CHARACTERIZATION OF SULFUR FLOWS
IN FARM DIGESTERS
at
NOBLEHURST FARMS

Prepared for

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Section 1
DESCRIPTION

The Noblehurst Farm is located south of Linwood, NY at the intersection of Stewart and Craig Roads. A schematic of the layout of the barns, raw manure reception pit, a digester with influent and effluent pits, separator/solids storage building and the engine/generator building is attached in the Appendix, Figure A-1. Raw manure from one freestall barns flows to the raw manure pit by gravity while manure from a second freestall barn is pumped to the pit. Manure from this “raw manure” pit is pumped with a Houle 4 inch dairy liquid manure pump to the digester. There are two options for bringing material with lower solids content to the influent reception pit to dilute the raw manure; 1) by gravity separated liquid from the separator and 2) pumping digester effluent. The effluent pump is primarily used to pump digester effluent to the separator. With all these combinations, measuring the mass flow to the digester was impossible.

The digester has a dividing wall in the middle forming two digesters. The manure is pumped to the digester influent pit where the flow divides by gravity to the two digesters. This is shown in the schematic. The effluent from each digester flows to a common effluent pit at the other end of the digester. Biogas from each digester is piped to the engine/generator building. There is a Roots meter for each digester. After the meters the lines join with one pipe to the engine. The Roots meter on the north digester was replaced with a temperature compensated (60 F) meter. The intent was to adjust the reading from the south digester meter based on the biogas temperature and pressure.

Section 2

RESULTS – 24 HOUR TEST, APRIL 5-6, 2007

Three times during the 24 hr test the biogas was tested for carbon dioxide and hydrogen sulfide. At each time 3 samples were taken. Carbon dioxide was measured using *Gastec* tubes and the *Bacharach* unit. Hydrogen sulfide was measured with *Gastec* tubes. The results of these tests are given in Table 2-1.

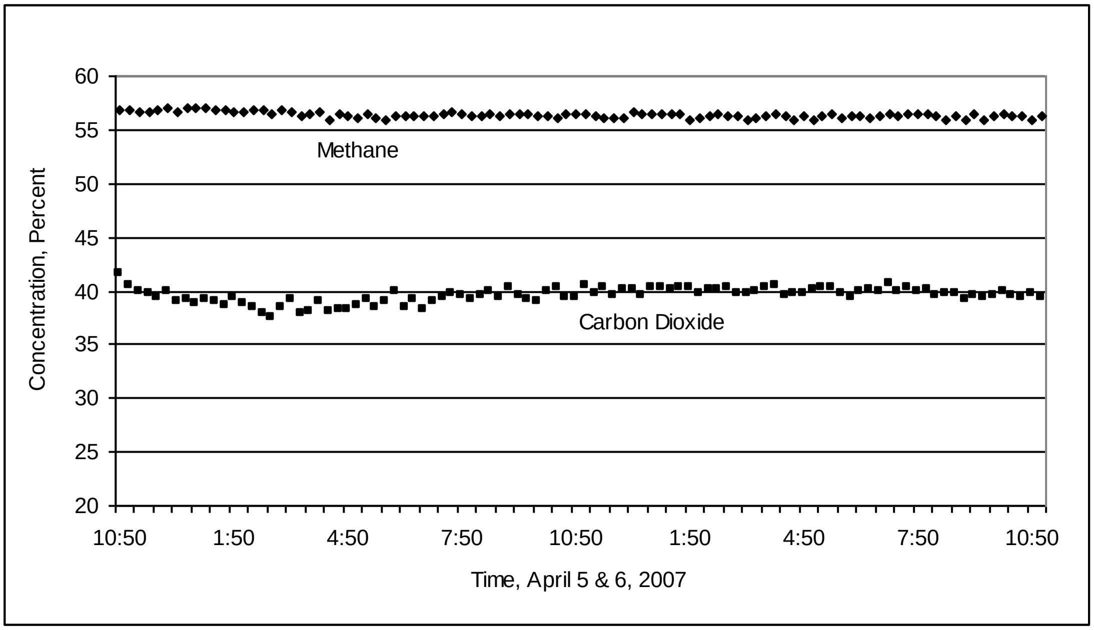
Table 2-1 Concentration of Carbon Dioxide and Hydrogen Sulfide

Test Number	CO_2		H_2S
	Tubes, %	Bacharach, %	
No. 1	38.7	40	3,500
4/5/2007 11:15	38.5	38	3,400
		38	3,500
No. 2	38	40	3,200
4/5/2007 3:10	36	36	3,150
	36	39	3,050
No. 3	39	37	2,200
4/6/2007 8:20	38	37	3,000
	38	38	2,800
Average	37.8	38.1	3,089
Standard Dev.	1.15	1.36	408
Confidence Int. ±	0.26	0.33	97.4

The carbon dioxide concentrations measured by the gas tubes was 37.8 ± 0.26% with a range of 36 to 39. The results from the test conducted with the Bacharach unit were similar to those from gas tubes, average was 38.1± 0.33% with a range of 4% instead of 3 for the gas tubes. The percentages from both of these instruments are based on the wet (saturated) gas entering the instrument.

During the 24 hr test the carbon dioxide and methane concentrations were measured with a GEM 2000 instrument. The results are shown in Figure 2-1. The concentrations for both CO_2 and CH_4 were relatively constant throughout the 24 hr period.

Figure 2-1. Methane and Carbon Dioxide Concentration in Biogas at Noblehurst Farms.



Results of a statistical analysis of the data gathered by the GEM 2000 unit are shown in Table 2-2. With regard to carbon dioxide, the range in percentage recorded by the GEM 2000 unit was 4.1% while the range for gas tubes and Bacharch unit was 3 and 4 respectively.

Table 2-2. Statistical Analysis of 24 hr data from GEM 2000.

Parameter	Methane	Carbon Dioxide
Average	56.4	39.5
Std Deviation	0.28	0.72
Confidence interval	0.056	0.142
Maximum	57.1	41.5
Minimum	55.9	37.4

Three methods for determining the concentration of CO_2 and CH_4, 1) GEM 2000 unit, 2) gas tubes and 3) Bacharach unit were compared. The results of this comparison are given in Table 2-3. The GEM2000 measures the gases in terms of a dry biogas. The sum of the percent CH_4 and CO_2 (56.4 + 39.5) is 95.9% which implies the volume occupied by water vapor and trace gases was 4.1%. The gas tubes and Bacharach unit refer to wet biogas. In-other-words, for gas tubes and Bacharach units the biogas is made up of CO_2 and other gases including methane, water vapor and trace gases. For anaerobic digesters the percent methane is generally determined by measuring the CO_2 using a Bacharach unit and then subtracting that value from 100. This approach will always yield elevated values for percent methane.

The average concentration of methane in the biogas, as determined by subtracting CO_2 levels from 100 was 62.1%. The concentration of methane, taking into account just the water vapor, averaged 59.7%. Comparing this value with the CH_4 measured by the GEM2000 unit, the trace gases would occupy 3.3% of the volume.

Table 2-3. Comparison of Tests for Carbon Dioxide and Methane (average values).

	CO_2, %	CH_4, %		
Instrument	Measured	(100 - CO_2)		
GEM 2000 (24 hr)	39.5		56.4	*
Gas Tubes(24 hr) [9 samples, Dave L.]	37.7	62.3	59.7	**
Bacharach (24-hr) [9 samples, Dave L.]	38.1	61.9	59.3	**
Bacharach (30-day) [180 samples, operator]	37.8	62.2	60.1	**

* Measured directly

** Computed methane = 100 - CO_2 - water vapor

Water vapor based on avg biogas temp

			Water Vapor	
Avg biogas temp, 30 day	66	°F	2.15	%
Avg biogas temp, 24 hr	72	°F	2.65	%

Section 3

RESULTS – 30 DAY TEST, JANUARY 29 – FEBRUARY 25, 2007

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

Table 3-1. Summary of Results of the 30 Day Test.

Parameter	Meter 1 (west)			Meter 2 (east)			Combined	
	Temp °F	Biogas ft3/day, STP	CH4 %	Temp °F	Biogas ft3/day, STP	CH4 %	Press. in water	H2S ppm
Daily Average	67.5	22,088	58.6	65.3	24,137	59.1	12.7	3,392
Std Deviation	4.8	7,102	3.3	3.6	5,578	3.4	0.28	520
Confidence	1.7	2,387	1.2	1.3	1,875	1.2	0.10	71
No. of Samples	34	34	34	34	34	34	34	206

The length of day varied slightly due to a variation in the time when readings were taken. Meter 1 was temperature compensated [60 F & 14.696 psia] and Meter 2 was not temperature compensated. The data from Meter 2 was converted to STP so the two digesters can be compared on the same basis. The methane content of the biogas was calculated based on the measured percent carbon dioxide and temperature of the saturated biogas (converted to percent water vapor).

The daily production of biogas for each digester [West, Meter 1 and East, Meter 2] is plotted in Figure 3-1. The biogas production of the West digester fluctuated from a high of 36,000 to a low of 11,600 while the East digester had a high of 39,000 and a low of 13,500 cuft/day (STP). The temperature of the biogas at the gas meter also varied considerably. These temperatures are plotted in Figure 3-2. There may be little relationship between gas meter temperature and actual digester temperature. The comments written on the data sheets indicated this was a cold period. See Table 3-2.

Table 3-2. Ambient Air Temperature and Biogas Temperature.

Date	Air Temperature, F	Biogas Temperature at Meter, F	
30 Jan	15 - 20	73	70
3 Feb	10	69	65
4 Feb	5	69	57
5 Feb	0	65	62
13 Feb	3	54	56

Because biogas production and gas temperatures both varied, the relationship between the two parameters was investigated. The biogas production is plotted against biogas temperatures for both digesters in Figure 3-1. A trend line was drawn to show that there was a mild relationship.

Figure 3-1. Production of Biogas, West and East Digesters.

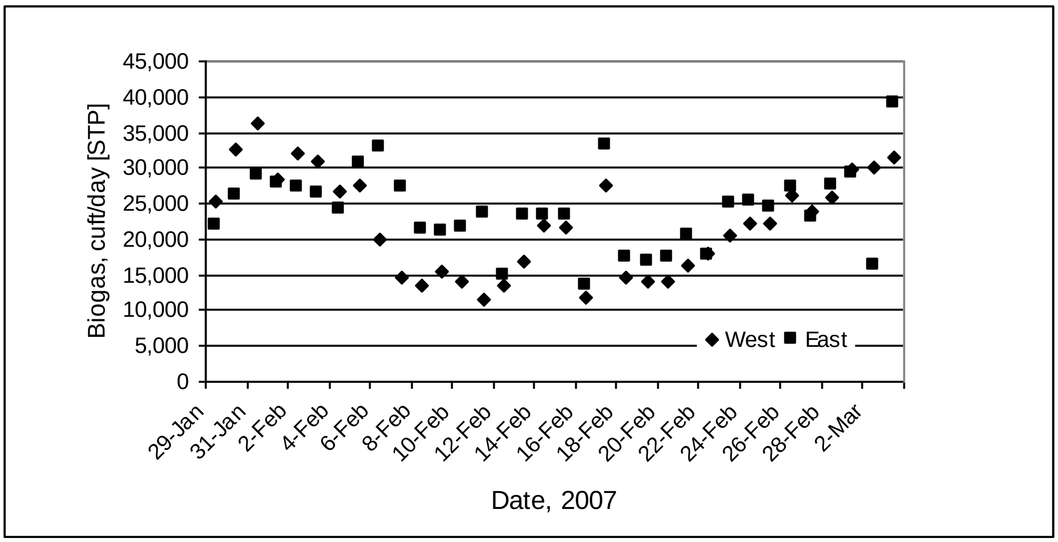


Figure 3-2. Temperature of the Biogas at the Gas Meters.

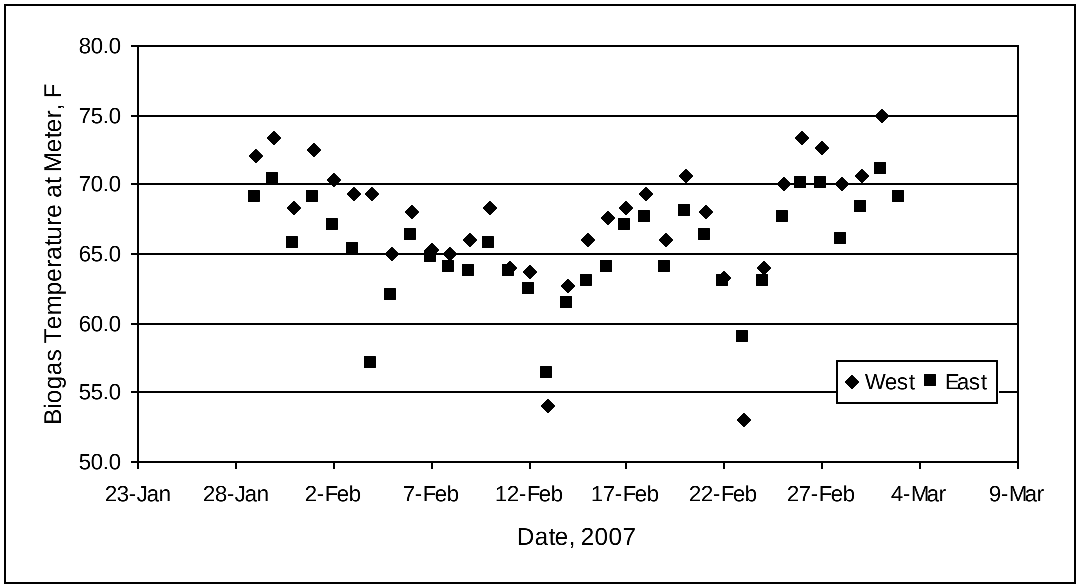
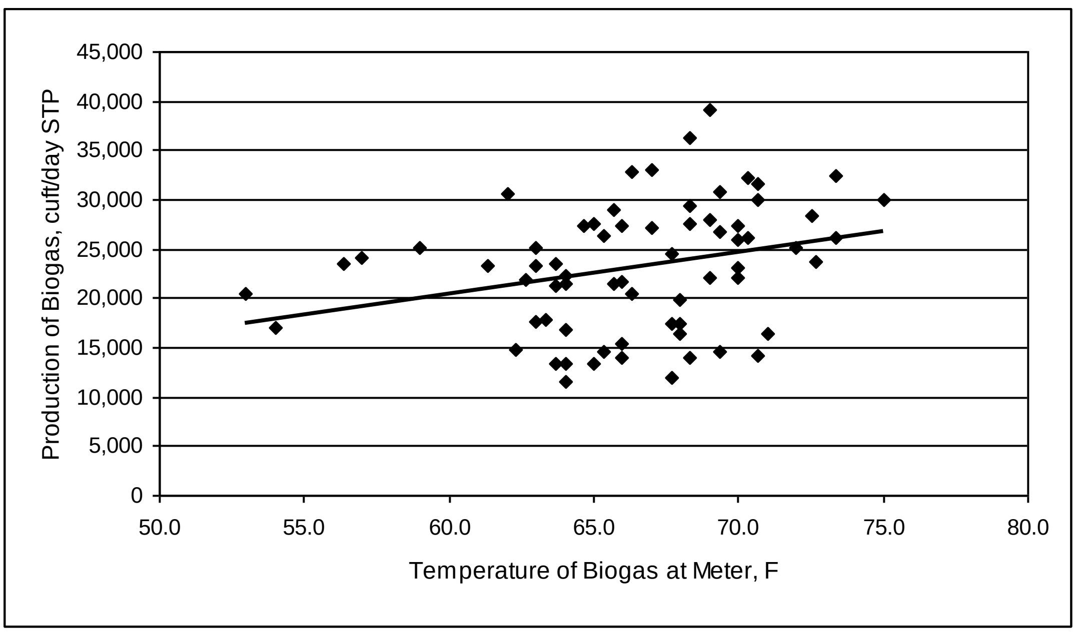
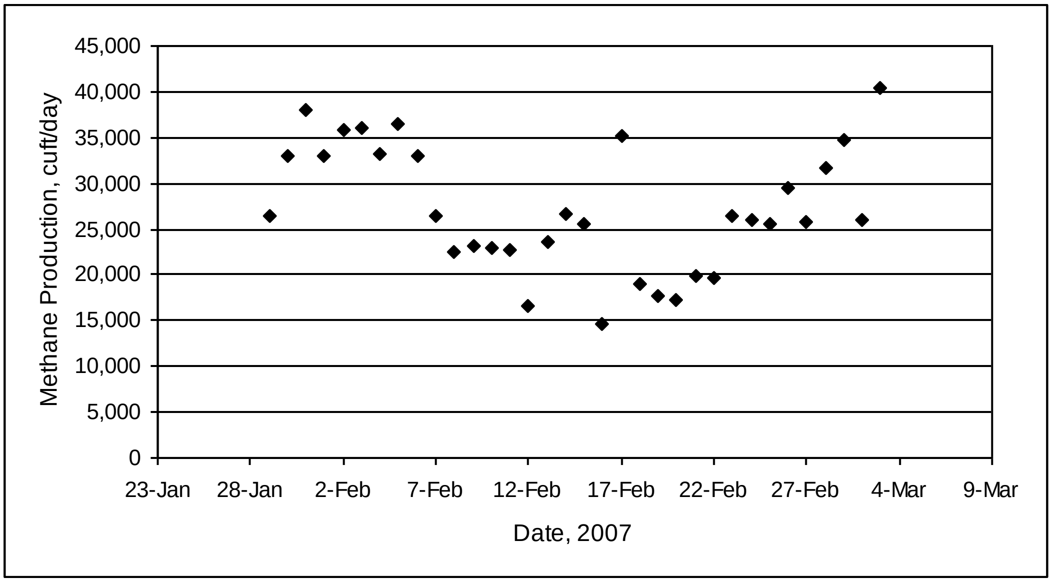


Figure 3-3. Relationship Between Production of Biogas and Gas Temperature at Meter.



The concentration of carbon dioxide in the biogas was measured with a *Bacharach* unit. This measurement was made after the two gas streams were combined, just prior to entering the engine. Assuming the concentration of the individual gas streams had the same CO_2 concentration and using the temperature of the biogas at the meters, the concentration of methane was calculated as a function of date. Combining these values with the flow of biogas for that day, the production of methane in cubic feet per day [60 F] was calculated. These values are plotted in Figure 3-4. These values varied considerable during the 30 days making if impossible to produce consistent levels (kW) of electricity.

Figure 3-4. Production of Methane by the Two Digesters [STP].



The concentration of hydrogen sulfide in the digester biogas was sampled at the same location as the carbon dioxide and measured with gas tubes. See Figure 3-5. Using this data and the flow of biogas the mass flow of H_2S [lb/day] was calculated. The mass flow is plotted in Figure 3-6. There is similar pattern for H2S, methane, temperature and biogas production, higher at the beginning and ending of the 30 day test and lower during the middle of the test.

Figure 3-5. Concentration of Hydrogen Sulfide in Biogas.

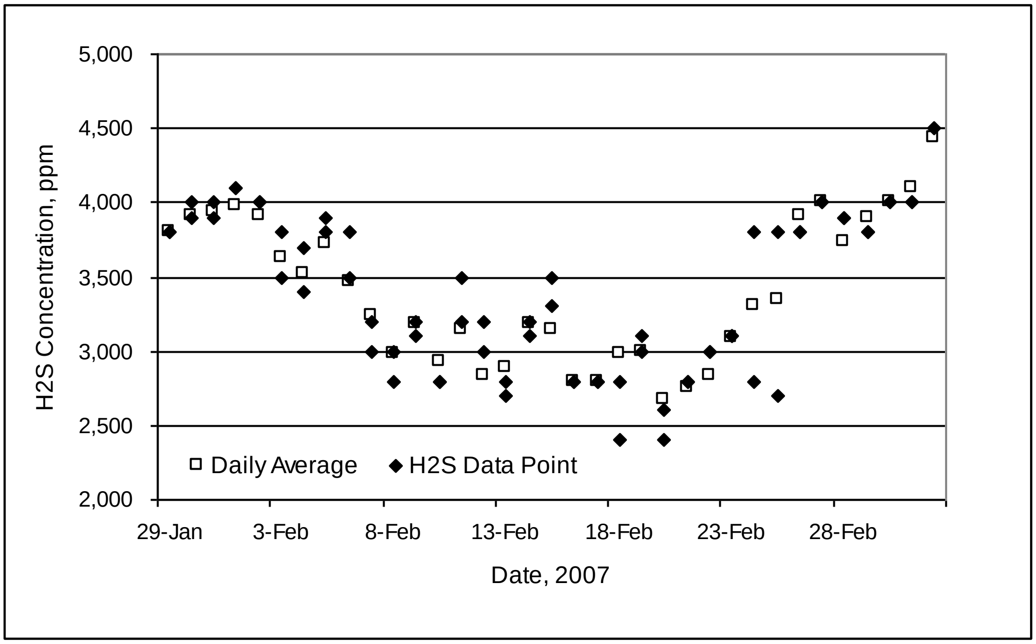
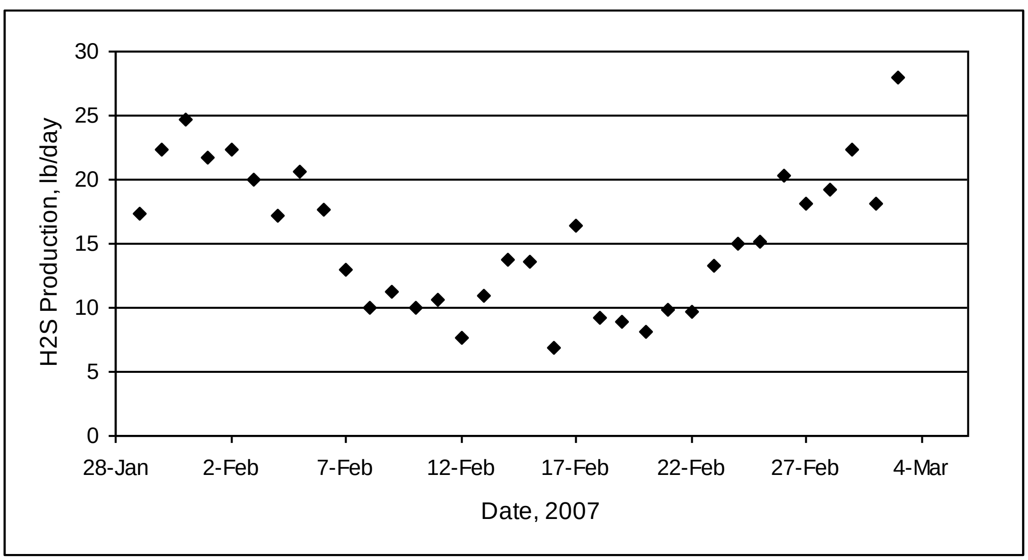


Figure3-6. Mass Flow of Hydrogen Sulfide from Digesters.



Section 4
MASS FLOW OF SULFUR

Samples of the total mixed ration (TMR), drinking water, 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 by Dairy One, Inc. in Ithaca, NY. Drinking water was analyzed by Community Science Institute, also located in Ithaca, NY.

TOTAL MIXED RATION

Manure from three groups of cows was fed to the digester, two groups of milking cows, Group 5 & 2, and a dry cows group. The number of animal reported to be in each group is given in Table 4-1. The results of the analysis of the TMR and the pounds of sulfur for each group of cows are given in Table 4-2.

Table 4-1. Groups of Cows and Number in Each Group.

Group Name	Number
Milking – Group 2	236
Milking – Group 5	237
Dry Cow	163

Table 4-2. Sulfur content in the TMR, TMR Consumed and Pounds of Sulfur.

TMR				
		Milkers, Group 5		
Date	lbs consumed	Sample	S % as fed	lbs S/day
1/17/2007	24,000	G1 S1	0.1	24.0
		G1 S2	0.1	24.0
2/22/2007	24,000	G2 S1	0.1	24.0
		G2 S2	0.09	21.6
3/27/2007	24,000	G2 S1	0.09	21.6
		G2 S2	0.1	24.0
Average	24,000		0.097	**23.2**
Std Dev				1.239
Confidence Interval ±				0.99

		Milkers, Group 2		
Date		Sample	S % as fed	lbs S/day
1/17/2007	21,000	G5 S1	0.11	23.1
		G5 S2	0.1	21.0
2/22/2007	21,000	G5 S1	0.1	21.0
		G5 S2	0.11	23.1
3/27/2007	21,000	G5 S1	0.09	18.9
		G5 S2	0.11	23.1
Average	21,000		0.103	**21.7**
Std Dev				1.71
Confidence Interval ±				1.37

		Dry Cow		
Date		Sample	S % as fed	lbs S/day
1/17/2007	10,600	Dry Cow S1	0.12	12.72
		Dry Cow S2	0.13	13.78
2/22/2007	10,600	Dry Cow S1	0.1	10.60
		Dry Cow S2	0.11	11.66
3/27/2007	10,600	Dry Cow S1	0.13	13.78
Average	10,600		0.12	**12.51**
Std Dev				1.38
Confidence Interval±				1.21

Total sulfur **57.4** lbs/day

DRINKING WATER

The drinking water at Noblehurst Farms comes from wells. The results of the analysis of the cow drinking water are given in Table 4-3. The sulfur content averaged 0.245 lb per 1,000 gallons. The contribution of the drinking water to the sulfur input to the manure averaged 3.4 lb/day.

Table 4-3. Sulfur in Cow Drinking Water.

DRINKING WATER

Date	sulfate mg/L	Sulfur lbs/1000 gal	lbs S/day
1/18/2007	91.3	0.26	3.57
	90.9	0.25	3.56
2/22/2007	90	0.25	3.53
3/27/2007	34*		
6/15/2007	77.5	0.22	3.04
* not used in avg	average	0.245	**3.4**
	Std Dev		0.260
	Confidence Interval ±		0.294

conversion factor; mg sulfate/l to lb sulfur/1000gal		0.0028	
Water, gal/day	22 gal/cowday and 636 cows	13,992	gal/day

MANURE

The properties (total solids and sulfur) for the digester influent and effluent are given in Table 4-4. The concentration of total solids decreased about 1.7% during digestion, 8.32 to 6.61%.

Table 4-4. Properties of the Digester Influent and Effluent.

Date	Influent			Effluent		
	Sample	TS %*	% S*	Sample	TS%*	% S*
1/17/2007	NHDI1	10.5	0.040	NHDE1	6.11	0.025
	NHDI2	9.05	0.040	NHDE2	6.53	0.03
2/22/2007	NHDI1	9.62	0.035	NHDE1	6.15	0.03
	NHDI2	9.9	0.045	NHDE2	6.2	0.03
3/27/2007	NHDI1	6.14	0.025	NHDE1	6.92	0.03
	NHDI2	5.93	0.030	NHDE2	7.17	0.03
	NHDI3	7.09	0.035	NHDE3	7.19	0.035
	Average	8.32	0.036		6.61	0.030
	Std Dev		0.006			0.003
	Conf Int ±		0.005			0.002

* Data from Dairy One, Inc.

The percent sulfur decreased from 0.036 to 0.030%. To calculate the mass flow of sulfur into and out of the digester the mass flow of influent and effluent must be known.

BEDDING

Separated solids are used for bedding.

MILKING CENTER WASTEWATER

This wastewater is added to the manure in the reception pit. Reviewing the formulas for the chemicals used showed no sulfur.

MILK

The concentration of sulfur in milk is low but with the volume of milk shipped from the farm, the sulfur in milk can not be ignored. Table 4-5 shows the calculation for the sulfur in the milk is 9 lbs per day.

Table 4-5. Sulfur in Milk.

RHA lbs/cow-yr	lbs/cow day	# of Cow	Sulfur* %	S lbs S/cow day	Total lbs S/day
23,858	65.4	473	0.03	0.02	**9.3**

* based on data from Trace Minerals Research

MASS FLOW OF MANURE

Measuring the influent and effluent could not be accomplished. Sometimes digester effluent and separator liquid are pumped back to the reception pit to dilute the raw manure entering from the freestall barns. There was no way to monitor/record the operation of these pumps. The influent piston pump would become partially plugged making it difficult to calibrate this pump. Thus monitoring the operation of this pump was not a good indicator of the digester influent.

The equations published by The American Society of Agricultural & Biological Engineers (ASABE) to calculate the manure total solids produced by the dairy animals were used. This gave a total solids production of 10,300 lb per day. Mass balance equations for the total solids and water were also written. The results of these equations are shown in Table 4-6. This analysis was based on data resulting from the 30 day tests. The data for the biogas came from Table 4-7, Analysis for Biogas. This analysis assumes that 90% of the weight of dry biogas (3,160 lb/day) came from the destruction of volatile solids and 10% from water. This method also takes into consideration the water in the biogas. With the changes in these parameters the loss of total solids was 2,840 lb/day. The settled solids (primarily fixed solids) were assumed to be negligible.

Table 4-6. Mass Balance Method of Determining Influent and Effluent.

Vo =	44,494	ft3/day, dry			Volume of biogas
CH4 =	0.596				Concentration of methane
CO2 =	0.378				Concentration of carbon dioxide
IPTS =	8.32	%			Percent total solids in influent
EPTS =	6.61	%			Percent total solids in effluent
IPS =	0.036	%			Percent sulfur in influent
EPS =	0.030	%			Percent sulfur in effluent
B =	3,247	lb biogas/day dry			Weight of biogas
T =	66	F			Biogas temperature at meter
T =	19.1	C			
bVS =	2,922	90%*			Volatile solids consumed
bW =	325	10%*			Mass of water consumed
Dw =	0.00089	lb water/ft3 biogas			
We =	39.6	lb water/day			Water in saturated biogas
ITS =	0.0832	ITW=	0.917		Total solids in influent
ETS =	0.0661	ETW=	0.934		Total solids in effluent
ITM =	158,333	lb/day	18,627	gpd	Total mass of influent
ETM =	155,046	lb/day	18,241	gpd	Total mass of effluent
Δ TM =	3,287	lb/day			Change in mass
ITS =	13,171	lb/day			Total solids in influent
ETS =	10,249	lb/day			Total solids in effluent
Δ TS =	2,922	lb/day			Total solids "lost"
Sulfur In	56.5	lb/day			Sulfur in influent
Sulfur Out	46.51	lb/day			Sulfur in effluent
Δ Sulfur	10.0	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.

This mass balance method predicted the influent total solid to be 13,700 lb/day. Compared to the 10,300 lbs to TS for the ASABE equation, this allowed for 3,400 lb of TS entering the reception pit from other sources (separated liquid and recycled digester effluent). The loss of sulfur in the digester (influent – effluent) was 10.5 lbs/day.

BIOGAS

The results of analyzing the biogas for sulfur are shown in Table 4-7. Data from the 30 day test [average biogas produced per day, gas temperature and pressure along with the concentration of carbon dioxide] were used. See Appendix A, Table A-1. Because one of the biogas meters was temperature compensated (22,088 ft^3/day average at 60 F) and the second meter was not (24,435 ft^3/day average), the flow of gas through the non-compensated meter was converted to “60 F” gas flow 22,556 ft^3/day and added to the second meter to get the actual total flow (44,640 ft3/day). The flow of sulfur from the digester in the biogas was 12.5 lb per day.

Table 4-7. Analysis of the Biogas.

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

Input Data - yellow area

Biogas temp @ meter	66.4	F
Pressure in gas line	12.7	in H_2O
Biogas flow (meter)	44,640	cuft/day
Elevation of meter	1,044	ft
H_2S (dry basis)	3,390	ppm
CO_2 (dry basis)	37.8	%
P_{elev}	14.143	psia
P_m	0.459	psig
P_{line}	14.602	psia
Volume of water vapor	2.19	%
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	66.4	F	45,488	cuft/day
Biogas flow (dry) at	66.4	F	44,494	cuft/day
Concentration of methane, CH_4			61.9	%
Volume of CH_4 @	66.4	F	27,524	ft^3/day
Volume of CH_4 @ STP			25,560	ft^3/day
Weight of CH_4			**1,140**	**lb/day**
HEATING VALUE (low)			24,529,972	Btu/day
			1,022,082	Btu/hr
Raw biogas			539	Btu/ft^3
			299	kW
Volume of H_2S @	66.4	F	150.8	ft^3/day
Volume of H_2S @ STP			140.1	ft^3/day
Weight of H_2S			13.3	lb/day
Weight of Sulfur (S)			**12.5**	**lb/day**
Volume of water vapor	66.4	F	994	ft^3/day
Weight of water vapor			0.0470	lb/ft^3 of water vapor
Water			47	lb/day
			5.6	gal/day

Table 4-8. Summary of Sulfur Flow, Noblehurst Farms.

Parameter	Value	
Number of Cows	592	Given (equivalents)
	Sulfur, lb/day	
TMR	57.4	Measured concentration, mass given
Drinking water	3.4	Measured concentration, calculated volume
Milk	9.3	Mass given, concentration - reference
Raw Manure	51.5	[57.4 + 3.4 – 9.3 = 51.5]
Digester influent	56.5	Measured concentration and mass
Digester effluent	46.5	Measured concentration and mass
"Lost" in digester	10.0	By difference
Biogas	12.5	Measured concentration and mass

APPENDIX

Figure A-1. Schematic Drawing of the Noblehurst Farm.

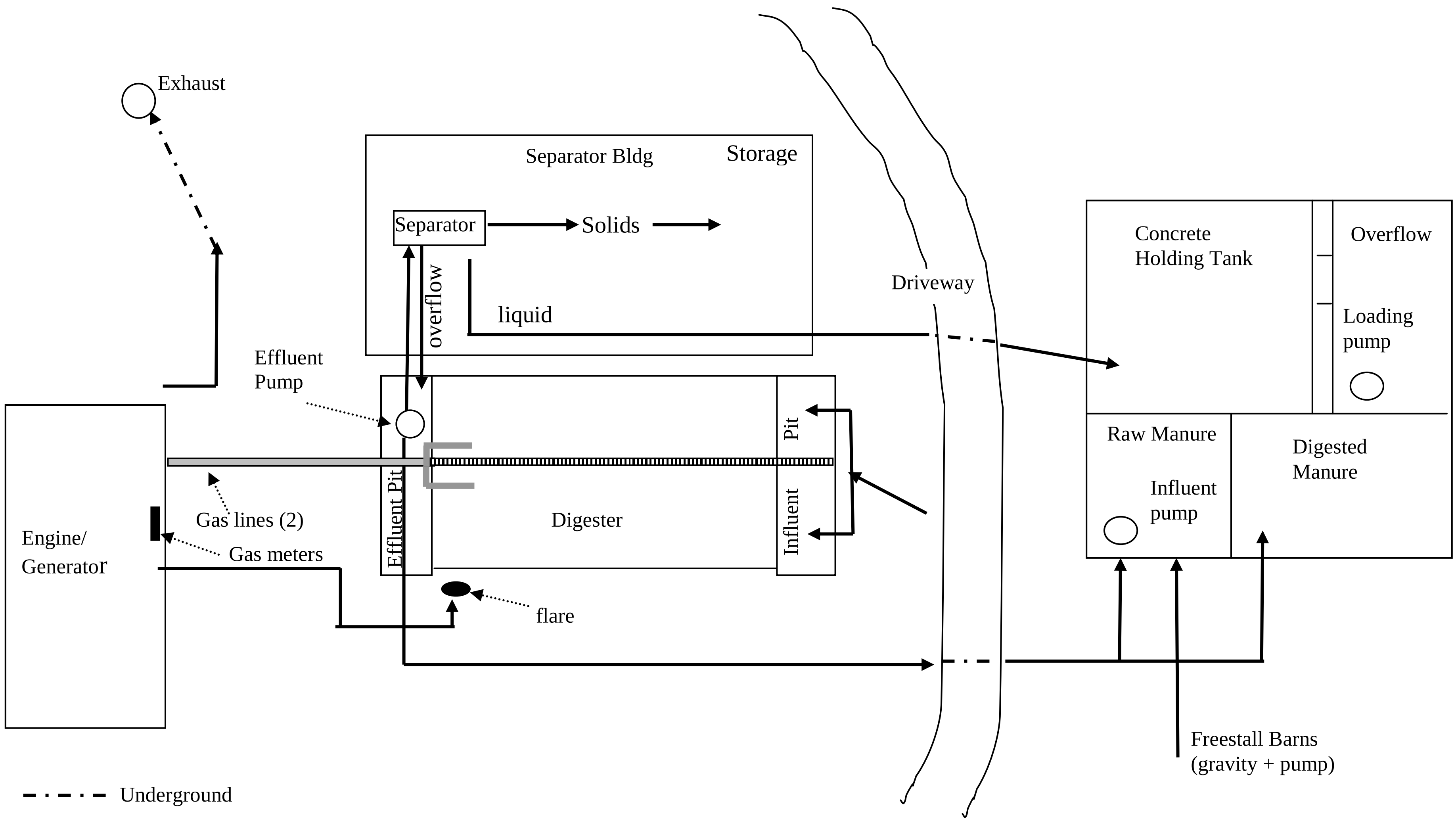


Figure A-2. Mass Flow Diagram of Sulfur, Noblehurst Farm.

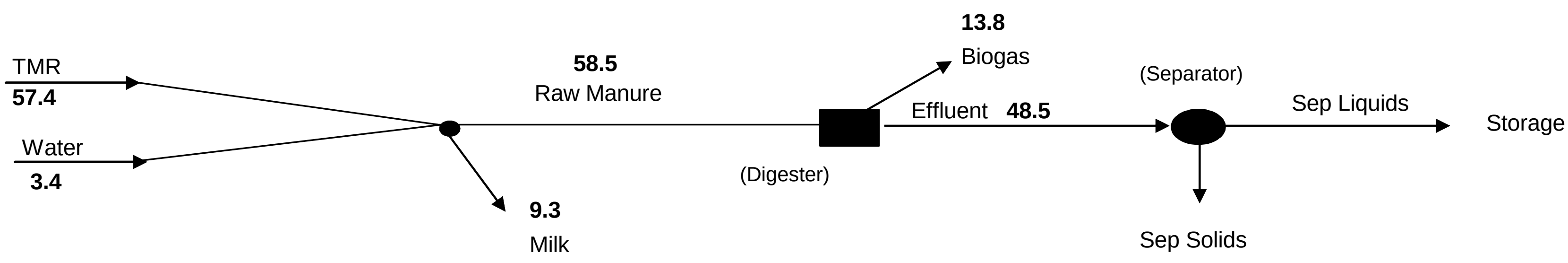


Table A-1. 30-Hour Test Data, Noblehurst Farm.

Day #	Date 2007	Time	Biogas Meters											H2S			CO2			Comments
			Meter 1, temperature compensated					Meter 2					combined Meters Avg/day	ppm*			ppm/%			
			Temp	Avg	Press	Reading	Avg/ day	Temp	Avg	Press	Reading	Avg/ day		#1	#2	Avg/ day	#1	#2	Avg/ day	
1	29-Jan	12:00pm	72		13	3,029		71		13.0	1,251			3,800	3,800		41	41		
		5:45pm	72	72.0	13	3,098	25,200	67	69.0	13.0	1,312	22,500	47,700	3,800	3,800	3,800	39	39	40.00	
2	30-Jan	8:00am	71		13	3,281		67		13.0	1,476			4,000	3,900		42	39		15-20°F outside
		12:05pm	76		13	3,331		74		13.0	1,519			3,800	3,900		40	39		
		6:00pm	73	73.3	13	3,412	32,500	70	70.3	13.0	1,583	26,800	59,300	3,900	4,000	3,917	39	38	39.50	
3	31-Jan	7:45am	67		13	3,606		64		13.0	1,744			4,000	3,900		38	38		oil change - some back flow (?)
		12:00pm	68		13	3,658		66		13.0	1,777			3,800	4,000		38	38		
		5:30pm	70	68.3	13	3,739	36,200	67	65.7	13.0	1,847	29,400	65,600	3,900	4,000	3,933	38	39	38.17	
4	1-Feb	9:25am	70		13	3,968		66		13.0	2,038			4,100	4,100		39	39		
		5:00pm	75	72.5	13	4080	28,400	72	69.0	13.0	2,132	28,500	56,900	4,000	3,700	3,975	35	35	37.00	
5	2-Feb	7:30am	69		12.3	4,252								4,000	4,000		36	36		restart #2 meter, shut off
		12:00pm	71		12.5	4,644								4,000	4,000		36	36		
		4:30pm	71	70.3	12.6	4,372	32,200					27,600	59,800	3,700	3,800	3,917	35	36	35.83	
6	3-Feb	9:00am	69		13	4,574		65		13.0	2,270			3,500	3,800		32	33		10° outside
		12:00pm	69		13.5	4,616		65		13.5	2,306			3,800	3,700		36	34		
		6:00pm	70	69.3	12.6	4,684	30,800	66	65.3	12.6	2,366	26,700	57,500	3,400	3,600	3,633	32	32	33.17	
7	4-Feb	9:00am	68		13	4,882		65		13.0	2,537			3,400	3,700		32	32		5° outside
		1:00pm	70		12.5	4,919		67		12.5	2,569			3,500	3,500		31	33		
		4:00pm	70	69.3	13	4,952	26,700	39	57.0	13.0	2,574	24,100	50,800	3,500	3,500	3,517	32	32	32.00	
8	5-Feb	7:45am	62		12.5	5,149		59		12.5	2,778			3,800	3,900		34	36		0° outside, -30° wind chill 8:00am
		11:30am	66		13.5	5,195		63		13.5	2,823			3,500	3,800		33	34		
		6:00pm	67	65.0	13.4	5,270	27,500	64	62.0	13.4	2,901	30,800	58,300	3,600	3,700	3,717	34	34	34.17	
9	6-Feb	8:00am	67		12.6	5,424		65		12.6	3,086			3,500	3,800		34	34		
		12:30pm	69		12.7	5,466		68		12.7	3,145			3,200	3,500		35	34		
		5:30pm	68	68.0	12.6	5,508	19,900	66	66.3	12.6	3,210	33,300	53,200	3,400	3,400	3,467	34	33	34.00	
10	7-Feb	8:30am	64		12.6	5,623		63		12.6	3,419			3,000	3,200		34	34		
		12:30pm	67		12.8	5,644		66		12.8	3,463			3,000	3,000		33	34		
		5:15pm	65	65.3	15	5,675	14,500	65	64.7	15.0	3,527	27,600	42,100	3,600	3,600	3,233	33	33	33.50	5pm no feed
11	8-Feb	7:45am	64		12.7	5,768		63		12.7	3,695			2,800	3,000		32	32		
		12:00pm	66		12.6	5,794		65		12.6	3,471			2,800	2,900		32	32		
		5:30pm	65	65.0	12.5	5,825	13,400	64	64.0	12.5	3,912	21,700	35,100	3,200	3,200	2,983	33	33	32.33	

Table A-1. 30-Hour Test Data, Noblehurst Farm, Cont.

Day #	Date 2007	Time	Biogas Meters: Meter 1, temperature compensated: Temp	Avg	Press	Reading	Avg/ day	Meter 2: Temp	Avg	Press	Reading	Avg/ day	combined Meters Avg/day	H2S ppm*: #1	#2	Avg/ day	CO2 ppm/%: #1	#2	Avg/ day	Comments
12	9-Feb	7:30am	63		12.5	5,902		61		12.5	3,912			3,200	3,100		33	33		
		1:00pm	67		12.5	5,930		65		12.5	3,948			3,000	3,000		35	34		
		6:30pm	68	66.0	11.9	5,960	15,500	65	63.7	11.9	3,986	21,400	36,900	3,400	3,400	3,183	33	35	33.83	
13	10-Feb	10:00am	68		12.5	6,057		65		12.5	4,126			2,800	2,800		32	32		
		2:05pm	69		13	6,083		67		13.0	4,167			3,000	3,000		30	32		
		6:10pm	68	68.3	12.5	6,110	14,000	65	65.7	12.5	4,206	21,800	35,800	3,000	3,000	2,933	32	33	31.83	
14	11-Feb	8:30am	60		12.5	6,197		61		12.5	4,344			3,500	3,200		32	33		
		2:00pm	67		12.6	6,225		66		12.6	4,389			3,200	3,000		32	33		
		6:00pm	65	64.0	12.4	6,246	11,600	64	63.7	12.4	4,423	23,800	35,400	3,000	3,000	3,150	32	33	32.50	
15	12-Feb	7:30am	64		12.5	6,313		61		12.5	4,582			3,000	3,200		34	34		added CO2 fluid,
		12:00pm	67		12.8	6,335		66		12.8	4,560			2,600	2,600		42	41		new 4H tubes for
		6:00pm	60	63.7	12.3	6,364	13,400	60	62.3	12.3	4,604	14,900	28,300	2,800	2,800	2,833	40	40	38.50	H2S
16	13-Feb	7:30am	55		12.5	6,447		57		12.5	4,731			2,800	2,700		39	40		3° outside temp
		12:00pm	55		12.6	6,476		57		12.6	4,775			2,800	2,800		40	42		
		5:30pm	52	54.0	12.3	6,513	17,000	55	56.3	12.3	4,826	23,300	40,300	2,900	3,300	2,883	41	41	40.50	
17	14-Feb	7:30am	63		12.6	6,617		62		12.6	4,964			3,100	3,200		38	38		
		12:00pm	62		13	6,665		61		13.0	5,017			3,200	3,200		38	39		
		5:30pm	63	62.7	12.6	6,704	21,900	61	61.3	12.6	5,058	23,500	45,400	3,200	3,200	3,183	38	40	38.50	
18	15-Feb	8:00am	64		12.6	6,836		61		12.6	5,199			3,300	3,500		40	42		
		2:00pm	67		13	6,891		65		13.0	5,259			3,200	3,000		40	40		
		5:30pm	67	66.0	13	6,925	21,600	63	63.0	13.0	5,296	23,500	45,100	2,900	3,000	3,150	40	40	40.33	
19	16-Feb	7:30am	67		13	7,052		63		13.0	5,434			2,800	2,800		40	39		
		1:00pm	69		12.7	7,103		65		12.7	5,491			2,800	2,800		38	38		
		5:30pm	67	67.7	12.8	7,139	11,900	64	64.0	12.8	5,533	13,600	25,500	2,800	2,800	2,800	38	39	38.67	
20	17-Feb	7:30am	68		12.5	7,171		65		12.5	5,570			2,800	2,800		38	39		
		12:00pm	70		12.6	7,209		68		12.6	5,606			2,800	2,800		39	38		
		5:30pm	67	68.3	12.5	7,252	27,600	68	67.0	12.5	5,653	33,600	61,200	2,800	2,800	2,800	38	38	38.33	
21	18-Feb	10:00am	74		12.9	7,447		69		12.9	5,906			2,400	2,800		37	37		
		4:00pm	67		12.5	7,488		65		12.5	5,956			3,100	3,200		36	38		
		7:00pm	67	69.3	12.5	7,546	14,600	69	67.7	12.5	5,999	17,700	32,300	3,200	3,200	2,983	37	38	37.17	
22	19-Feb	7:30am	64		12.6	7,593		61		12.6	6,083			3,000	3,100		38	38		
		12:15pm	74		12.7	7,622		71		12.7	6,116			3,000	3,000		40	40		
		5:30pm	60	66.0	13	7,649	14,000	60	64.0	13.0	6,149	17,000	31,000	2,800	3,100	3,000	40	40	39.33	Shut down for oil
23	20-Feb	7:30am	71		13	7,733		68		13.0	6,253			2,400	2,600		40	42		
		12:30pm	71		12.8	7,761		68		12.8	6,288			2,800	2,700		40	43		
		5:30pm	70	70.7	10.6	7,792	14,100	68	68.0	10.6	6,328	17,800	31,900	2,700	2,800	2,667	40	44	41.50	

Table A-1. 30-Hour Test Data, Noblehurst Farm, Cont.

Day #	Date 2007	Time	Biogas Meters: Meter 1, temperature compensated: Temp	Avg	Press	Reading	Avg/ day	Meter 2: Temp	Avg	Press	Reading	Avg/ day	combined Meters Avg/day	H2S ppm*: #1	#2	Avg/ day	CO2 ppm/%: #1	#2	Avg/ day	Comments
		7:30am	64		12.5	7,874		62		12.5	6,431			2,800	2,800		42	42		
24	21-Feb	12:00pm	69		11.5	7,899		68		11.5	6,462			2,600	2,800		42	43		
		6:00pm	71	68.0	12.6	7,941	16,400	69	66.3	12.6	6,518	20,800	37,200	2,700	2,800	2,750	46	41	42.67	
		7:30am	61		12.7	8,038		62		12.7	6,639			3,000	3,000		42	42		
25	22-Feb	12:00pm	63		12.8	8,070		63		12.8	6,677			2,400	3,000		42	44		
		5:00pm	66	63.3	12.8	8,106	17,900	64	63.0	12.8	6,754	17,800	35,700	2,800	2,800	2,833	40	42	42.00	
		7:30am	36		12.6	8,217		56		12.6	6,817			3,100	3,100		40	44		
26	23-Feb	10:30am	58		12.5	8,240		57		12.3	6,871			3,000	3,800		42	43		Out of 50 ml tubes
		4:00pm	65	53.0	12.4	8,283	20,500	64	59.0	12.4	6,919	25,100	45,600	3,000	2,500	3,083	34	39	40.33	
		7:00am	60		12.5	8,422		57		12.5	7,068			3,800	2,800		42	43		
27	24-Feb	11:15am	65		13	8,456		64		13.0	7,104			3,800	2,800		42	44		
		3:30pm	67	64.0	12.8	8,480	22,200	68	63.0	12.8	7,147	25,400	47,600	3,800	2,800	3,300	40	42	42.17	
		9:00am	65		12.6	8,644		63		12.3	7,322			3,800	2,700		40	42		
28	25-Feb	2:00pm	72		12.3	8,673		70		12.5	7,378			3,500	2,500		42	42		
		6:00pm	73	70.0	12.5	8,730	22,100	70	67.7	12.5	7,410	25,000	47,100	3,800	3,800	3,350	40	42	41.33	
		7:30am	72		13.3	8,865		69		13.0	7,572			3,800	3,800		40	41		
29	26-Feb	12:00pm	73		13.2	8,911		70		13.2	7,622			4,000	4,000		40	41		
		5:30pm	75	73.3	13	8,973	26,100	71	70.0	13.0	7,689	28,000	54,100	3,900	4,000	3,917	40	42	40.67	
		7:30am	72		13	9,126		69		13.0	7,852			4,000	4,000		40	41		
30	27-Feb	12:00pm	72		12.8	9,173		70		12.8	7,906			4,000	4,000		40	40		
		4:30pm	74	72.7	12.9	9,223	23,800	71	70.0	12.9	7,961	23,500	47,300	4,000	4,000	4,000	40	41	40.33	
		7:30am	62		12.5	9,364		54		12.5	8,087			3,900	3,900		37	38		
31	28-Feb	12:00pm	75		12.9	9,412		72		12.4	8,132			3,800	3,800		37	37		
		4:00pm	73	70.0	12.6	9,445	26,000	72	66.0	12.6	8,171	27,800	53,800	3,500	3,500	3,733	36	37	37.00	
		7:30am	67		12.4	9,624		66		12.4	8,365			3,800	3,800		36	36		
32	1-Mar	12:30pm	74		13	9,680		72		13.0	8,422			3,900	3,900		36	37		
		5:30pm	71	70.7	12.6	9,751	29,900	67	68.3	12.6	8,491	29,900	59,800	4,000	4,000	3,900	38	40	37.17	
		7:30am	75		13	9,923		71		13.0	8,664			4,000	4,000		40	40		
33	2-Mar	12:00pm	75		13	9,980		72		13.0	8,718			4,000	4,000		38	40		
		6:00pm	75	75.0	12.6	10,051	30,000	70	71.0	13.6	8,789	16,800	46,800	4,000	4,000	4,000	38	40	39.33	
		7:30am	70		13	10,223		69		13.0	8,832			4,000	4,000		40	40		
34	3-Mar	12:00pm	72		13	10,267		70		13.0	8,973			4,200	4,200		38	38		
		6:00pm	70	70.7	12.5	10,325	31,600	68	69.0	12.5	9,024	39,800	71,400	4,100	4,100	4,100	38	38	38.67	
		10:30am	66		12.6	10,539		64		12.6	9,230			4,500	4,500		39	40		
35	4-Mar	2:00pm	67		12.7	10,578		65		12.7	9,273			4,300	4,500		40	41		
		8:00pm	64	65.7	12.7	10,638		64	64.3	12.7	9,343			4,400	4,400	4,433	40	40	40.00	

	Meter 1 (temp compensated, 60F): Temp		Press	Reading	Avg/day	Meter 2: Temp		Press	Reading	Avg/day	Combined	H2S ppm*: #1	#2	Avg/day	CO2%: #1	#2	Avg/day
Average	67.4		12.7	21,994	22,088	65		12.7	23,497	24,435	46,524						
										22,556	(at STD)						
Avg both meters	66.3		12.7											3,392			37.8
Standard Dev	5.61		0.43	1,980	7,102	4.91		0.44	2259	5,686	11,569			519.79			3.45
Confidence Int ±	0.77		0.06	272	2,387					1970	4009			71.0			0.47
(# of samples)	203		203	203	34									206			206

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

Noblehurst Farms
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	65.5	473	137.1	64,841	17.4	8,242	12.7%	3,008,383
Dry Cows, Body Weight	1500	163	80.9	13,194	10.1	1,643	12.5%	359,762
Heifers, average Body Weight	1200		60.7	0	7.9	0	13.0%	0
Total				78,035		9,885	12.7%	3,368,145

118,809 lb/day @ 8.32% TS
13,978 gal/day @ 8.45 lb/gal
567 cow equivalents

Milking Center Wastewater	Gal/cow-day	Gal/day	Lb/day
		0	0
Total			78,035

*Rolling Herd Average, lb/cow-yr 23,900