,516	76,143	2,824,520
3/19	112,331	76,190	2,903,826
3/20	113,071	76,233	2,970,233
3/21	113,885	76,279	3,014,380
Average	79,407	5,037	52,238

Total from Digester	131,645	cuft/day
Engine	74,370	56.5%
Boiler	5,037	3.8%
Flare	52,238	39.7%

Table A-3. ASABE, Calculating Manure Production.

		Animal	Manure Prod		Total Solids			Total Solids
		Number	lb/animal-day	lb/day	lb/animal-day	lb/day	% TS	collected, lb/yr
Milking Cows, RHA*, lb/cow-day	56.2	463	131.1	60,689	16.5	7,655	12.6%	2,794,172
Dry Cows, Body Weight	1500	90	80.9	7,285	10.1	907	12.5%	331,069
Heifers, average Body Weight	700	0	51.8	0	6.7	0	13.0%	0
Total				67,975		8,562	12.6%	3,125,240
				7,553	gal/day			

		Gal/cow-day	Gal/day	Lb/day		
Milking Center Wastewater		Gal/cow-day	Gal/day	Lb/day		
		8	3,704	30,891		
	Total			98,866	11912	gal/day
					518	equivalent cows