CHARACTERIZATION OF SULFUR FLOWS IN FARM DIGESTERS at TWIN BIRCH DAIRY

Prepared for

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Section 1
DESCRIPTION

Twin Birch Dairy is located on Benson Rd between Owasco and Skaneateles Lakes. A schematic of the layout of the reception and effluent pits, digester, separator and other associated equipment is attached in the appendix. The reception pit [29.6 ft x 29.6 ft x 11.7 ft deep] is located in the same barn as the milking parlor. The volume of this pit is 546 gallons per inch of depth. Alley scrapers run continuously to bring the manure to cross pits where manure then flows to the reception pit by gravity. Manure from the following animal groups was being digested during this study. The medium and small heifers are housed at another location. Roughly half the manure from these heifers was hauled to the reception pit. Wastewater from the milking center also flows to the reception pit.

Table 1-1. Number of Animals .

Animals Groups	Number
Main milking group	904
Fresh cows	87
Prefresh cows	123
Medium heifers	202
Small heifers	324

A Houle piston pump pumps the manure from the reception pit through a heat exchanger, located on top of the digester, to the digester. The pump operates on a 12 minute cycle: 3 minute mix, 5 minute pump, 4 minutes off. This pump operates 600 minutes per day. Manure is pumped uniformly over the 24 hour day. Hot water from the microturbine heat exchangers and biogas fired boiler is used to heat the manure prior to entering the digester.

As the raw manure is pumped into the digester, the digested manure overflows a dike and flows by gravity to the effluent pit adjacent to the digester. The effluent pit is 12 ft x 28 ft x 11.4 ft. The volume of this pit is 209 gallons per inch of depth.

Each night the digested manure is pumped to a separator to separate the solids from the liquid. The separated liquid flows directly to a “separated liquid” pit next to the effluent pit. This liquid is pumped to a storage lagoon to await land application. The separated solids are conveyed to an adjacent storage building by an overhead flat belt conveyor and pile to encourage heating prior to being used for bedding. The solids are not composted.

Biogas is pumped from the digester using a blower whose speed is controlled by an adjustable speed drive and a pressure transducer. A slight positive pressure is maintained in the hard cover digester. The biogas is piped to the generator building Roots (temperature compensated) meter. Ahead of the Roots meter excess biogas is bled off through a *Varec* valve to a flare. Pressure at the Roots meter was maintained at 25 inch of water. Then biogas for the microturbines was passed through a condenser to remove water vapor then to compressors and finally to four microturbines/generators sets. The Roots meter measures the biogas for the microturbines and the boiler. Two "*Pete's Plugs*" were installed on the biogas meter. This permitted the use of a bimetal stem thermometer to monitor the temperature e of the biogas at the meter and for attaching a pressure gage to monitor pressure. An analog pressure gage (Dwyer Instrument, Inc.) was installed near the gas meter.

Two series of tests were conducted during this study, a 24 hr and a 30 day. These tests were designed to characterize the source of sulfur and its flow on farms with digesters and engines. Raw data from these tests are given in the appendix.

Section 2
RESULTS – 24HOUR TEST, JANUARY 28-29, 2008

Four (4) times during the 24 hour period the biogas was tested for carbon dioxide (*Gastec* gas tubes and *Bacharach* unit) and hydrogen sulfide (*Gastec* gas tubes). Duplicate tests were run at each time. Table 2-1 gives the results of these tests.

Table 2-1. Concentration of Carbon Dioxide and Hydrogen Sulfide (dry basis) 28 & 29 Jan 08.

Test Number	CO_2		H_2S	Tempeature
	Tubes, %	Bacharach, %		F
No. 1 13:45	42.5	38	4,800	72
	45	38	5,000	
No. 2 16:15	40	42	6,000	74
	42.5	39	6,000	
No. 3 10:30	40	40	5,500	74
	40	41	5,500	
No. 4 12:15	40	40	5,500	73
	41	40	5,500	
Average	41.4	40	5,475	73.3
Standard Dev.	1.83	1.39	420	1.0
Confidence Int ±	0.50	0.3	94.4	0.22

The carbon dioxide concentration measured by the gas tubes and *Bacharach* unit were well within the standard deviations. Care must be taken when analyzing biogas with either piece of equipment.

During the 24 hour test the concentrations of carbon dioxide and methane were measured every 15 minutes with a *GEM 2000* instrument. This data is plotted in Figure 2-1. Difficulty was encountered in measuring methane. The alleged reason was an interference caused by the hydrogen sulfide and the methane sensor. This did not occur with an earlier unit. The concentration of methane (dry basis) was calculated by subtracting the concentration of carbon dioxide and hydrogen sulfide from 100. The results (average of two readings) from measuring CO_2 with the gas tubes and Bacharach unit are also plotted in Figure 1.

Figure 2-1. Carbon Dioxide and Methane Concentration in Biogas (dry basis).

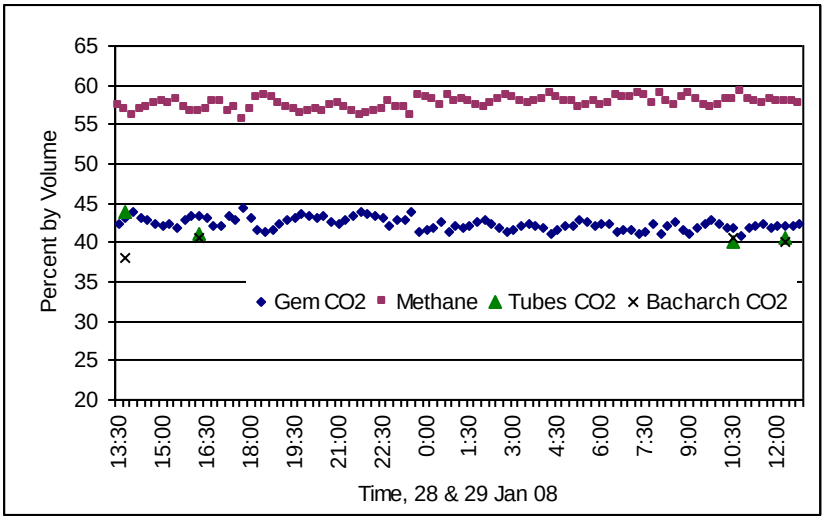


Table 2-2. Statistical Analysis of 24 hr Data shown in Figure 2-1.

Parameter	Average	Std Deviation	Confidence Interval
Methane	57.6	0.77	0.16
Carbon Dioxide	42.4	0.77	0.16

The 24 hour test was conducted more than a year later so the results can not be compared. The three methods of analyzing for CO_2 [gas tubes, *Bacharach* and *GEM 2000*] and the resulting concentration of CH_4 were compared. The concentrations of hydrogen sulfide and carbon dioxide were considerably different in late 2007 compared to January 2008. At this time there is no explanation for the differences. The results are shown in Table 2-3.

Table 2-3. Comparison of Tests for Carbon Dioxide and Resulting Concentration of Methane (dry basis).

Equipment	H_2S, ppm	CO_2	CH_4*
GEM 2000 (24 hr test, 90 samples 28 & 29 Jan 08)	5,500	42.4	57.0
Gas tubes (24 hr test, 8 samples, DCL)	"	41.4	58.0
Bacharach (24 hr test, 8 samples, DCL)	"	40	59.4
Bacharach (30 day test, 7 Nov – 6 Dec 07, 180 samples, operator)	3,700	36.1	63.5

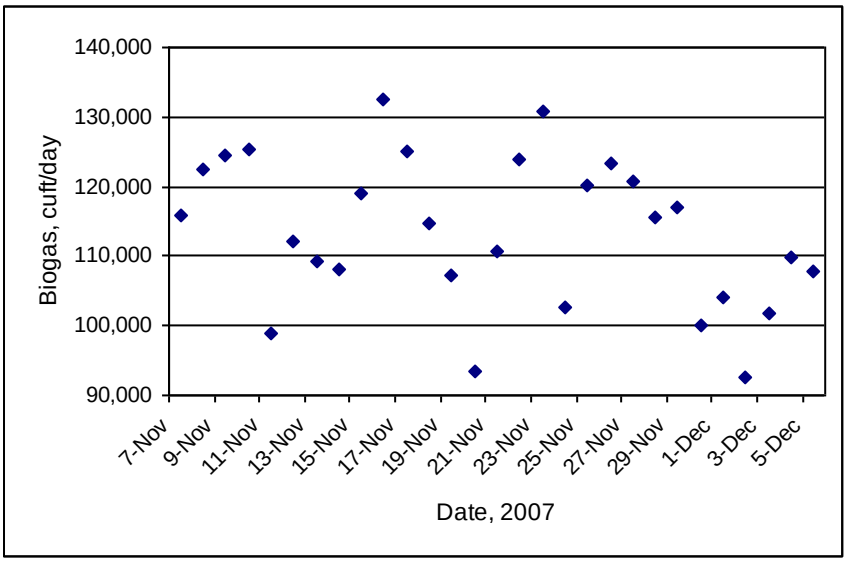
* $CH_4 = 100 - CO_2 - H_2S$

Section 3
RESULTS – 30 DAY TEST, NOVEMBER 7 TO DECEMBER 6, 2007

During the 30 day test the operator measured and recorded the following data three times each day; biogas temperature and pressure at the meter, reading from the biogas meter, two samples each for hydrogen sulfide (gas tubes) and carbon dioxide (Bacharach unit). The raw data can be found in the Appendix, Table A-1. The *Roots* biogas meter was temperature compensated (60 F).

The production of biogas during the "30 day test" averaged 111,200 ft^3/day. The maximum was 130,700 and the minimum was 92,500 ft^3/day. The daily production is plotted in Figure 3-1. Some of the variation in daily production was due to a variation in "length of day" due to the time when the readings were taken.

Figure 3-1. Biogas Production at Twin Birch Farms During 30 Day Test.



The average daily temperature (three readings) of the biogas at the meter is plotted in Figure 3-2. The average gas temperature was 79.3 F. There were no comments regarding why the gas temperature declined during the last five days of the test. Perhaps the ambient air temperature dropped during this time. The pipe from the digester to the generator building is underground. The production of biogas was generally lower during those days which could indicate that the digester temperature had decreased.

The concentration of carbon dioxide in the biogas was measured by the operator with a *Bacharach* unit. There were 180 samples tested. Not all data points appear in the plot because the values were often the same on a given time or day. This data is plotted in Figure 3-3. The average concentration of CO_2 was 36.1 percent (dry basis)

Figure 3-2. Daily Temperature of the Biogas at the Meter, 30 day test, average of three readings.

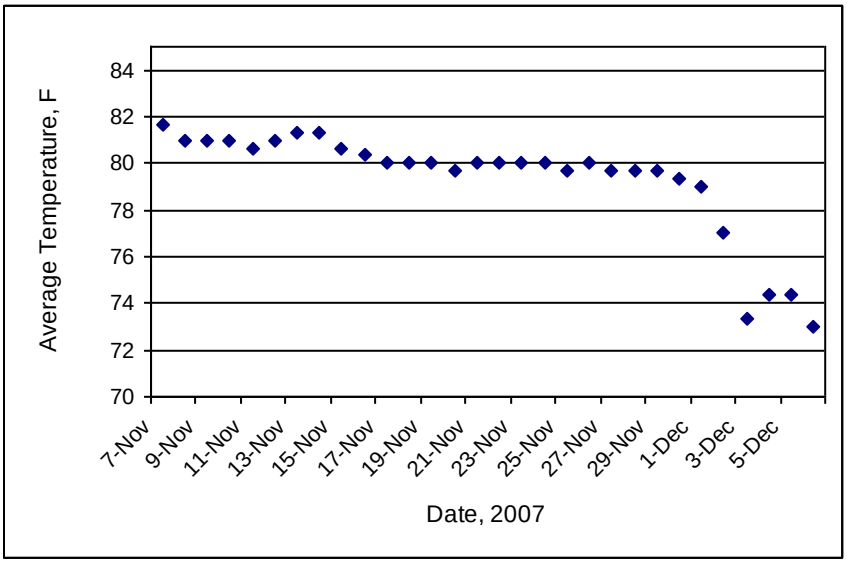
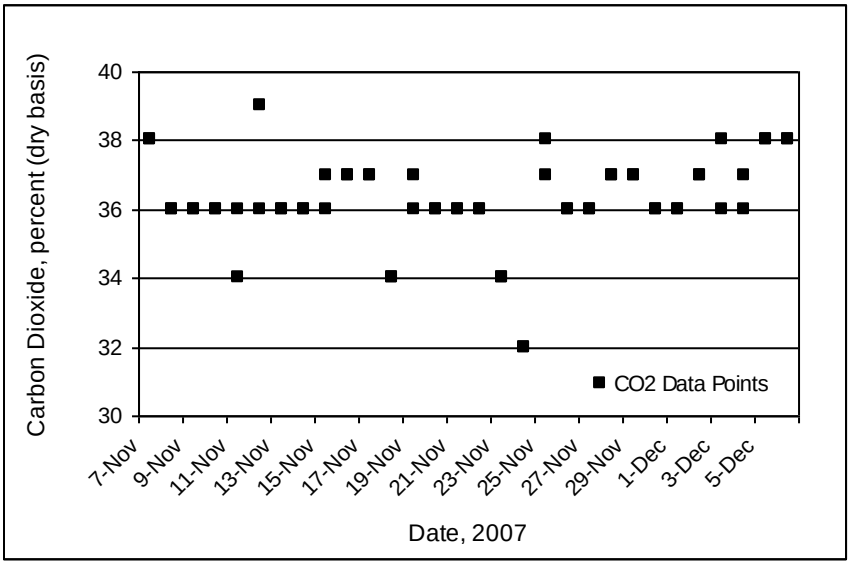


Figure 3-3. Concentration of Carbon Dioxide Measured with Bacharch Unit, 30 day test (dry basis).



The concentration of hydrogen sulfide of the biogas was measured using a gas tube. Two samples were analyzed three times each day. There were 180 samples. The results of these tests are plotted in Figure

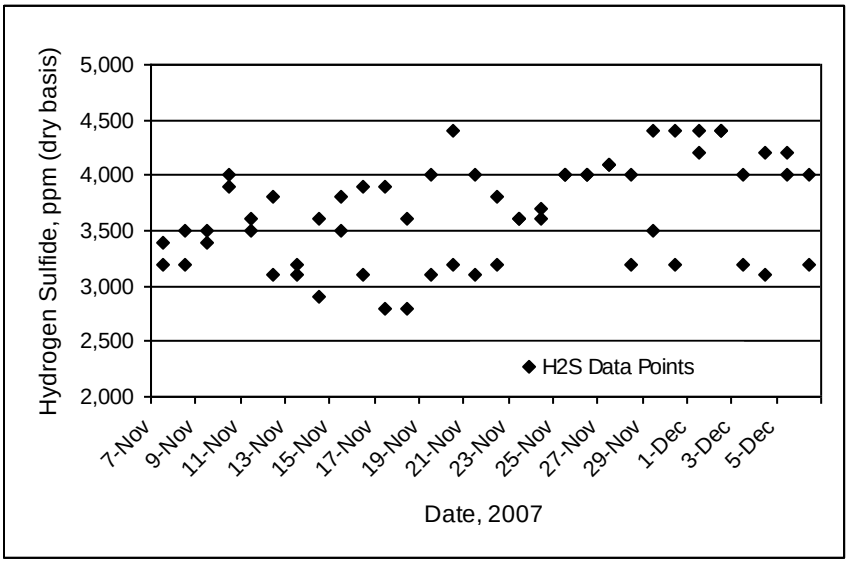
3-4. Again not all the data points are seen in this plot in Figure 3-4. The average concentration of H2S was 3,700 ppm with a maximum concentration of 4,400 ppm while the lowest concentration was 3,200 ppm.

Table 3-1 lists the average values for each parameter tested during the 30 day test along with the standard deviation, confidence interval and the number of raw data points.

Table 3-1. Summary of Data from 30 Day Test at Twin Birch Farms.

Item	Temp, F	Press, in H_2O	Biogas, ft^3/day	H_2S, %	CO_2, %
Average	79.3	15.0	111,190	3,700	36.1
Standard Deviation	2.4	0.1	10,730	520	1.0
Confidence Interval±	0.51	0.001	3,900	75.3	0.15
No. of Samples	90	90	29	180	180

Figure 3-4. Concentration of Hydrogen Sulfide (dry basis), 30 day test.



Section 4
MASS FLOW OF SULFUR

Samples of the total mixed ration (TMR), drinking water, digester influent and effluent and bedding (separated solids) were taken at three different times during the study. The TMR, digester influent and effluent and separated solids were analyzed by Dairy One, Inc. in Ithaca, NY. The drinking water was analyzed for sulfate and condensate water was analyzed for sulfide by Community Science Institute, Ithaca, NY.

TOTAL MIXED RATION

The results of the analysis for sulfur in the TMR are given in Table 4-1.

Table 4-1. Sulfur in TMR at Twin Birch Farms.

	Small Heifer				
Date	lbs/day Delivered	lbs/day consumed (100 %)	Sample	S % (as fed)	lbs S/day
11/8/2007	11,110	11,100	TBHS1	0.07	7.77
			TBHS2	0.07	7.77
			TBHS3	0.07	7.77
11/21/2007	11,080	11,080	TBHS1	0.07	7.76
			TBHS2	0.09	9.97
			TBHS3	0.08	8.86
12/7/2007	13,740	13,740	TBHS1	0.09	12.37
			TBHS2	0.08	10.99
			TBHS3	0.08	10.99
		Average		0.080	**9.4**
		Standard Dev			1.8
		Confidence Integral ±			1.16

Table 4-1. Sulfur in TMR at Twin Birch Farms, cont.

Medium Heifer					
Date	lbs Delivered	lbs consumed (100%)	Sample	S % (as fed)	lbs S/day
11/8/2007	17,390	17,390	TBHM1	0.07	12.17
			TBHM2	0.08	13.91
			TBHM3	0.08	13.91
11/21/2007	13,740	13,740	TBHM1	0.08	10.99
			TBHM2	0.08	10.99
			TBHM3	0.08	10.99
12/7/2007	21,740	21,740	TBHM1	0.07	15.22
			TBHM2	0.07	15.22
			TBHM3	0.07	15.22
		Average		0.074	**13.18**
		Standard Dev			1.9
		Confidence Integral ±			1.24

Fresh Cows					
Date	lbs/day Delivered	lbs/day consumed (97.5%)	Sample	S % (as fed)	lbs S/day
11/8/2007	8,130	7,927	TBFC1	0.13	10.30
			TBFC2	0.13	10.30
			TBFC3	0.13	10.30
11/21/2007	8,300	8,093	TBFC1	0.1	7.93
			TBFC2	0.1	7.93
			TBFC3	0.1	7.93
12/7/2007	11,930	11,632	TBFC1	0.1	11.63
			TBFC2	0.1	11.63
			TBFC3	0.09	10.47
		Average		0.104	**9.7**
		Standard Dev			1.5
		Confidence Integral ±			0.99

Pre-Fresh Cows					
Date	lbs/day Delivered	lbs/day consumed (97.5%)	Sample	S % (as fed)	lbs S/day
11/8/2007	7,900	7,703	TBPF1	0.16	12.32
			TBPF2	0.24	18.49
			TBPF3	0.22	16.95
11/21/2007	8,630	8,414	TBPF1	0.12	10.10
			TBPF2	0.1	8.41
			TBPF3	0.15	12.62
12/7/2007	9,150	8,921	TBPF1	0.15	13.38
			TBPF2	0.16	14.27
			TBPF3	0.14	12.49
		Average		0.164	**13.2**
		Standard Dev			3.1
		Confidence Integral ±			2.03

Table 4-1. Sulfur in TMR at Twin Birch Farms, cont.

Main Milking Group					
Date	lbs/day Delivered	lbs/day consumed (97.5%)	Sample	S % (as fed)	lbs S/day
11/8/2007	96,910	94,487	TBMMG1	0.11	103.94
			TBMMG2	0.12	113.38
			TBMMG3	0.12	113.38
11/21/2007	70,710	68,942	TBMMG1	0.11	75.84
			TBMMG2	0.11	75.84
			TBMMG3	0.13	89.62
12/7/2007	96,930	94,507	TBMMG1	0.1	94.51
			TBMMG2	0.1	94.51
			TBMMG3	0.1	94.51
		Average		0.110	**95.1**
		Standard Dev			13.8
		Confidence Integral ±			9.01

Total sulfur **129.3** lbs/day

The sulfur (S) content of the TMR consumed by the dairy animals at Twin Birch is estimated to be 141 lb per day. The assumption was made that about half of the manure from the small and medium heifers was added to the digester influent pit. Thus the total sulfur entering the system from the TMR would be 129 lb/day.

DRINKING WATER

Samples of the cow drinking water were taken on three occasions for analysis for sulfur. The drinking water consumed by the various animal groups was assumed to be 45,000 gal/day, see Table 4-2. Animal numbers were taken from Table 1. Only one half of the heifers were included. The conversion factor for changing mg SO_4/l to lbs S/1,000 gal is 0.0028. The results given in Table 4-3 show that 5.0 lb of sulfur enter the system each day.

Table 4-2. Water Consumed by Dairy Animals at Twin Birch Farms.

Animal Groups	Number	Gal/day	Total Gal/day
Main milking group	904	42	38,000
Fresh cows	87	30	2,600
Prefresh cows	123	25	3,000
Medium heifers (1/2)	101	15	1,500
Small heifers (1/2)	162	10	1,600
Total			46,700

Table 4-3. Sulfur in Drinking Water at Twin Birch Farms.

DRINKING WATER				
Date	Sample	mg Sulfate/L	lbs S/1000 gal	lbs S/day
11/7/2007	TBF Cow Water	43.8	0.12	5.73
11/24/2007		32.5	0.09	4.25
	average	38.2	0.107	**5.0**
	Standard Dev	1.04		
	Confidence Int ±	1.45		

conversion factor; mg sulfate/l to lb sulfur/1000gal 0.0028
Water Consumption, 46,700 gal/day

The total sulfur consumed by the dairy herd (for those animals whose manure reaches the digester) was 134 lbs/day.

BEDDING/SEPARATED SOLIDS

The separated solids used for bedding were analyzed for sulfur. The results are shown in Table 4-4. The following information was provided by the farm owner.

Spreader Capacity	363 ft^3
Density of solids (wet)	25.2 lb/ft^3
Weight per load	9,150 lbs
Loads per week	
Milking herd	16
Heifers	3 (6 loads are delivered per week but only half goes to digester)
Weight per day (avg)	24,800 lb wet wt.

Table 4-4. Analysis of Separated Solids at Twin Birch Farms.

Bedding (Separated Solids)					
Date	lbs/day	Sample	TS %	S % (as used)	lbs S/day
11/7/2007	24,800	TBSSB1	29.1	0.12	29.76
		TBSSB2	28.5	0.12	29.76
		TBSSB3	27.4	0.12	29.76
12/7/2007	"	TBSSB1	26.1	0.12	26.10
		TBSSB2	27.0	0.13	27.00
			27.2	0.14	
1/29/2008	"	TBSSB1	24.5	0.11	26.10
		TBSSB2	24.5	0.10	27.00
	Average		**26.8**	**0.12**	**27.9**
	Standard Dev		1.68	0.012	
	Confidence Integral ±		1.17	0.008	

FOOT BATH

The contents of the footbath find their way into the digester. Fourteen (14) pounds of cupric sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) are used four days per week. This equates to an average of 8 lbs/day. The molecular weight of cupric sulfate pentahydrate is 249.5. Sulfur with a molecular weight of 32, represents only 12.8% of the weight of the footbath chemical. Thus the contribution of sulfur would average 1.0 lb S/day.

MILK

The concentration of sulfur in milk is low but because the volumes are large sulfur in milk must be considered. Table 4-5 shows the information concerning sulfur in the milk at Twin Birch Farms.

Table 4-5. Sulfur in Milk Produced at Twin Birch Farms.

RHA lbs/cow-yr	lbs/cow day	# of Cow	Sulfur* %	S lbs S/cow day	Total lbs S/day
24,900	68.2	990	0.03	0.020	**20.3**

* 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 4-6. The concentration of total solids (TS) decreased about 3.5 percent while the concentration of sulfur decreased from 0.064 to 0.051.

Table 4-6. Properties of Digester Influent and Effluent at Twin Birch Farms.

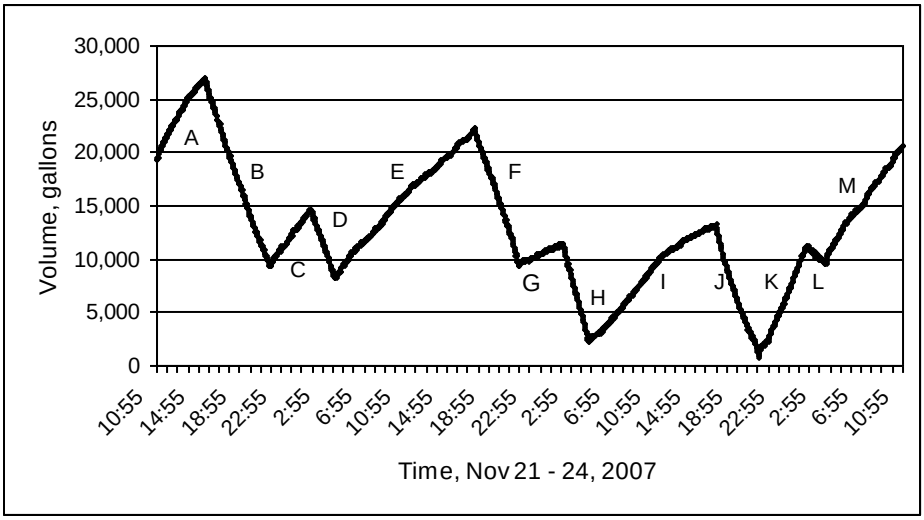
	Influent			Effluent		
Date	Sample	% TS	% S	Sample	% TS	% S
11/8/2007	TBIN1	10.43	0.07	TBEF1	8.28	0.05
	TBIN2	8.11	0.06	TBEF2	8.11	0.06
	TBIN3	10.13	0.07	TBEF3	8.07	0.06
11/21/07	TBIN1	12.51	0.06	TBEF1	12.22	0.065
	TBIN2	11.31	0.06	TBEF2	7.25	0.045
				TBEF3	8.43	0.045
12/11/2007	TBIN1	12.25	0.065	TBEF1	7.96	0.045
	TBIN2	12.72	0.06	TBEF2	8.42	0.045
	TBIN3	18.53*	0.065	TBEF3	7.58	0.045
	Average	11.07	0.064		8.48	0.051
	Stand Dev	1.648	0.004		1.513	0.008
	Conf Int ±	1.221	0.003		1.121	0.005

* The value of 18.53 was not used and is not included in the average because it was determined to be an outlier based on the Dixon Q-test

Measuring the mass flow of manure from the reception/influent pit to the digester was impossible because there was a continual addition of manure to the pit while the pump was operating. The large pit, as described earlier, complicated measuring flow rate by monitoring the change in depth with the ultrasonic device. The mass flow of manure through the systems was calculated/estimated by using two methods, ASABE formula and mass balance.

The flow of digester effluent into the effluent pit and from the effluent pit to the separator was measured. The operation of the pump was monitored between November 7 and 21, 2007. The average operating time was 383 minutes. Generally the separator was operated at night give the rest of the day to determine the inflow rate (effluent). This allowed the calculation of the pump capacity. A plot of the data obtained from the ultrasonic device between November 21 and 24 is shown in Figure 4-1. The ultrasonic device measures the distance from the top of the pit to the liquid surface. The gallons of liquid removed or added during a specific time can be calculated. The different sections A - M, pump On or pump Off, are listed in Table 4-7. The time is length of time for each section in hours and minutes.

Figure 4-1. Output from Ultrasonic Device Measuring the Depth of Liquid in Effluent Pit.



The "change gallons" is the gallons added (pump off) or removed (pump on) during each section. The rate is the change in gallons divided by the time. The average inflow (pump off) from the digester was 21.9 gpm or 31,500 gal/day. The average flow from the effluent pit to the separator was 69.8 gpm, the rate of decrease in volume (47.9 gpm) plus the inflow rate (21.9 gpm). With an average operating time of 383 minutes per day the flow of effluent to the separator averaged was 26,700 gal/day.

Table 4-7. Operation of Separator Pump, 21-24 Nov 07.

Pump OFF				Pump ON			
Section	Time, hr:min	Change gallons	Rate, gal/min	Section	Time, hr:min	Change gallons	Rate, gal/min
A	4:38	7,683	27.6	B	6:16	17,636	46.9
C	4:56	3,026	22.6	D	2:20	6,462	46.2
E	13:28	14,079	17.4	F	4:22	12,978	49.5
G	4:06	2,216	9.0	H	3:06	8,732	46.9
I	11:46	10,430	14.8	J	4:10	12,500	50.0
K	4:34	10,576	38.6	L	2:04	770	6.2*
M	7:14	10,045	23.1				
		Average	21.9			Average	47.9

Average Pump Capacity = 69.8 gpm

* The value for Section L was not used and is not included in the average because it was determined to be an outlier based on the Dixon Q-test

The mass balance method depends on the concentration of total solids in the influent and effluent and the production of biogas. The analysis of the biogas based on data from the 30 day test is shown in Table 4-8. The production of dry biogas was computed to be 110,880 cuft per day. This value is used in the mass

Table 4-8. Analysis of Biogas at Twin Birch Farms.

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

Input Data		
Biogas temp @ meter	79.3	F
Pressure in gas line	15.0	in H_2O
Biogas flow (meter)	111,200	cuft/day
Elevation of meter	870	ft
H_2S (dry basis)	3,700	ppm
CO_2 (dry basis)	36.1	%
P_{elev}	14.235	psia
P_m	0.542	psig
P_{line}	14.777	psia
Volume of water vapor	3.34	%
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	79.3	F	114,713	cuft/day
Biogas flow (dry) at	79.3	F	110,880	cuft/day
Concentration of methane, CH_4			63.5	%
Volume of CH_4 @	79.3	F	70,442	ft^3/day
Volume of CH_4 @ STP			64,616	ft^3/day
Weight of CH_4			**2,882**	**lb/day**
HEATING VALUE (low)			62,012,516	Btu/day
			2,583,855	Btu/hr
Raw biogas			541	Btu/ft^3
			757	kW
Volume of H_2S @	79.3	F	410.3	ft^3/day
Volume of H_2S @ STP			376.3	ft^3/day
Weight of H_2S			35.7	lb/day
Weight of Sulfur (S)			**33.6**	**lb/day**
Volume of water vapor	79.3	F	3,833	ft^3/day
Weight of water vapor			0.0459	lb/ft^3
Water			176	lb/day
			21.1	gal/day

balance method shown in Table 4-9. This method is based on mass balance equations for solids and water through the digester. This analysis predicts the total solids entering the digester were 28,000 lb TS per day and 20,800 lb TS per day in the effluent. The weight of the dry biogas produced was calculated to be 8,050 lbs per day.

The results of these three analysis, ASABE equation, ultrasonic depth monitoring and mass balance, are summarized in Table 4-10. Referring to Table 4-10, adding the bedding to the ASABE total solids gives a total of 27,200 lb TS/day in the manure. Using the TS concentration of 0.1107, yields a wet weight of 245,700. The difference in value for influent from ASABE equation and bedding is only 800 lb TS/day less than the total solids computed with the mass balance method. The total solids in the digester effluent computed with the mass balance method (20,800) was only 1,900 lbs (9 %) less than that measured with the ultrasonic depth device and the lab analysis for total solids. For analyzing sulfur flow through the system, the average pounds entering the digester per day, 248,000, will be used.

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

Vo =	110,900	ft3/day, dry			Volume of biogas
CH4 =	0.635				Concentration of methane
CO2 =	0.36				Concentration of carbon dioxide
IPTS =	11.07	%			Percent total solids in influent
EPTS =	8.48	%			Percent total solids in effluent
IPS =	0.064	%			Percent sulfur in influent
EPS =	0.051	%			Percent sulfur in effluent
B =	8,055	lb biogas/day dry			Weight of biogas
T =	79	F			Biogas temperature at meter
T =	26.1	C			
bVS =	7,250	90%	*		Volatile solids consumed
bW =	806	10%	*		Mass of water consumed
Dw =	0.00127	lb water/ft3 biogas			
We =	141.0	lb water/day			Water in saturated biogas
ITS =	0.111	ITW=	0.889		Total solids in influent
ETS =	0.085	ETW=	0.915		Total solids in effluent
ITM =	253,495	lb/day	29,823	gpd	Total mass of influent
ETM =	245,299	lb/day	28,859	gpd	Total mass of effluent
Δ TM =	8,196	lb/day			Change in mass
ITS =	28,051	lb/day			Total solids in influent
ETS =	20,801	lb/day			Total solids in effluent
Δ TS =	7,250	lb/day			Total solids "lost"
Sulfur In	162	lb/day			Sulfur in influent
Sulfur Out	125	lb/day			Sulfur in effluent
Δ Sulfur	36.2	lb/day			Sulfur "lost"

*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.

Table 4-10. Summary of Mass Flow of Influent to and Effluent from Digester.

Parameter (method)	Lb/day	Gal/day	TS lb/day
ASABE Equation (influent)*	172,000	20,200+	20,500
Bedding			6,700
Total (manure from barn)	245,700	<<<	27,200
Influent (mass balance)	250,700	29,500+	28,000
Effluent (mass balance)	242,600	28,500+	20,800
Flow of effluent to pit [ultrasonic]		31,500	22,700
Flow to separator [ultrasonic]		26,700	

* Includes 1,300 gal (10,800 lbs) of milking center wastewater, does not include bedding

\+ Assumes 8.5 lb/gal

Combining the data in Table 4-6 and Table 4-10, the flow of sulfur into the digester (from the barn) would be 248,000 x 0.064% = 159 lb S/day. The sulfur leaving the digester would be 242,600 x 0.051% = 124 lb S/day. The sulfur "lost" in the digester would be 35 lb S/day. The results of analyzing of the biogas given in Table 4-8 are summarized in Table 4-11. This analysis is shown in the Appendix.

Table 4-11. Summary of Results from Analysis of Biogas.

Parameter	Value	Units
Volume of wet biogas	114,700	Cubic feet per day (79.3 ºF)
Weight of sulfur in biogas	33.6	Lbs S per day
Weight of methane in biogas	2,880	Lbs CH_4 per day
Heating value of methane	2,584,000	Btu/hr
Weight of water in biogas	21.1	Lbs per day

A summary of the flow of sulfur through the dairy is given in Table 4-12.

Table 4-12. Summary of Sulfur Flow at Twin Birch Farms.

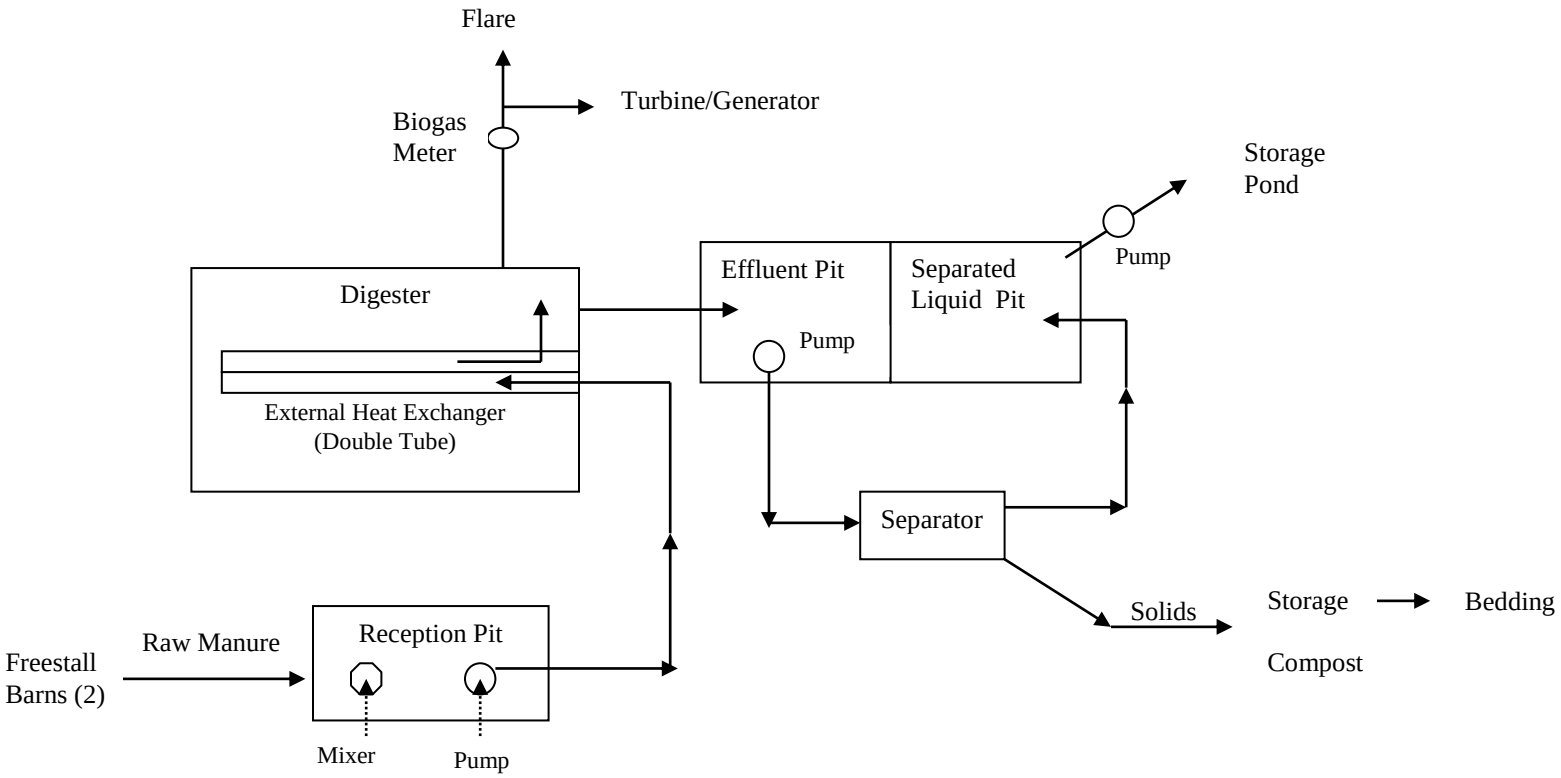
Parameter	Value	
Number of Cows	1,160	Given (equivalents)
	Sulfur, lb/day	
TMR	129	Measured concentration, mass given
Drinking water	5.0	Measured concentration, calculated volume
Bedding (separated solids)	27.9	Measured concentration, mass given
Foot Bath	1.0	Mass given
Milk	20.3	Mass given, concentration - reference
Raw Manure	143	[129 + 5.0 – 20.3 + 27.9 + 1 = 142.9]
Digester influent	159	Measured concentration and mass
Digester effluent	124	Measured concentration and mass
"Lost" in digester	35	By difference
Biogas	33.6	Measured concentration and mass

The difference between the amount of sulfur in the biogas and the difference in sulfur content between the digester influent and effluent is small (<10%). Considering calculating the sulfur in the influent and effluent (mass flow of manure and analysis of manure) vs measuring flow of biogas and concentration of sulfur, the biogas would be deemed the more reliable.

Condensers and traps to remove moisture were built into the gas handling system ahead of the gas turbines. Condensate was measured in mid February 2008. The P trap at the bottom of the hill collected 1 quart, low pressure tank 4 quarts, high pressure tank 6 quarts and downstream of turbines 0.125 quarts. This gave a total of 11.12 quarts or 2.78 gallons per day. At 8.34 lbs/gal, the weight of the condensate would be 23.2 lbs per day. The condensate was tested for sulfide. The concentration was 11.8 mg HS^-/l or 11.4 mg S/l [11.4 ppm]. With only 23.2 lbs of condensate per day, the sulfur removed in the condensate was only 0.00026 lb S/day.

APPENDIX

Figure A-1. Schematic Drawing of Twin Birch Dairy.



Not to scale

Figure A-2. Mass Flow Diagram of Sulfur, Twin Birch Dairy.

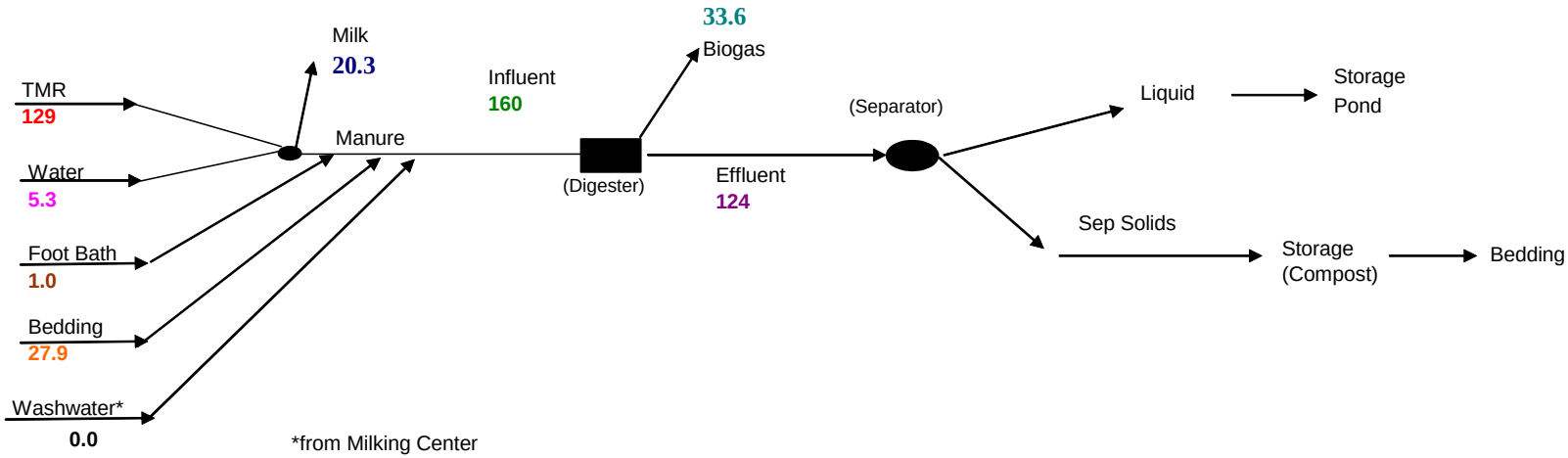


Table A-1. 30-Day Test Data, Twin Birch Farms

Day #	Date 2007	Time	Biogas Meters			Biogas cuft/day	H2S ppm		CO2 ppm, %		Comments
			Temp	Press	Reading		#1	#2	#1	#2	
1	7-Nov	8:45am	81	15	17,906		3200	3400	38	38	
		11:35am	82	15	18,058		3800	3600	36	36	
		4:35am	82	15	18,293	115,800	3600	3600	36	36	
2	8-Nov	7:10am	81	15	19,064		3500	3200	36	36	1 load heifer manure
		11:40am	81	15	19,283		3600	3600	36	36	
		4:15pm	81	15	19,586	122,500	3100	3600	36	36	
3	9-Nov	7:15am	81	15	20,289		3500	3400	36	36	
		11:45am	81	15	20,522		4000	3600	36	36	
		4:25pm	81	15	20,175	124,600	3800	3900	36	36	
4	10-Nov	7:30am	81	15	21,535		4000	3900	36	36	
		12:30pm	81	15	21,768		4000	4000	36	36	
		5:00pm	81	15	21,990	125,400	3600	3900	36	36	1 load heifer manure
5	11-Nov	7:19am	80	15	22,789		3600	3500	34	36	
		12:30pm	81	15	22,951		3600	3800	34	36	
		4:40pm	81	15	23,123	99,000	3800	3800	36	35	high pressure Low ???
6	12-Nov	7:08am	81	15	23,779		3100	3800	39	36	
		12:00pm	81	15	23,920		3900	36	37	37	
		4:30pm	81	15	24,200	112,200	3800	4000	36	36	
7	13-Nov	7:05am	81	15	24,901		3200	3100	36	36	
		12:00pm	81	15	25,106		3500	3500	36	36	
		4:10pm	82	15	25,242	109,200	3500	3700	36	36	
8	14-Nov	7:10am	81	15	25,993		2900	3600	36	36	1 load heifer manure
		11:45am	81	15	26,190		3600	3600	36	36	
		5:00pm	82	15	26,427	108,200	3600	3600	36	36	
9	15-Nov	7:05am	81	15	27,075		3500	3800	36	37	
		12:00pm	81	15	27,265		3700	3600	36	36	
		5:00pm	80	15	27,557	118,900	3600	3700	36	36	
10	16-Nov	7:10am	80	15	28,264		3100	3900	37	37	1 load heifer manure
		12:15pm	80	15	28,300		3900	4000	36	36	
		4:55pm	81	15	28,739	132,600	4000	4000	36	36	
11	17-Nov	8:30am	80	15	29,590		2800	3900	37	37	
		12:40pm	80	15	29,787		4000	4000	36	36	
		5:45pm	80	15	30,042	125,000	4200	3200	36	36	

Table A-1. 30-Day Test Data, Twin Birch Farms, cont.

Day #	Date 2007	Time	Biogas Meters Temp	Press	Reading	Biogas cuft/day	H2S ppm #1	#2	CO2 ppm, % #1	#2	Comments
12	18-Nov	8:00am	80	15	30,840		2800	3600	34	34	
		11:50am	80	15	31,002		3000	4000	36	36	
		5:34pm	80	15	31,285	114,700	3200	4200	38	38	
13	19-Nov	7:00am	80	15	31,987		3100	4000	36	37	
		12:00am	80	15	32,134		3800	4000	36	36	
		5:00pm	80	15	32,395	107,100	4100	4100	36	36	
14	20-Nov	7:10am	80	15	33,058		3200	4400	36	36	
		11:48am	80	15	33,206		3600	4000	36	36	
		5:10pm	79	15	33,357	93,400	3000	3900	36	36	
15	21-Nov	7:05am	80	15	33,992		3100	4000	36	36	
		11:50am	80	15	39,212		2800	3600	36	36	
		4:35pm	80	15	39,425	110,600	3000	4200	36	36	
16	22-Nov	8:00am	80	15	35,098		3200	3800	36	36	
		12:40pm	80	15	35,412		3200	4000	36	36	2 load heifer manure
		5:00pm	80	15	35,820	124,000	3300	3700	36	34	
17	23-Nov	7:05am	80	15	36,338		3600	3600	34	34	
		12:00pm	80	15	36,602		3800	3800	34	34	
		5:00pm	80	15	36,853	130,700	3600	3600	32	32	
18	24-Nov	7:00am	80	15	37,645		3600	3700	32	32	
		2:30pm	80	14.5	37,976		4100	4000	36	36	1 load
		5:30pm	80	15	38,095	102,600	4100	4000	36	36	
19	25-Nov	6:30am	79	15	38,671		4000	4000	38	37	
		1:10pm	80	15	38,951		4000	4000	35	36	
		4:30pm	80	15	39,105	120,300	4000	4000	36	36	
20	26-Nov	7:00am	80	15	39,874		4000	4000	36	36	
			80	15	40,140		4000	4000	36	36	2 load
		5:30pm	80	15	40,400	123,400	4000	4000	36	36	
21	27-Nov	7:00am	79	15	41,108		4100	4100	36	36	
		12:35pm	80	15	41,324		4200	4100	36	36	
		5:10pm	80	15	41,619	120,800	4200	4200	36	36	
22	28-Nov	7:10am	79	15	42,316		3200	4000	37	37	
		12:15pm	80	15	42,410		4100	4400	37	37	
		5:15pm	80	15	42,792	115,500	4400	4400	36	36	
23	29-Nov	7:04am	79	15	43,471		3500	4400	37	37	2 load
		12:05pm	80	15	43,685		4400	4400	36	36	
		5:10pm	80	15	43,943	117,000	4400	4400	36	36	

Table A-1. 30-Day Test Data, Twin Birch Farms, cont.

Day #	Date 2007	Time	Biogas Meters Temp	Press	Reading	Biogas cuft/day	H2S ppm #1	H2S ppm #2	CO2 ppm, % #1	CO2 ppm, % #2	Comments
24	30-Nov	7:10am	78	15	44,641		3200	4400	36	36	
		12:10pm	80	15	44,805		4400	4400	36	36	2 load
		5:00pm	80	15	45,048	100,100	4400	4400	36	36	
25	1-Dec	7:00am	78	15	45,642		4200	4400	36	36	
		12:00pm	79	15	45,810		4400	4400	36	36	
		4:30pm	80	15	46,023	104,100	4400	4400	36	36	
26	2-Dec	6:45am	75	15	46,683		4400	4400	37	37	
		12:30pm	77	15	46,803		4400	4400	37	37	
		5:00pm	79	15	47,075	92,500	4400	4400	38	38	
27	3-Dec	7:00pm	73	15	47,608		3200	4000	38	36	1 load
		12:00pm	75	15	47,803		4000	4200	36	36	
		4:30pm	72	15	47,988	101,800	4200	4200	36	36	
28	4-Dec	7:00am	72	15	48,626		3100	4200	36	37	
		12:00pm	76	15	48,851		3400	4200	36	36	
		5:30pm	75	15	49,104	109,800	4000	4200	36	36	
29	5-Dec	7:30am	73	15	49,724		4200	4000	38	38	
		12:10pm	75	15	49,900		4000	4000	38	38	3 load
		4:45pm	75	15	50,150	107,800	4000	4000	38	34	
30	6-Dec	7:00am	73	15	50,802		3200	4000	38	38	
		11:20am	74	15	51,008		3200	4000	37	37	worked on vacuum pump all day
		5:00pm	72	15	51,232		4000	4000	36	36	
	Average		79.3	15.0		111,186		3,700		36.1	
	Std Dev		2.4	0.1		10,726		515		1.0	
	Conf Int ±		0.51	0.01		3,904		75.26		0.15	
	# of Samples		90	90		29 0		180		180	

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

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	68.2	991	138.9	137,602	17.7	17,528	12.7%	6,397,789
Dry Cows, Body Weight	1500	123	80.9	9,956	10.1	1,240	12.5%	271,476
Heifers, average Body Weight	700	263	51.8	13,611	6.7	1,769	13.0%	387,518
Total		1,377		161,170		20,537	12.7%	7,056,783

[half of manure from heifers goes to digester)

161,170	lb/day @ 12.7% TS	
19,073	gal/day @ 8.45 lb/gal	
1,161	cow equivalents	

Milking Center Wastewater	Gal/day	Lb/day
	1,300	10,842
	Total	172,012

Total Solids Content, manure	0.127
Total Solids Content, all	0.119

*Rolling Herd Average, lb/cow-yr	24,900
Days per year	365
Days in freestall per year	365
Days - freestall & corral	0
Days - corral	0
Percent of Manure Collected	
Freestall	100%
Freestall & corral	80%
Corral	60%