CHARACTERIZATION OF SULFUR FLOWS IN FARM DIGESTERS at EMERLING FARMS

Prepared for

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Section 1
DESCRIPTION

The Emerling Farm is located Rt 246 north of Perry, NY. A schematic of the layout of the barns, reception pit, digester and engine/generator building is attached in the Appendix, Figure A-1. Raw manure from cows in two freestall barns and wastewater from the milking center are collected in a reception pit. The manure from one barn housing milking cows flows by gravity from the cross alley to the reception pit. Manure from the second barn that houses low and medium producers, dry cows, heifers and springs was pumped to the pit once a day. Alley scrapers are used in both barns. There are 948 milking cows in three groups, 155 springers and heifers and 71 dry cows.

When the study started manure was being pumped to the digester once each afternoon. The pump, located in a "dry well" adjacent to the reception pit, was a *Houle* piston pump with a 19 inch diameter cylinder and a 46 inch stroke. There were 3 strokes per minute giving a theoretical capacity of 170 gpm.
The digester with a soft top was designed for a 20 day HRT (hydraulic retention time). The effluent from the digester flows by gravity to a storage pond.

Section 2
RESULTS – 24 HOUR TEST, JANUARY 21-22, 2008

Four 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 values are for a dry gas.

Table 2-1. Concentration of Carbon Dioxide and Hydrogen Sulfide & Biogas Pressure and Temperature.

Test Number	CO_2		H_2S	Pressure	Temperature
	Tubes, %	Bacharach, %		(inch water)	F
No. 1	28	32	2,400	-1.5	56
1/21/2008 11:15	27	34	2,500		
		34			
No. 2	27	33	1,900	-1.0	57
1/21/2008 14:15	22	35	2,200		
	32				
No. 3	35	35	2,700		
1/21/2008 17:15	30	32	2,700		
No. 4	32	37.5	2,800	-3.0	58
1/22/2008 9:15	32	35	2,400		
Average	29.4	34	2,450		
Standard Dev.	3.88	1.73	298		
Confidence Int ±	0.87	0.39	71		

The average carbon dioxide concentration measured by the gas tubes was 29.4% with a confidence interval of ± 0.87 at 5% level. The range would be 28.5 to 30.3%. The average CO_2 value from the Bacharach unit was 34% with a confidence interval of ± 0.39 at 5% level. The CO_2 level measured by the tubes was outside the confidence level of the Bacharach unit and vise versa. With a negative gas pressure considerable care must be taken to insure that no air is admitted into the hose between readings. Also, with the *Bacharach* unit squeeze bulb there may not be as much gas delivered to the unit per squeeze of the bulb.

During the 24 hr test carbon dioxide and methane concentrations were measured with a *GEM 2000* unit. Samples were taken every 15 minutes. The values for carbon dioxide are plotted in Figure 2-1. A problem was encountered while measuring methane with the GEM 2000 unit. There apparently was some interference caused by the hydrogen sulfide. The company suggested that because these values are for a dry gas and there are few trace gases such as hydrogen sulfide, the concentration of CH4 could be calculated by difference. These values are also plotted in Figure 2-1. There was a slight increase in the

level of carbon dioxide with an accompanying decrease in methane over the 24 hour period. Because the digester was fed for 5minutes every 30 minutes there is no apparent reason why the concentration should change over the 24 hour period. The statistical analysis of the data from the *GEM 2000* is shown in Table 2-2. The values of percent CO2 obtained with the gas tubes and Bacharach unit also indicated a small increase over the 24 hr period. However, the comparison between these three analyzers is shown in Figure 2-2. The *Bacharach* and gas tubes were consistently lower than the *GEM 2000*. Some of this variation may be due to the negative pressure causing air to enter the hose connecting the biogas pipe and the instrument between samples.

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

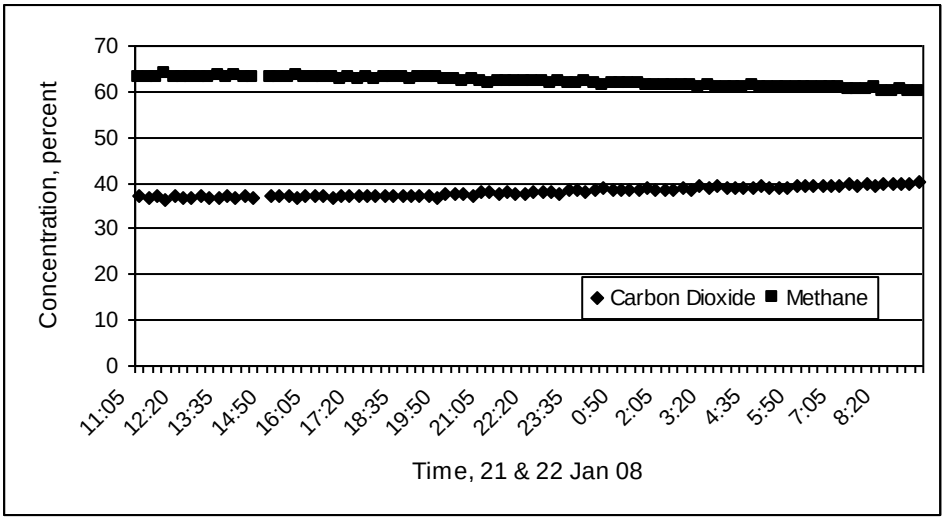
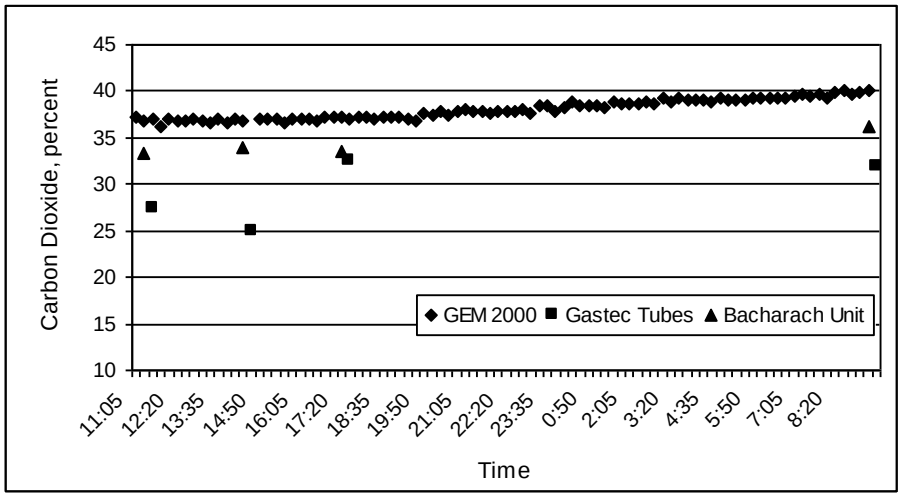


Table 2-2. Statistical Analysis of Data from *GEM 2000* Unit.

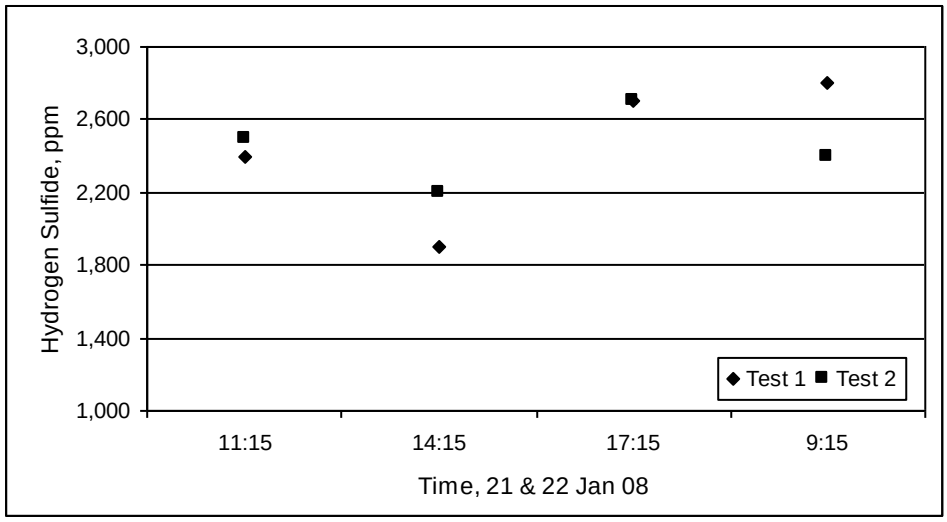
	Average	Std Dev	Confid Int.	Max	Min
CO_2	38.1	1.0	0.21	40.1	36.3
CH_4	61.7	1.0	0.21	63.5	59.7

Figure 2-2. Carbon Dioxide Concentration Measured with Three Analyzers.



The concentration of hydrogen sulfide also increased slightly over the 24 hours. This data is plotted in Figure 2-3. The average of the two reading at 11:15 on 21 January was 2,450 ppm, the same as the average for the 24 hours. The next morning at 9:15 the average concentration had increased to 2,600 ppm.

Figure 2-3. Concentration of Hydrogen Sulfide in Biogas at Emerling Farm.



Section 3
RESULTS – 30 DAY TEST, JANUARY 18 to FEBRUARY 16, 2007

During the 30 day test the operator recorded the following data three times per day: reading from biogas meter and biogas temperature and pressure at gas meter. At the same time two samples were taken from measuring the concentration of carbon dioxide with a Bacharach unit and two additional samples for were taken for measuring the concentration of hydrogen sulfide with gas tubes. The raw data recorded is listed in the Appendix, Table A-1.

An analysis of the data recorded during the 30 day test is presented in Table 3-1 below. The average daily production of biogas was 88,200 cubic feet with a maximum of 101,000 and a minimum of 76,000.

Table 3-1. Summary of Results of the 30 Day Test at Emerling Farms (18 January to 16 February 2007).

	Temp ° F	Press. inch water	Biogas cu ft/day	H2S ppm	CO2 %
Average	56.0	4.4	88,200	3,540	30.9
Standard Dev.	7.3	1.2	7,730	720	3.9
Confidence Interval ±	1.7	0.3	2,900	120	0.1
# of samples	73	73	27	137	128

The daily production of biogas is plotted in Figure 3-1. The length of day varied slightly due to a variation in the time when readings were taken. The decline was about 20,000 cubic feet or 20% in gas production over the 30 day period. There is no ready explanation for the decline. However, the temperature of the biogas at the gas meter average of 3 readings, as shown in Figure 3-2, declined roughly 15 degrees over this same period. The relationship between the biogas temperature at meter and the temperature of the digester is not known. This decline in gas temperature may have been due to a decrease in digester temperature, ambient air temperature around the soft cover or ground temperature where the gas line in located.

The concentration of carbon dioxide in the biogas was measured by the operator with a Bacharach unit. The CO_2 concentrations are plotted in Figure 3-3. The daily averages are plotted, generally the average of 6 samples. There were 146 samples out of a possible 180. The average concentration was 29% with a maximum of 38 and a minimum of 12%. The individual data point are also plotted, however there are not 146 data point shown because there may have been two or more data points the same on a given day.

Figure 3-1. Biogas Production at Emerling Farms, 30 Day Test.

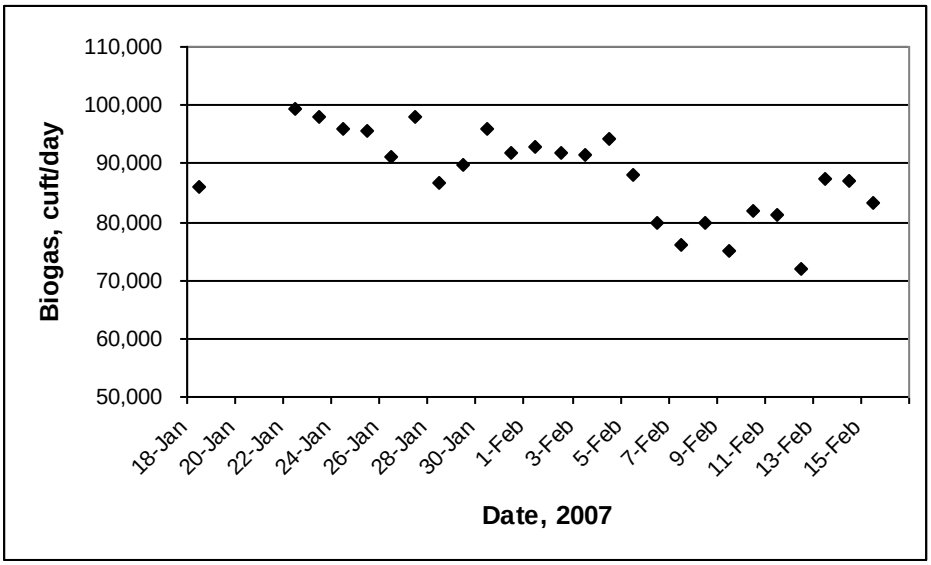
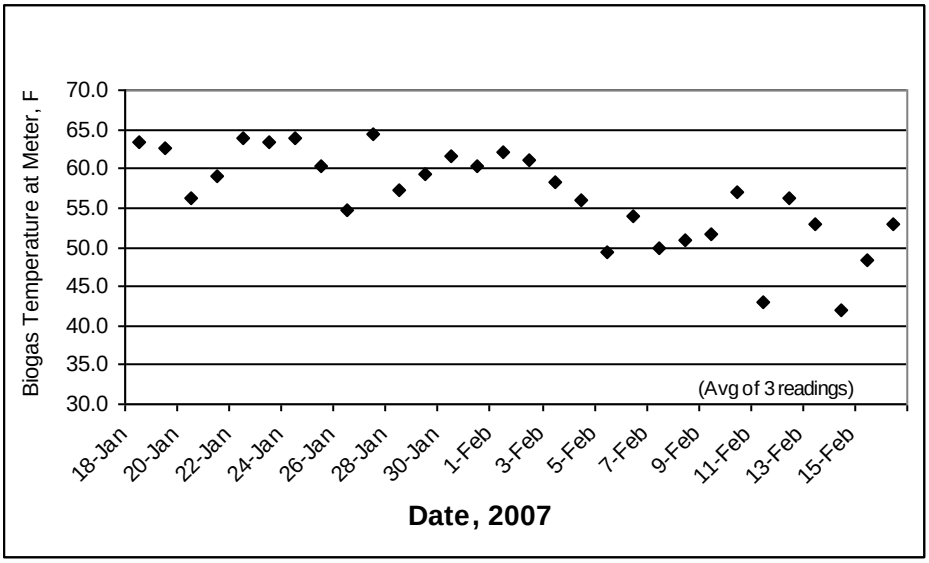


Figure 3-2. Daily Temperature of Biogas at Meter, 30 Day Test.



Between January 18th and February 10 there was a decline in the concentration of CO_2 similar to the decline in the production of biogas shown in Figure 3-1 and temperature in Figure 3-2. At 7:50 am on February 8 the CO_2 level was 12%. At 7:25 pm the next day the level was 32%. A note on the data sheets on Feb 12 states that Fyrite fluid was added to the CO_2 analyzer. This low fluid probably affected the previous readings. Removing the data points with a value of 24 or less, the average CO_2 was 30.9%.

The concentration of hydrogen sulfide in the biogas was tested using gas tubes. Two samples were to be analyzed three times per day. We have 146 data points out of a possible 180. The daily averages (6 points) are plotted in Figure 3-4. Not all the actual data points were plotted due to the arrangement of the spreadsheet. The average concentration of H_2S was 3,240 ppm with a maximum of 5,400 and a minimum 100 ppm. There were 8 readings less than 1,000 ppm. During this time the pressure in the digester bag cover was reported to be low. Excluding the reading from February 11 – 14, the average concentration of hydrogen sulfide was 3,500 ppm. This value will be used in analyzing the flow of sulfur.

Figure 3-3. Concentration of Carbon Dioxide in Biogas Measured with a Bacharach Unit.

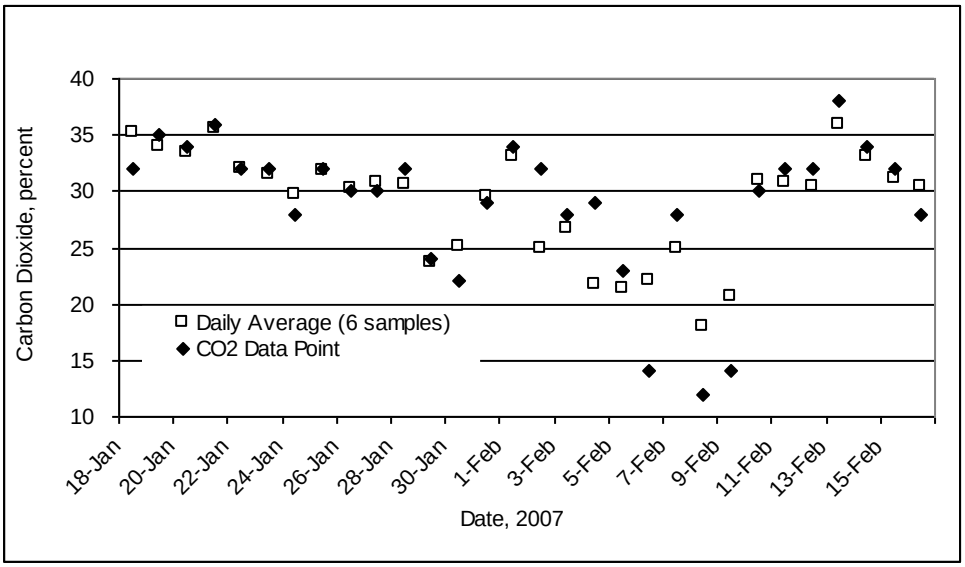
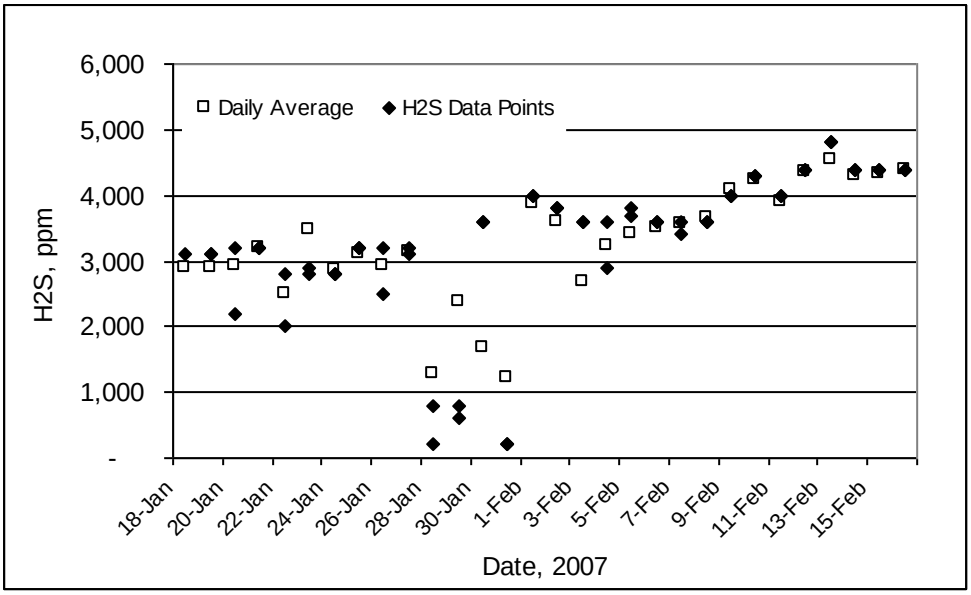


Figure 3-4. Concentration of Hydrogen Sulfide Measured with Gas Tubes, 30 Day Test.



SECTION 4
MASS FLOW OF SULUR

Samples of the total mixed ration (TMR), drinking water, digester influent and effluent were takes at three different times during the study. The TMR and digester influent and effluent were analyzed for total solids (TS) and sulfur by Dairy One, Inc. in Ithaca, NY. The amount of TMR fed to the various groups of dairy cows was obtained from the owner for each sampling date. Drinking water which comes from a lake was analyzed by Community Science Institute also located in Ithaca, NY.

TOTAL MIXED RATION

There were six groups of cows each with a unique TMR. The makeup of the herd is given in Table 4-1. The results of the analysis of sulfur in the TMR are shown in Table 4-2. The total sulfur (s) in the TMR for the entire herd was 134 lb/day.

Table 4-1. Groups of Cows, Number is Each Group and TMR Fed per Day.

Group Name	Number	Lb TMR/day
Milkers	576	62,960
Milkers, medium	232	26,080
Milkers, low	140	14,630
Springers	55	4,100
Heifers	100	5,100
Dry	71	5,800
Total	1,174	

Table 4-2. Sulfur Content in TMR at Emerling Farms.

	Milkers (high)			Milkers (Low)			Milkers (Med)		
Date	Sample	% S TMR (as fed)	lbs S/day	Sample	% S TMR (as fed)	lbs S/day	Sample	% S TMR (as fed)	lbs S/day
1/17/2007	M1	0.11	69.3	ML9	0.09	13.2	MED5	0.1	26.1
	M2	0.10	63.0	ML10	0.12	17.6	MED6	0.11	28.7
3/27/2007	M1	0.12	75.6	ML9	0.11	16.1	MED5	0.12	31.3
	M2	0.13	81.8	ML10	0.09	13.2	MED6	0.12	31.3
5/29/2007	M1	0.12	75.6	EFL MG1	0.12	17.6	EF MMG1	0.13	33.9
	M2	0.13	81.8	EFL MG2	0.12	17.6	EF MMG2	0.13	33.9
	M3	0.12	75.6						
Average		0.12	**74.7**		0.11	**15.8**		0.12	**30.9**
Std Dev			6.73			2.15			3.05
Confidence Interval ±			4.99			1.72			2.44

	Springers			Heifer			Dry Cow		
Date	Sample	% S TMR (as fed)	lbs S/day	Sample	% S TMR (as fed)	lbs S/day	Sample	% S TMR (as fed)	lbs S/day
1/17/2007	S3	0.08	3.28	H8	0.07	3.57	DC7	0.06	3.48
	S4	0.08	3.28						
3/27/2007	S3	0.11	4.51	H4	0.05	2.55	DC1	0.1	5.80
							DC2	0.08	4.64
5/29/2007	SPG1	0.12	4.92	H1	0.06	3.06	DC1	0.11	6.38
				H2	0.07	3.57	DC2	0.12	6.96
Average		0.10	**4.00**		0.06	**3.19**		0.09	**5.45**
Std Dev			0.85			0.49			1.40
Confidence Interval ±			0.83			0.48			1.37

Total Sulfur, avg **134** lbs S/day

DRINKING WATER

The drinking water the farm comes from a lake via the village of Perry. The results of the analysis of the drinking water are given in Table 4-3. The sulfur content was very low, averaging 0.053 lb S per 1,000 gallons.

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

DRINKING WATER			
Date	Sulfate Sample (mg/L)	Sulfur lbs/1000 gal	lbs S/day
1/19/2007	19.5	0.055	1.24
	18.75	0.053	1.19
3/27/2007	21.0	0.059	1.33
6/15/2007	17.0	0.048	1.08
Average		0.053	**1.21**
Std Dev			0.106
Confidence Interval ±			0.120

conversion factor; mg sulfate/l to lb sulfur/1000gal	0.0028
Water Consumption, gal/day	22,700

The owner stated that the cows 22,700 gallons per day. The sulfur consumed by the cows in their drinking water was 1.21 lb per day.

MILK

The concentration of sulfur in milk is low but because there are large volumes of milk produced, sulfur in the milk must be considered. Table 4-47 shows the information concerning the sulfur in the milk at Emerling Farms. The sulfur in the milk shipped was 20.2 lb S per day.

Table 4-4. Sulfur in Milk Shipped from Emerling Farm.

RHA lbs/cow-yr	lbs/cow-day	# of Cow	Sulfur* %	S lbs S/cow-day	Total lbs S/day
26,000	71.2	948	0.03	0.021	20.2

* based on data from Trace Minerals Research

MANURE

The properties (percent total solids and sulfur) for the digester influent and effluent are given in Table 4-5. The concentration of total solids decreased about 1.7% during digestion, 8.81 to 7.08%.

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

	Influent					Effluent*		
Date	Sample	% TS^	lbs/day (wet)	% S^	lb S/day^	Sample	S %^	lb S/day
1/17/2007	EFDI1	8.32	224,760	0.035	78.7	EFDE1	0.040	89.9
	EFDI2	10.1	185,332	0.035	64.9	EFDE2	0.025	46.3
3/27/2007	EFDI1	10.3	180,851	0.030	54.3	EFDE1	0.035	63.3
	EFDI2	9.14	204,595	0.030	61.4	EFDE2	0.035	71.6
	EFDI3	9.49	197,050	0.030	59.1	EFDE3	0.020	39.4
5/29/2007	EFDI1	8.46	221,040	0.035	77.4	EFDE1	0.025	55.3
	EFDI2	7.27	257,221	0.035	90.0	EFDE2	0.020	51.4
	EFDI3	7.37	253,731	0.035	88.8	EFDE3	0.025	63.4
Average		8.8	215,573	0.033	**71.8**		0.028	**60.1**
Std Dev					13.76			15.8
Confidence Interval ±					9.53			11.0

* assumes influent volume equals effluent volume
^ Data from Dairy One, Inc.

The samples taken in January was during the 30 day test and the sample taken in March was just after the end of the test. The average values for these two test dates (see Table 4-6) will be used in the mass balance method shown in Table 4-7.

The change in concentration of sulfur between influent and effluent is questioned. Table 6 below shows the averages for each sampling date and the change. There was very little change in January and no change in March.

Table 4-6. Concentration of Total Solids and Sulfur and Change in Sulfur Through Digester.

Date	Avg Influent		Avg Effluent		Change in Sulfur Content
	TS %	Sulfur %	TS %	Sulfur %	
January 17	9.2	0.035	6.7	0.0325	0.0025
March 27	9.6	0.030	7.9	0.030	0.000
Average	9.48	0.0325	7.45	0.0313	0.0012
May 29	7.7	0.035	6.5	0.0233	0.0117

MASS FLOW

Using the equations developed by American Society of Agricultural & Biological Engineers (ASABE) (see Appendix A-2), the total solids produced by the cows were calculated. This method gave 18,700 lb TS/day. The amount of sawdust bedding used at Emerling Farm was not available. An assumed value of 2.0 lb TS/cow-day is used. With 1,008 equivalent cows, the total solids in the bedding would be 2,000 lb/day. Adding this to the manure gives a total of 20,700 lb TS per day.

The influent pump was described earlier. A monitor was placed on the electric motor that drives the hydraulic pump on February 13. After 1.5 months the monitor was removed. The average operating time was 5.0 hr/day.

At the end of the study the time clock was set to operate the pump for 5 minutes each 30 minutes, 48 pumping cycles per day. The monitor was again placed on the motor for 2 weeks (29 May to 12 June). The pump averaged 5.12 minutes per cycle or 4.1 hr/day.

In May a test was conducted using an ultrasonic depth monitor. The unit was installed over the reception pit to measure the depth (gallons) of manure in the pit at Emerling. A portion of the results from that recording are shown in Figure 4-1. The change in volume of manure in the pit with 13 pumping cycles was 9,090 gallons. The average pumping rate was 700 gallons per cycle with 5.12 minutes per cycle. The pumping rate was 136 gpm. The efficiency of the Houle pump was 80% [136 gpm/170 theoretical gpm]. This test showed a flow of 33,500 gallons per day [136 gpm x 5.12 min/cycle x 48 cycles/day]. At 8.5 lb/gal, the flow was 284,700 lb/day. With a TS content of 7.70% in May the flow of total solids was 21,900 lb/day. The concentration of sulfur in the influent on May 29 was 0.035%. This gives a flow of sulfur into the digester of 99.6 lb S/day.

The Mass Balance Method (see Table 4-7) was used to calculate the total solids flow. Data from the 30 day test (biogas production, concentration of methane and hydrogen sulfide) was used along with the average concentration of total solids and sulfur in the influent and effluent (samples taken in January and February during the 30 day test). The total solids influent flow was 25,900 lb/day. This method also predicted the sulfur in the influent was 97.1 lb/day. This is very close to the 99.6 computed above.

Some cooking oil was being added to the digester to reduce the floating material. Obviously the digester produced biogas from this cooking oil. The mass balance method calculates the reduction of total solids (volatile solids) based on the production of biogas. Thus the computed influent total solids will be larger, 25,900 vs 21,900. The Mass Balance Method showed the loss of sulfur in the digester to be 16.4 lb S/day.

Figure 4-1. Ultrasonic Test at Reception Pit at Emerling Farms.

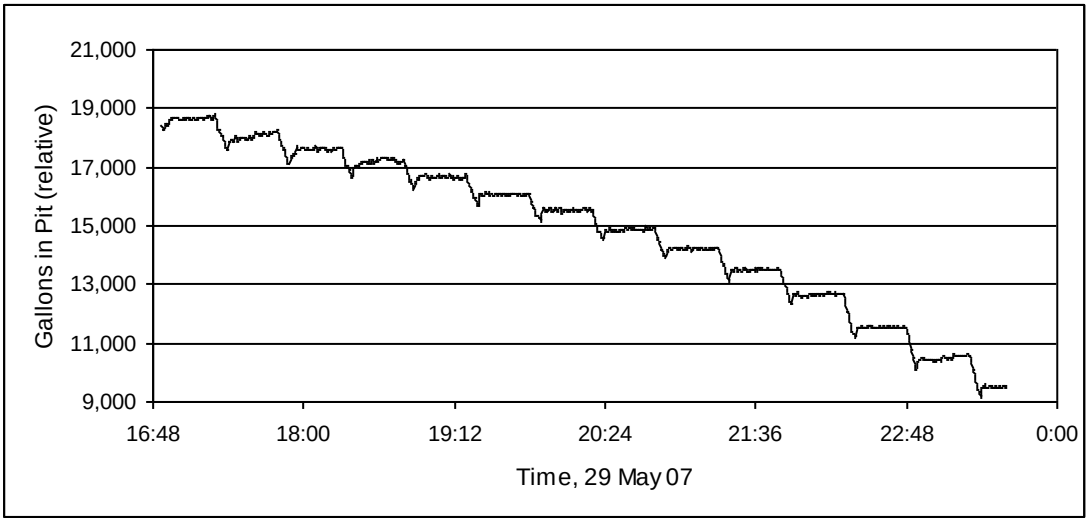


Table 4-7. Mass Balance Method for Determining Loss of Sulfur.

Analysis of Digesters, Mass Balalnce using Jan and Mar data

Vo =	89,600	ft3/day, dry			Volume of biogas
CH4 =	0.687				Concentration of methane
CO2 =	0.309				Concentration of carbon dioxide
IPTS =	8.81	%			Percent total solids in influent
EPTS =	7.08	%			Percent total solids in effluent
IPS =	0.033	%			Percent sulfur in influent
EPS =	0.028	%			Percent sulfur in effluent
B =	6,144	lb biogas/day dry			Weight of biogas
T =	56	F			Biogas temperature at meter
T =	13.3	C			
bVS =	5,530	90%*			Volatile solids consumed
bW =	614	10%*			Mass of water consumed
Dw =	0.00066	lb water/ft3 biogas			
We =	59.5	lb water/day			Water in saturated biogas
ITS =	0.0881	ITW=	0.912		Total solids in influent
ETS =	0.0708	ETW=	0.929		Total solids in effluent
ITM =	294,255	lb/day	34,618	gpd	Total mass of influent
ETM =	288,051	lb/day	33,888	gpd	Total mass of effluent
Δ TM =					
Δ	5,530	lb/day			Total solids "lost"
Sulfur In	97.1	lb/day			Sulfur in influent
Sulfur Out	80.7	lb/day			Sulfur in effluent
Δ Sulfur					

*Richards, B.K., R.J. Cummings, T.E. White, W.J. Jewell. Methods For Kinetic Analysis of Methane Fermentation in High Solids Biomass Digester, Biomass and Bioenergy, Vol. 1, No. 2, pp 65-73, 1991.

BIOGAS

The biogas was analyzed to determine the pounds of sulfur discharged in the gas per day. This analysis is shown in Table 4-8. Data from the 30 day test [average biogas produced per day, gas temperature and pressure along with the concentration of carbon dioxide] were taken from Table 3-1 and used in this analysis. This analysis calculated that 26 lb/day of sulfur were discharged from the digester in the biogas. This is nearly 10 lb/day more that predicted by the Mass Balance Method. The average level of H_2S in the biogas recorded during the 30 day test was 3,540 ppm. During the 24 hour test the average level was 2,450 ppm. If this concentration is used in the analysis of biogas below the sulfur discharged in the biogas is 18.0 lb S/day. This could be one explanation.

Table 4-8. Analysis of Biogas at Emerling Farms.

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

Input Data - yellow area		
Biogas temp @ meter	56.0	F
Pressure in gas line	4.4	in H_2O
Biogas flow (meter)	88,200	cuft/day
Elevation of meter	1,360	ft
H_2S (dry basis)	3,540	ppm
CO_2 (dry basis)	30.9	%
P_{elev}	13.975	psia
P_m	0.159	psig
P_{line}	14.134	psia
Volume of water vapor	1.55	%
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

Calculations (assume pressure at 1 atm)				
Biogas flow (wet) at	56.0	F	91,013	cuft/day
Biogas flow (dry) at	56.0	F	89,600	cuft/day
Concentration of methane, CH_4			68.7	%
Volume of CH_4 @	56.0	F	61,596	ft^3/day
Volume of CH_4 @ STP			56,486	ft^3/day
Weight of CH_4			**2,519**	**lb/day**
HEATING VALUE (low)			54,209,395	Btu/day
			2,258,725	Btu/hr
Raw biogas			596	Btu/ft^3
			662	kW
Volume of H_2S @	56.0	F	317.2	ft^3/day
Volume of H_2S @ STP			290.9	ft^3/day
Weight of H_2S			27.6	lb/day
Weight of Sulfur (S)			**26.0**	**lb/day**
Volume of water vapor	56.0	F	1,413	ft^3/day
Weight of water vapor			0.0479	lb/ft^3
Water			68	lb/day
			8.1	gal/day

A summary of the sulfur flow at the Emerling Farms is given in Table 4-9. The disparity between the computed sulfur in the "manure" leaving the freestall barn (117 lb S/day) and the computed sulfur in the digester influent (99.6 and 97.1) can not be explained. TMR is the largest contributor of sulfur because of the mass of TMR fed each day. Small errors in sampling and measuring concentrations of sulfur in the TMR could cause large changes in the mass of sulfur.

Table 4-9 Summary of Sulfur Flow at Emerling Farms

Parameter	Value	Units & Comments
Cow Equivalents*	1,008	
Sulfur to cow:TMR	134	lb S/day
Drinking water	1.2	"
Total	135.2	"
Milk	- 20.2	"
Manure from cow	115	" by difference
Bedding	2	"
Total leaving freestall	117	" Computed
Digester influent	99.6	" Mass flow
Digester influent	97.1	" Mass Balance Method
Digester effluent	80.7	"
Change	16.4	" Difference
Biogas	26.0	" Biogas analysis
Discrepancy	9.6	"
* based on ASABE equations, see Appendix, Table A2		

APPENDIX

Figure A-1. Schematic Drawing of the Emerling Farms

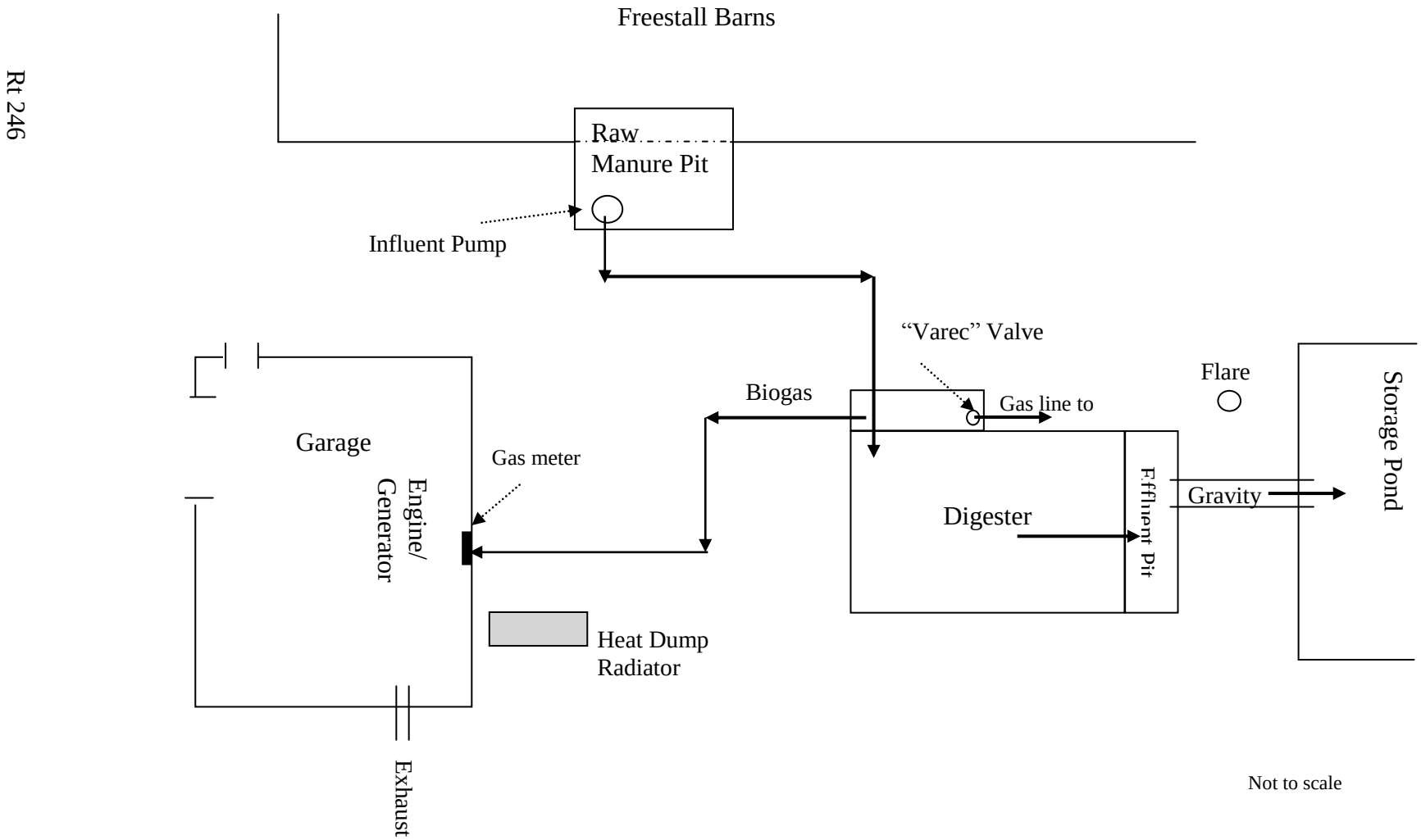


Figure A-2. Mass Flow Diagram of Sulfur, Emerling Farms.

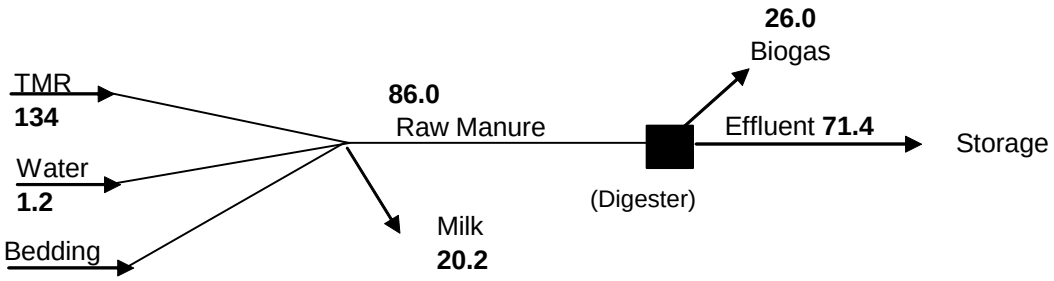


Table A-1. 30-Day Test Data, Emerling Farms.

Day #	Date 2007	Time	Biogas Meters					H2S			CO2			Comments
			Main					ppm		Avg/	%		Avg/	
			Temp	Avg Temp	Press	Reading	Avg/ day	#1	#2	day	#1	#2	day	
1		7:20am	62		6	737		3,100			32	38		Saw: Mike - pump bulb 20
	18-Jan	8:30pm	65		4	1,151		2,800	2,800		37	34		times for better sample -
				63.5			85,900			2,900			35	Stan
2		7:20am	62		5	1,596		3,100	3,100		35	34		
	19-Jan	2:00pm	63		4	1,868		2,400	3,000		33	34		
				62.5			1,001			2,900			34	
3		7:30am	55		4	2,597		2,200	3,200		34	32		
	20-Jan	1:00pm	56		4.5	2,812		3,300	3,200		36	34		
		7:30pm	58	56.3	4	3,087		2,800	2,900	2,933	33	32	34	
4		7:30am	59		4	2,598		3,200	3,200		36	35		
	21-Jan													
				59.0						3,200			36	
5		7:45am	64		4	4,588		2,000	2,800		32	32		
	22-Jan	11:20am	64		4.5	4,729		2,400	2,800		32	32		
				64.0			99,500			2,500			32	
6		8:00am	63		4.5	5,583		2,900	2,800		32	34		
	23-Jan	1:00pm	64		4.5	5,785		5,400	2,800		30	30		
				63.5			98,000			3,475			32	
7		7:45am	64		4.5	6,563		2,800	2,800		28	33		
	24-Jan	1:00pm	64		4	6,749		2,800	3,000		28	30		
				64.0			96,000			2,850			30	
8		7:45am	62		4.5	7,523		3,200	3,200		32	30		
	25-Jan	1:00pm	60		4.5	7,727		3,000	3,100		32	31		
		7:00pm	59	60.3	4	8,012	95,500	3,200	3,000	3,117	34	32	32	
9		7:45am	46		0	8,478		3,200	8,500		30	28		
	26-Jan	1:00pm	57		5.5	8,627		3,000	3,000		32	30		
		7:45pm	61	54.7	5	8,899	91,100	2,800	3,000	3,917	30	31	30	
10		7:30am	64		5	9,389		3,200	3,100		30	31		
	27-Jan													
		7:30pm	65	64.5	4.5		97,900	3,100	3,100	3,125	31	31	31	
11		7:30am	63		6	10,368		200	800		32	32		Bag ??? Low Pressure
	28-Jan	2:20pm	63		6	10,644		100	200		30	30		Motor was off from 6pm to
		8:00pm	46	57.3	0	10,764	86,700	3,200	3,200	1,283	30	30	31	8pm
12		7:30am	59		5	11,235		600	800		24	23		
	29-Jan	1:00pm	59		5	11,425		3,200	3,200		24	25		
		6:30pm	60	59.3	5	11,634	89,800	3,200	3,200	2,367	22	24	24	
13		7:20am	60		6	12,133		3,600	3,600		22	22		
	30-Jan	11:20am	63		6	12,290		1,200	1,000		24	26		
		6:40pm	62	61.7	6	12,588	95,900	400	200	1,667	29	28	25	Low bag pressure

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

Day #	Date 2007	Time	Biogas Meters					H2S			CO2			Comments
			Main					ppm		Avg/	%		Avg/	
			Temp	Avg Temp	Press	Reading	Avg/ day	#1	#2	day	#1	#2	day	
14	31-Jan	7:25am	60		6	13,092		200	200		29	29		
		11:00am	62		6	13,231		300	300		32	31		
		8:10pm	59	60.3	5	13,555	92,000	2,500	3,800	1,217	28	28	30	
15	1-Feb	7:45am	60		4	14,012		4,000	4,000		34	34		
		2:00pm	64		4	14,258		3,800	370		32	32		
				62.0			92,900			3,043			33	
16	2-Feb	7:45am	64		5	14,941		3,800	3,800		32	32		
		10:00pn	58	61.0	5	15,480	91,800	3,200	3,600	3,600	18	18	25	
17	3-Feb	7:25am	57		5	15,859		3,600	3,600		28	30		
		1:30pm	62		6	16,085		800	800		20	20		
		8:30pm	56	58.3	5	16,346	91,500	3,600	3,600	2,667	32	30	27	
18	4-Feb	7:30am	55		5	16,774		3,600	2,900		29	30		
		12:00pm	57		5	16,951		3,600	2,800		14	14		
				56.0			94,300			3,225			22	
19	5-Feb	7:45am	49		5	17,717		3,800	3,700		23	23		
		1:00pm	50		4.5	14,925		2,800	3,200		14	12		
		6:30pm	49	49.3	4.5	18,110	88,200	3,400	3,600	3,417	26	30	21	
20	6-Feb	8:10am	52		4.5	18,599		3,600	3,600		14	14		
		2:45pm	56		5	18,839		3,200	3,600		30	30		
				54.0			80,000			3,500			22	
21	7-Feb	7:25am	50		4.5	19,399		3,600	3,400		28	30		
		1:15pm	54		4	19,589		3,600	3,600		24	24		
		6:10pm	46	50.0	3.5	19,704	75,900	3,600	3,600	3,567	21	23	25	
22	8-Feb	7:50am	51		4	20,158		3,600	3,600		12	12		
		1:00pm	51		3	20,341		3,600	3,800		24	24		
				51.0			80,000			3,650			18	
23	9-Feb	8:15am	49		2	20,958		4,000	4,000		14	15		
		1;15pm	53		3	21,118		4,000	4,000		16	16		
		7:25pm	53	51.7	3	21,309	75,200	4,200	4,200	4,067	31	32	21	
24	10-Feb	7:20am	57		4	21,710		4,300	4,300		30	32		
		5:50pm	57	57.0	3	22,067	81,800	4,000	4,300	4,225	30	32	31	
25	11-Feb	7:30am	56		4	22,528		4,000	4,000		32	32		Added flued to CO2 tester
		12:50pm	30		4.5	22,706		3,600	4,000		30	29		Reading was then 36%
				43.0			81,300			3,900			31	
26	12-Feb	8:00am	57		3.5	23,341		4,400	4,400		32	30		
		2:10pm	52		5	23,456		4,200	4,200		32	30		
		8:20pm	60	56.3	4	23,656	72,000	4,800	4,200	4,367	30	29	31	

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

Day #	Date 2007	Time	Biogas Meters					H2S			CO2			Comments
			Main					ppm		Avg/	%		Avg/	
			Temp	Avg Temp	Press	Reading	Avg/ day	#1	#2	day	#1	#2	day	
27		7:45am	54		4.5	24,061		4,800	4,800		38	36		
	13-Feb	4:10pm	55		4	24,300		4,400	4,800		36	36		
		9:45pm	50	53.0	4.5	24,560	87,400	4,200	4,200	4,533	34	35	36	
28		7:40am	54		4	24,935		4,400	4,400		34	34		
	14-Feb	2:45pm	30		5	25,211		4,200	4,200		32	32		
				42.0			87,200			4,300			33	
29		7:35am	46		4	25,807		4,400	4,400		32	31		
	15-Feb	2:10pm	50		4	26,036		4,400	4,400		30	30		
		8:00pm	49	48.3	3.5	26,225	83,300	4,200	4,200	4,333	32	32	31	
30		7:40am	52		4	26,640		4,400	4,400		28	30		
	16-Feb	12:35pm	54		4.5	26,819		4,400	4,400		32	32		
				53.0						4,400			31	

Average	55.97		4.40	15,930	88,208		3,245		29	
St Dev	7.30		1.17	6,340	7,728		1240		5.9	
Confidence Interval ±	1.68		0.27	1,464	2,915		202		1.0	
(# of samples)	73		73	72	27		145		146	

Table A-2. Cow Manure Production, Based on ASABE Equations.

		Animal	Manure Prod		Total Solids			Total Solids
		#	lb/cow-day	lb/day	lb/cow-day	lb/day	% TS	collected, lb/yr
Milking Cows, RHA*, lb/cow-day	69.9	948	139.9	132,636	17.8	16,917	12.8%	6,174,604
Dry Cows, Body Weight	1500	71	80.9	5,747	10.1	716	12.5%	261,177
Heifers, average Body Weight	800	155	53.5	8,300	7.0	1,079	13.0%	393,835
Total				146,683		18,711	12.76	6,829,616
*Rolling Herd Average, lb/cow-yr	25,500							
						212,387	lb/day @ 8.81% avg TS	
						25,135	gal/day @8.45 lb/gal	
						1,049	cow equivalents	

Milking Center Wastewater	Gal/cow-day	Gal/day	Lb/day	
	8	7,584	63,251	
	Total		209,934	25293 gal/day

*Rolling Herd Average, lb/cow-yr	25,500		
Days per year	365	equivalent cows	1,049
Days in freestall per year	365		
Days - freestall & corral	0	Total Solids Content, manure	0.128
Days - corral	0	Total Solids Content, all	0.089
Percent of Manure Collected			
Freestall	100%		
Freestall & corral	80%		
Corral	60%		