CHARACTERIZATION OF SULFUR FLOWS IN FARM DIGESTERS at PATTERSON FARMS

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TABLE OF CONTENTS

Section		Page
1	DESCRIPTION	1-1
2	RESULTS – 24 HOUR TEST, APRIL 2 & 3, 2007	2-1
3	RESULTS – 30 DAY TEST, APRIL 26 to MAY 27, 2007	3-1
4	MASS FLOW OF SULFUR	4-1
	Total Mixed Ration	4-1
	Drinking Water	4-1
	Bedding/Separated Solids	4-2
	Foot Bath	4-2
	Milk	4-3
	Manure/Food Waste	4-3
	Mass Flow of Manure & Food Waste	4-4
APPENDIX		A-1

TABLE OF FIGURES

Figure		Page
2-1	Concentration of Hydrogen Sulfide Obtained from OMA 300 Analyzer	2-1
3-1	Biogas Production at the Patterson Farms during the 30 Day Test	3-1
3-2	Daily Temperature of Biogas at the Roots Meter, 30 Day Test	3-2
3-3	Concentration of Carbon Dioxide Measured with a Bacharach Unit, 30 day test (dry basis)	3-2
3-4	Concentration of Hydrogen Sulfide (dry basis), 30 day test	3-3
4-1	Results of Measuring the Distance to Surface at Influent Pit at Patterson Farm.	4-4
4-2	Results of Measuring the Distance to Surface at Food Waste Pit at Patterson Farm	4-5
A-1	Patterson Farms Flow Diagram	A-1
A-2	Mass Flow Diagram of Sulfur, Patterson Farms	A-2

TABLE OF TABLES

Table		Page
1-1	Number of Animals	1-1
2-1	Concentration of Carbon Dioxide and Hydrogen Sulfide (dry basis) 2 Apr 07	2-1
2-2	Data Recorded by Weeks from the *GEM 2000* Monitor, 2 April 07	2-2
3-1	Summary of Data from 30 Day Test at Patterson Farms	3-1
4-1	Sulfur in TMR at Patterson Farms	4-1
4-2	Sulfur in the Animal Drinking Water at Patterson Farms	4-2
4-3	Analysis of Separated Solids at Patterson Farms	4-2
4-4	Sulfur in the Milk Produced at Patterson Farms	4-3
4-5	Properties of the Raw Manure and Food Waste at Patterson Farms	4-3
4-6	Properties of the Digester Influent and Effluent at Patterson Farms	4-4
4-7	Analysis of Mass Flow Based on Measured Pump Capacity	4-5
4-8	Mass Balance Method of Determining Influent and Effluent Total Solids	4-6
4-9	Analysis of Biogas at Patterson Farms	4-7
4-10	Summary of Results from Biogas Analysis	4-7
4-11	Summary of Sulfur Flow at Patterson Farms	4-8
A-1	30-Day Test Data, Patterson Farms	A-3
A-2	Cow Manure Production, Based on ASABE Equations	A-6

Section 1
DESCRIPTION

The Patterson Farm is located on Townline Rd south and west of Auburn, NY. A schematic of the layout of the reception pits, digester, engine/generator building and the separator and solids storage is attached in the appendix. Initially the manure from the milking cows and heifers was pumped to the manure pit (5,200 gal/ft). From there the manure was pumped (Houle centrifugal pump) to the liquid/solid separator and the liquid was pumped back to the mix pit (5,000 gal/ft). Food waste from the food waste pit (2,100 gal/ft) was also pumped by a similar pump in the mix pit. This mixture, mixed with a Houle impeller agitator, was pumped to the anaerobic digester which has five agitators and a floating cover. The digester effluent flowed by gravity directly into the effluent pit (7,400 gal/ft). The effluent was pumped to an earthen storage for land application. Some liquid was pumped to the heifer barn to dilute that manure so it could be pumped. The separated solids were stored (composted) and then -used for bedding.

There was a need for more biogas so the system was reconfigured so that the manure and food waste mix was pumped directly to the digester. The digester effluent now is pumped to the separator with the liquid still going to the earthen lagoon and the solids used for bedding. Some additional wood shaving/sawdust is purchased for bedding.

The manure from the animals listed in Table 1-1was digested during this study. The digester feed pump
Table 1-1. Number of Animals.

Animal Group	Number
Milking	762
Fresh Cows	92
Treated Cows	27
Big Heifers	323
Calves	106

operated 21 times per day with a total operating time of 120 min/day. The food waste pump operated 12 times/day with a total operating time of 36 min/day.

The biogas from the digester flows through a *Varec* value to a Roots meter adjacent to the engine/generator. The biogas not used by the engine is piped to the flare. A *Fox* Thermal Instrument gas meter measures the biogas flowing to the flare. Two "*Pete's Plugs*" were installed in the Roots meter. This permitted the use of a bimetal stem thermometer to monitor the temperature of the biogas at the meter

and for attaching a pressure gage to monitor pressure. An analog pressure gage (*Dwyer Instrument, Inc*.) was installed at the gas meter.

Two series of tests were conducted during this study, a 24 hour test and a 30 day test. These tests were designed to characterize the source of sulfur and its flow on the farms dairy barns > pits > digester > separator and engine/generator set. Raw data from these tests are given in the appendix.

Section 2

RESULTS – 24 HOUR TEST, APRIL 2 & 3, 2007

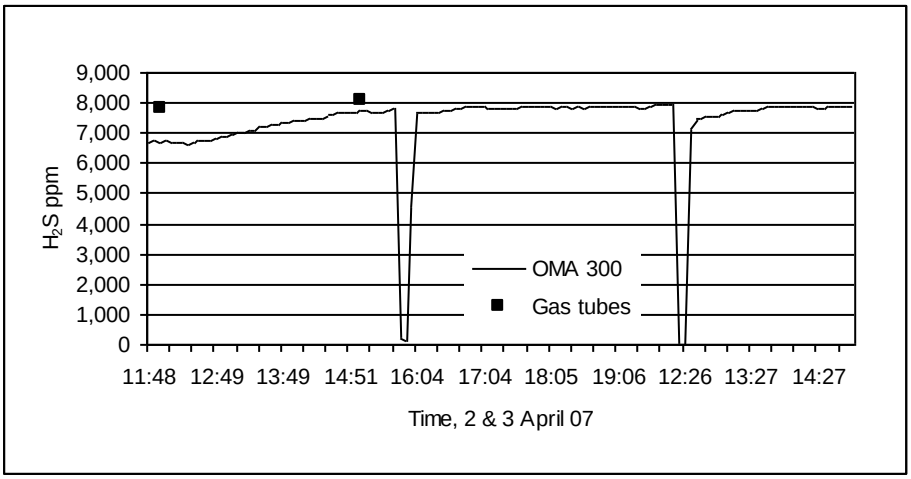
On April 2, 2007 a hydrogen sulfide analyzer (OMA 300 from Applied Analytics, Inc.) and a carbon dioxide and methane analyzer (GEM 2000 from LANDTEC) were installed to sample and analyzed the biogas at the Patterson Farm. During the 24 hour period concentration of carbon dioxide would be measured with Gastec gas tubes and the Bacharach unit and the concentration of hydrogen sulfide would also be measured with Gastec gas tubes. Triplicate tests were run each time. Table 2-1 gives the results of these tests.

Table 2-1. Concentration of Carbon Dioxide and Hydrogen Sulfide (dry basis) 2 Apr 07.

Test	Gas tube	Bacharach	Gas tube	Temperature
	CO_2, %		H_2S, ppm	F
No. 1	42	41	7,500	
11:00	43	41	8,000	74.6
	42	40	8,000	
No. 2	50	42	8,200	
14:00	48	42	8,000	73.6
	45	43	8,000	
Average	45.0	41.5	7,950	74.1
Stand dev	3.3	1.0	235	
Confidence	2.7	0.8	188	

Some difficulty was encountered with the OMA 300 H_2S analyzer. The data collected by the OMA 300 unit are plotted in Figure 2-1. The unit was started at 11:48 and stopped at 15:35 for an automatic blanking (zeroing). The unit was restarted at 15:59 and operated until 20:02 when it was shut down. The unit was started the next day (3 April) at 12:31 and operated until 14:58. The average concentration of hydrogen

Figure 2-1. Concentration of Hydrogen Sulfide Obtained from OMA 300 Analyzer.



sulfide between 16:04 and 20:02, after the unit had warmed up and zeroed, was 7,840 ppm.

The data automatically recorded by the *GEM 2000* carbon dioxide and methane analyzer was corrupted and not usable. However, Dr. Weeks recorded readings in his notes at three different times on 2 April 07. These are given in Table 2-2. The average concentration of carbon dioxide was 43.5%. Though the

Table 2-2. Data Recorded by Weeks from the *GEM 2000* Monitor, 2 April 07.

Time	CO_2, %	CH_4, %
15:29	43.6	56.3
16:15	43.9	56.1
19:22	43.1	56.9
Average	43.5	56.4
Std Dev	0.40	0.42
Confidence	0.46	0.47

times do not overlap the average concentration of carbon dioxide from the *Gastec* gas tubes was 45.0% and 41.5% from the *Bacharach* unit. This gives overall average concentration of 43.3% with a standard deviation of 2.7 and a confidence interval of ± 1.3.

Section 3

RESULTS – 30 DAY TEST, APRIL 26 TO MAY 27, 2007

During the 30 day test the operator measured and recorded the following data three time each day; biogas temperature and pressure at the meter, reading from the two biogas meters, test the biogas (2 samples) for hydrogen sulfide (gas tubes) and carbon dioxide (Bacharach unit). The raw data can be found in the Appendix, Table A-1. There are two biogas meters at the Patterson Farms, a *Roots* meter at the engine and a *Fox Thermal Instruments* meter in the pipe to the flare. Both meters are temperature compensated (60 F).

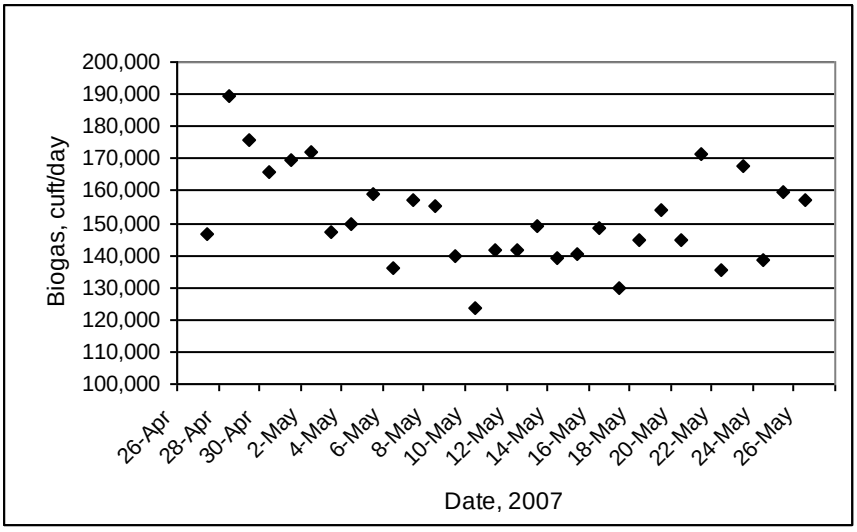
Table 3-1 lists the average values for each parameter tested during the 30 day test plus the standard deviation, confidence interval and the number of raw data points.

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

Parameter	Temp ºF	Press. in H2O	Engine cuft/day	Flare cuft/day	Total cuft/day	H2S %	CO2 %
Average	74	(18.8)	102,342	49,350	151,692	0.62	38
Standard Dev.	9.0	0.84	6,703	15,730	14,990	0.07	3.2
Conf. Inter ±	1.8	0.19	2,399	5,629	5,364	0.01	0.47
# of samples	91	78	30	30	30	182	180

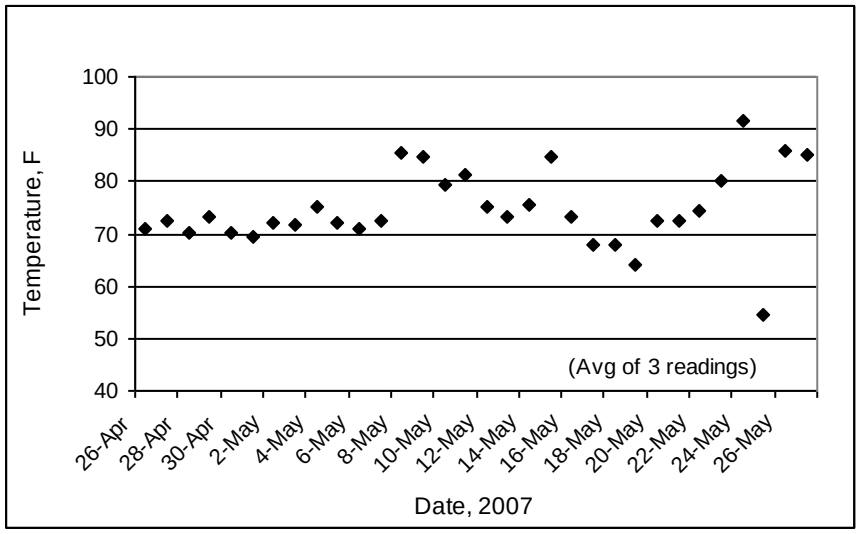
The production of biogas during the "30 day test" averaged 151,700 ft^3/day with a standard deviation of 15,000 or 10%. The maximum production was 189,600 and the minimum was 123,800 ft^3/day. Some of this variation was due to a variation in the amount of food waste fed, and the "length of day" due to the time when the readings were taken. The standard deviation of the biogas flow at the Roots meter was 6.5% of the average while the standard deviation at the flare meter was 32% of the average.

Figure 3-1. Biogas Production at the Patterson Farms during the 30 Day Test.



The average daily (three readings) temperature of the biogas at the meter is plotted in Figure 3-2. The average temperature was 74 F with a standard deviation of 9 F°. There were not comments made on the

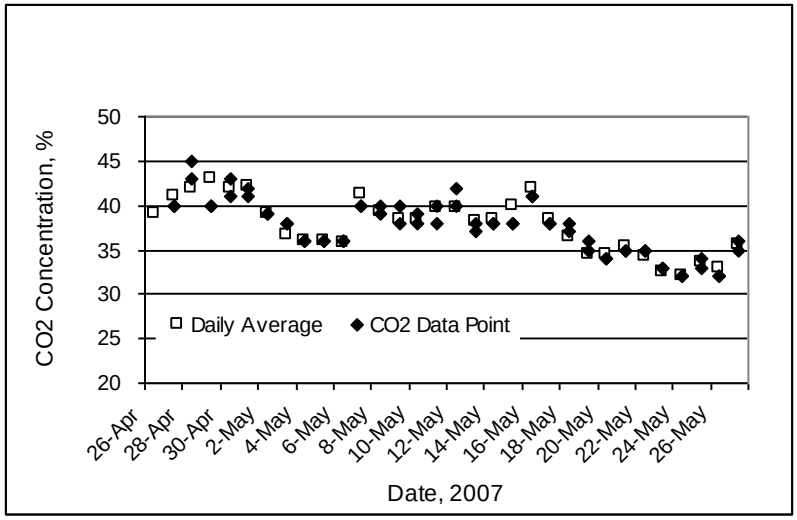
Figure 3-2. Daily Temperature of Biogas at the Roots Meter, 30 Day Test.



data sheets to indicate a reason for the rather large temperature swings. This digester has a floating membrane cover (black) with little space between the top of the digester fluid and the membrane (lower mass of biogas). Thus, ambient air temperature and solar radiation during the day and re-radiation at night could have a greater impact on biogas temperature than at a digester with an inflated bag cover or certainly a solid cover.

The average daily concentration of carbon dioxide and the actual data points as measured with a *Bacharach*

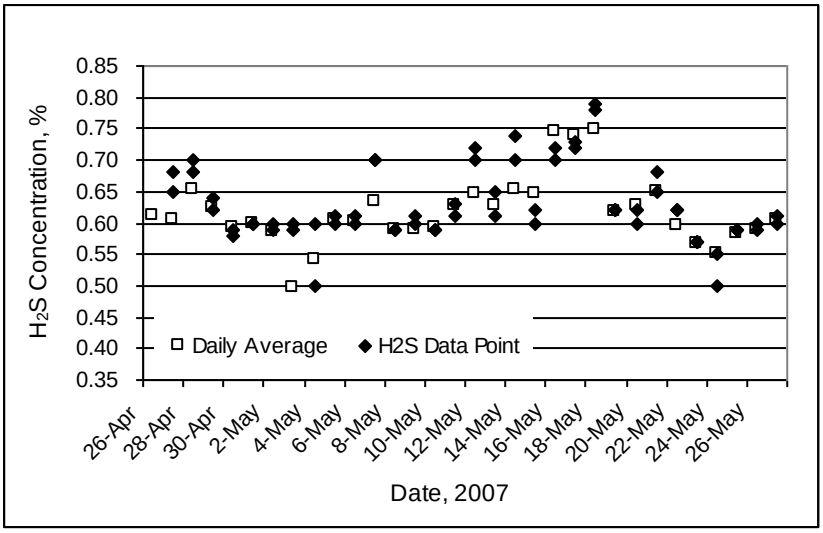
Figure 3-3. Concentration of Carbon Dioxide Measured with a Bacharach Unit, 30 day test (dry basis).



unit by the operator are shown in Figure 3-3. The average concentration for the 30 day study was 38% with a confidence interval of ± 0.47%. Not all 180 data points are shown in this plot because the values were often the same at the three times during a given day. The closeness of the data points to the daily average shows that there was less variability of the concentration during the day than there was between days and a consistency of measuring the concentration with the *Bacharach* unit.

The concentration of hydrogen sulfide in the biogas was measured with gas tubes. Two samples were analyzed three times each day. There were 182 readings recorded. The results of these tests are plotted in Figure 3-4 with a daily average and individual readings. Not all the readings can be seen because on a

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



given day two readings might be the same thus showing as one point. The average concentration of hydrogen sulfide for the 30 day test was 0.62% (6,200 ppm) with a confidence interval of ± 0.07% (700 ppm). There were no comments on the 30 day data sheets that might explain the variation in the concentration of H_2S. Comparing the biogas temperature in Figure 3-2 and the concentration of hydrogen sulfide above, both had considerable variation during the 30 day test more than carbon dioxide shown in Figure 3-3.

Section 4

MASS FLOW OF SULFUR

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

TOTAL MIXED RATION (TMR)

The results of the analysis of the TMR consumed at Patterson are given in Table 4-1.

Table 4-1. Sulfur in TMR at Patterson Farms.

	Fresh				Base (Milking Group)			
Date	Consumed, lbs/day	Sample	S % (as fed)	lbs S/day	Consumed, lbs/day	Sample	S % (as fed)	lbs S/day
12/20/2006	13,566	FreshA	0.12	16.3	84,027	BaseA	0.13	109
		FreshB	0.12	16.3		BaseB	0.12	101
4/30/2007	10,501	PF FC1	0.13	13.7	83,292	PF MG1	0.14	117
		PF FC2	0.14	14.7		PF MG2	0.14	117
5/16/2007	10,501	PF FC1	0.13	13.7	83,292	PF MG1	0.12	100
		PF FC2	0.13	13.7		PF MG2	0.12	100
	Average		0.13	**14.7**			0.13	**107**
	Standard Dev		0.008				0.010	
	Confidence Interval ±		0.006				0.008	

Date	Small Heifer				Large Heifer			
	Consumed, lbs/day	Sample	S % (as fed)	lbs S/day	Consumed, lbs/day	Sample	S % (as fed)	lbs S/day
12/20/2006	28,306	HeiferA*	0.15	42.5	(combined with Small Heifer)			
		HeiferB*	0.19	53.8				
4/30/2007	4,614	PF SH1	0.11	5.08	18,002	PF BH1	0.09	16.2
		PF SH2	0.10	4.61		PF BH2	0.08	14.4
5/16/2007	4,614	PFSH1	0.11	5.08	18,002	PF BH1	0.07	12.6
		PF SH2	0.10	4.61		PF BH2	0.09	16.2
	Average		0.11	**4.84**			0.08	**14.9**
	Standard Dev		0.01				0.010	
	Confidence Interval ±		0.006				0.009	

* not used in analysis

The sulfur (S) content of the TMR consumed by the dairy animals at Patterson Farms is estimated to be 146 lb per day.

DRINKING WATER

Drinking water for the dairy animals at Patterson Farm comes from two sources, well water and pond. The concentration of sulfate and sulfur in the drinking water is shown in Table 4-2. The tap (well) water had 36 time the sulfate than the pond water. The total consumption of water was 35,000 gal per day. The notes in

Table 4-2 show the distribution of the water to the different groups of animals. A total sulfur in the water consumed by the dairy cows was 41 lb S/day.

Table 4-2. Sulfur in the Animal Drinking Water at Patterson Farms.

Date	Sample	Sulfate mg/L	S lbs/1000 gal	lbs S/day	Sample	Sulfate mg/L	S lbs/1000 gal	lbs S/day
3/25/2007	Pond	24.75	0.07	1.4	Tap	1,040	2.91	42
4/26/2007	Pond1	28.5	0.08	1.6	Tap	982	2.75	40
1/5/2007					Tap	894	2.50	36
Average		26.6	0.07	**1.5**		972	2.72	**39**
Standard Deviation			0.007				0.11	
Confidence Interval ±			0.01				0.13	

Tap	14,500 gal	[556 cows at 26 gal/cow-day]
Pond	20,500 gal	[440 cows at 26 + 441 heifers at 20.5 gal/cow-day]
Total Sulfur	**41.0**	

conversion factor; mg sulfate/l to lb sulfur/1000gal = 0.0028

BEDDING/SEPARATED SOLIDS

Separated solids used for bedding was analyzed for sulfur. The results of these analyses are shown in Table 4-3. To determine the sulfur in the separated solids used for bedding, the assumption was made that the amount of bedding used was 4.0 lb TS/cow-day. With an average TS of 30.2%, the wet weight used was

Table 4-3. Analysis of Separated Solids at Patterson Farms.

Date	lbs/day	Sample	TS, %	S % (as used)	lbs S/day
1/5/2007	13,900	PFSS1	29.9	0.09	12.5
		PFSS2	30.4	0.09	
	Average		30.2	**0.09**	**12.5**
	Standard Dev		0.35		
	Confidence Integral ±		0.49		

13.2 lb/cow-day. Based on the American Society of Agricultural & Biological Engineers (ASABE) calculation (see Appendix A) for manure production, the "equivalent dairy cows" whose manure went to the digester was 1,050. Using this value the pounds of separated solids used per day would be 13,900. The sulfur added by the bedding is estimated to be 12.5 lb S/day.

FOOT BATH

There is no sulfur in the chemicals used in the foot bath at Patterson Farms.

MILK

The concentration of sulfur in the milk is low but because of the volumes are large sulfur in milk must be considered. Table 4-4 shows the information concerning sulfur in milk with a total of 16.1 lb S per day.

Table 4-4. Sulfur in the Milk Produced at Patterson Farms.

RHA lbs/cow-yr	lbs/cow day	# of Cow	Sulfur* %	S lbs S/cow day	Total lbs S/day
23,000	63	854	0.03	0.019	**16.1**

* based on data from Trace Minerals Research

MANURE / FOOD WASTE

The digester influent at Patterson Farms is a combination of raw manure (with bedding) and food waste. The properties of these two ingredients are given in Table 4-5. The considerable difference in the two samples of food waste taken 12 days apart illustrates the variation in the food waste. These two wastes could have a considerable difference in the biogas production.

Table 4-5. Properties of the Raw Manure and Food Waste at Patterson Farms.

	Raw Manure				Food Waste		
Date	Sample	TS %	S %	Date	Sample	TS %	S %
12/19/2006	R1	7.95	0.055	12/6/2006	FW1	46.6*	0.01
	R2	8.24	0.065		FW2	57.1*	0.01
	R3	8.15	0.065				
5/28/2007	RMI	8.88	0.06	12/18/2006	FW1	5.9	0.01
	RM2	8.73	0.06		FW2	5.9	0.01
	RM3	8.95	0.07	* values not used, error in analysis			
Average		**8.85**	**0.063**				
Standard Deviation		0.42	0.005				
Confidence Interval ±		0.28	0.003				

The properties of the digester influent (mixture of raw manure and food waste) are given in Table 4-6. The relative consistency of the digester influent shown in Table 4-6 indicates that the dairy manure is dominant assuming there was as much variation in food waste on these three sampling dates are there was on the two described above.

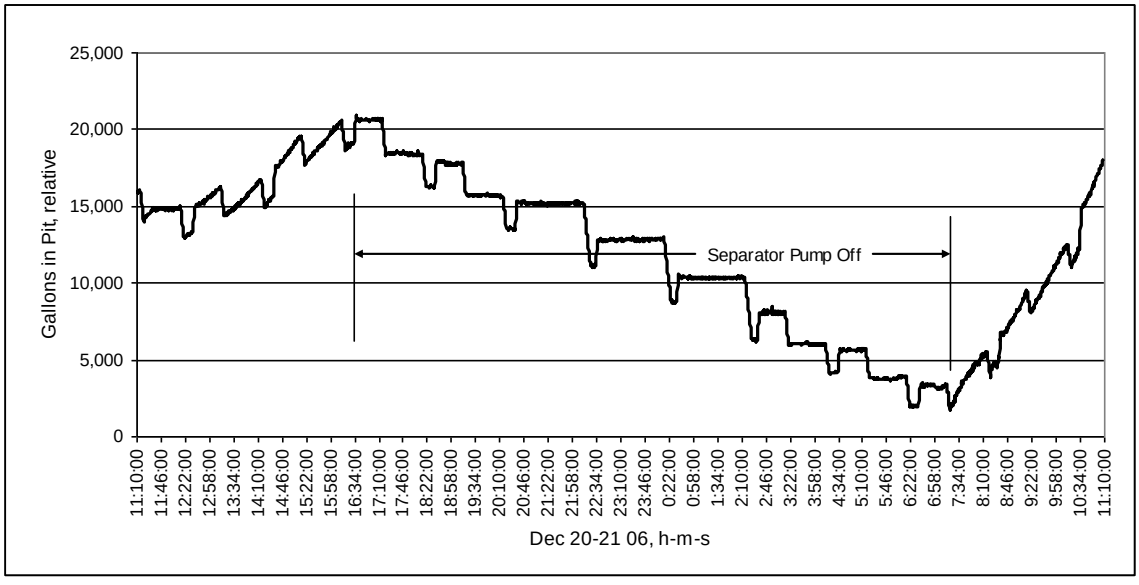
Table 4-6. Properties of the Digester Influent and Effluent at Patterson Farms.

	Influent (manure + food waste)			Effluent		
Date	Sample	TS %	S %	Sample	TS %	S %
4/30/2007	PFDI1	9.78	0.060	PFDE1	5.6	0.025
	PFDI2	8.5	0.055	PFDE2	5.6	0.030
	PFDI3	8.33	0.045	PFDE3	6.16	0.030
5/16/2007	PFDI1	8.69	0.050	PFDE1	5.12	0.030
	PFDI2	8.52	0.055	PFDE2	6.0	0.030
	PFDI3	8.49	0.060	PFDE3	5.41	0.030
5/28/2007	PFDI1	7.79	0.050	PFDE1	6.45	0.035
	PFDI2	9.6	0.065	PFDE2	6.46	0.035
Average		8.71	**0.055**		5.85	**0.031**
Standard Dev		0.66	0.007		0.49	0.003
Confidence Interval ±		0.46	0.005		0.34	0.002

MASS FLOW OF MANURE AND FOOD WASTE

The mass flow of manure/food waste mixture to the digester was measured by monitoring the level of waste in the influent pit with an Ultrasonic instrument. [Data was taken when the manure was separated prior to digester.] The result of this monitoring is shown in Figure 4-1. During the time the separator pump was off, the pump operated 80 minutes and delivered 30,445 gallons to the digester for an average influent pump capacity of 380 gpm. The influent pump operates 120 min per day [18 - 5 min and 3 – 10 min cycles] giving a daily flow of 45,600 gallons to the digester.

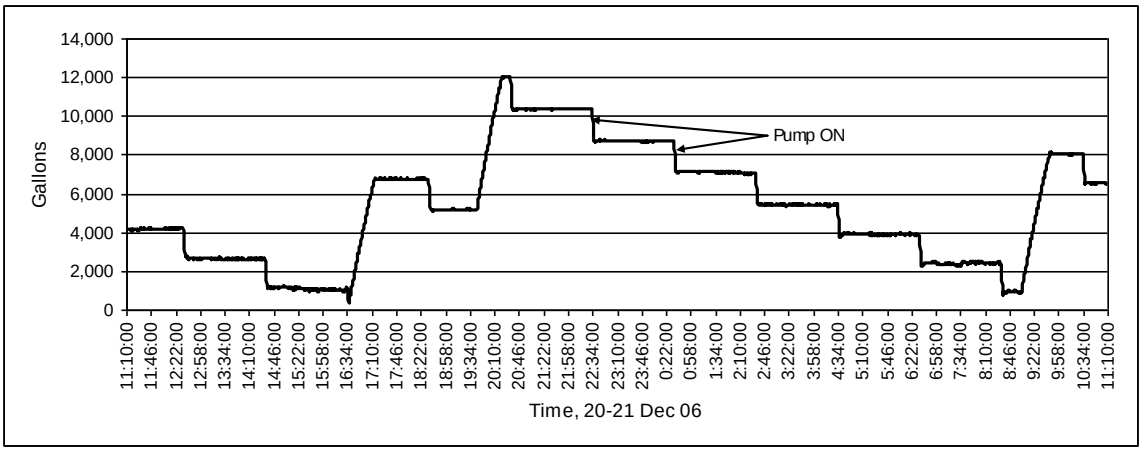
Figure 4-1. Results of Measuring the Distance to Surface at Influent Pit at Patterson Farm.



At 8.5 lb per gallons, the mass flow to the digester would be 387,600 lb/day. With a concentration of sulfur in the influent of 0.055%, the mass flow of sulfur to the digester would be 213 lb S/day.

The food waste pit was also monitored with the Ultrasonic instrument to determine the volume of food waste pumped to the influent pit. The result of this monitoring is shown in Figure 4-2. The decrease in gallons (vertical drop) in the pit shows when the pump was ON. The pump operates 12 times per day for 3 minutes each or a total of 36 min/day. The average pumping rate was 508 gal/min for a total of 18,300 gpd.

Figure 4-2. Results of Measuring the Distance to Surface at Food Waste Pit at Patterson Farm.



With a total influent flow of 45,600 and a flow of food waste of 18,300 gal per day, the flow of manure, including bedding, would be 27,300 gal/day. Using the data from monitoring pump capacity and the analyses of the various components, the mass flows of manure and food waste were calculated. These are

Table 4-7. Analysis of Mass Flow Based on Measured Pump Capacity.

Parameter	Lb TS/day	% TS	Lb/day (wet)	Sulfur %	Sulfur Lb/day	Lb/gal	Gal/day
Raw Manure (ASABE)	18,030						
Bedding (calculated)	4,080						
Total “manure”	22,100	8.85*	249,800	0.063	157	8.5	29,400
Food Waste	11,660	7.6	153,700	0.01	15.3	8.4	18,300*
Total to Digester	33,760	8.71*	387,600	0.055	213	8.5	45,600*

Notes: * measured

18,030 + 4,080 = 22,100 / 0.0885 = 249,800 / 8.5 = 29,400

45,600 x 8.5 = 387,600 x 0.0871 = 33,760 – 22,100 = 11,660

18,300 x 8.4 = 153,700, 11,600 / 153,700 = 0.076

45,600 – 18300 ≠ 29,400

shown in Table 4-7. The gallons per day were off by 1,100 gal/day and the total solids content of the food waste was 1.7% higher that measured (see Table 3-5). The sum of the sulfur in the manure and food waste did not equal the sulfur calculated to be in the influent.

The mass balance is a second method for determining the mass flow of manure and sulfur into and out of the digester. The results of this analysis are shown in Table 4-8. The data need for this analysis includes total solids content and concentration of sulfur in the influent and effluent (see Table 4-6) and the analysis of the biogas. This analysis is shown in Table 4-9. The production of dry biogas was computed to be 162,000 cuft/day. This value was used in the mass balance method.

Table 4-8. Mass Balance Method of Determining Influent and Effluent Total Solids

Vo =	161,996	ft3/day, dry			Volume of biogas
CH4 =	0.615				Concentration of methane
CO2 =	0.379				Concentration of carbon dioxide
IPTS =	8.71	%			Percent total solids in influent
EPTS =	5.85	%			Percent total solids in effluent
IPS =	0.055	%			Percent sulfur in influent
EPS =	0.031	%			Percent sulfur in effluent
B =	11,980	lb biogas/day dry			Weight of biogas
T =	74	F			Biogas temperature at meter
T =	23.3	C			
bVS =	10,782	90%*			Volatile solids consumed
bW =	1198	10%*			Mass of water consumed
Dw =	0.00110	lb water/ft3 biogas			
We =	178.9	lb water/day			Water in saturated biogas
ITS =	0.0871	ITW=	0.913		Total solids in influent
ETS =	0.0585	ETW=	0.942		Total solids in effluent
ITM =	351,810	lb/day	43,976	gpd	Total mass of influent
ETM =	339,651	lb/day	42,456	gpd	Total mass of effluent
Δ TM =					
Δ	10,782	lb/day			Total solids "lost"
Sulfur In	193.5	lb/day			Sulfur in influent
Sulfur Out	104.0	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.

The mass balance method predicted the mass flow into the digester of 352,000 lb/day compared to 387,000 lb/day from analyzing the influent pump operation. For the sulfur entering the digester the two values are 213 and 194 lb S/day, respectively. The “loss” of sulfur during the digestion process was 89.5 lb S/day

while the analysis of the biogas predicted a loss of 76.9 lb S/day. The results of analyzing the biogas is summarized in Table 4-10.

Table 4-9. Analysis of Biogas at Patterson Farms.

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

Input Data - yellow area		
Biogas temp @ meter	74.0	F
Pressure in gas line	-18.8	in H_2O
Biogas flow (meter)	151,690	cuft/day
Elevation of meter	528	ft
H_2S (dry basis)	6,180	ppm
CO_2 (dry basis)	37.9	%
P_{elev}	14.416	psia
P_m	(0.679)	psig
P_{line}	13.737	psia
Volume of water vapor	2.81	%
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	74.0	F	166,674	cuft/day
Biogas flow (dry) at	74.0	F	161,996	cuft/day
Concentration of methane		CH_4	61.5	%
Volume of CH_4 @	74.0	F	99,598	ft^3/day
Volume of CH_4 @ STP			85,775	ft^3/day
Weight of CH_4			**3,826**	**lb/day**
HEATING VALUE (low)			82,318,177	Btu/day
			3,429,924	Btu/hr
Raw biogas			494	Btu/ft^3
			1,005	kW
Volume of H_2S @	74.0	F	1,001	ft^3/day
Volume of H_2S @ STP			862	ft^3/day
Weight of H_2S			81.7	lb/day
Weight of Sulfur (S)			**76.9**	**lb/day**
Volume of water vapor	74.0	F	4,678	ft^3/day
Weight of water vapor			0.0463	lb/ft^3
Water			217	lb/day
			26.0	gal/day

Table 4-10. Summary of Results from Biogas Analysis.

Parameter	Value	Units and Comments
Volume of wet biogas	151,690	Cubic feet per day @ 74º F measured by meter
Weight of sulfur in biogas	76.9	Lb Sulfur per day
Weight of methane	3,826	Lb CH_4 per day
Heating value of methane	3,430,000	Btu per day
Weight of water in biogas	217	Lb per day

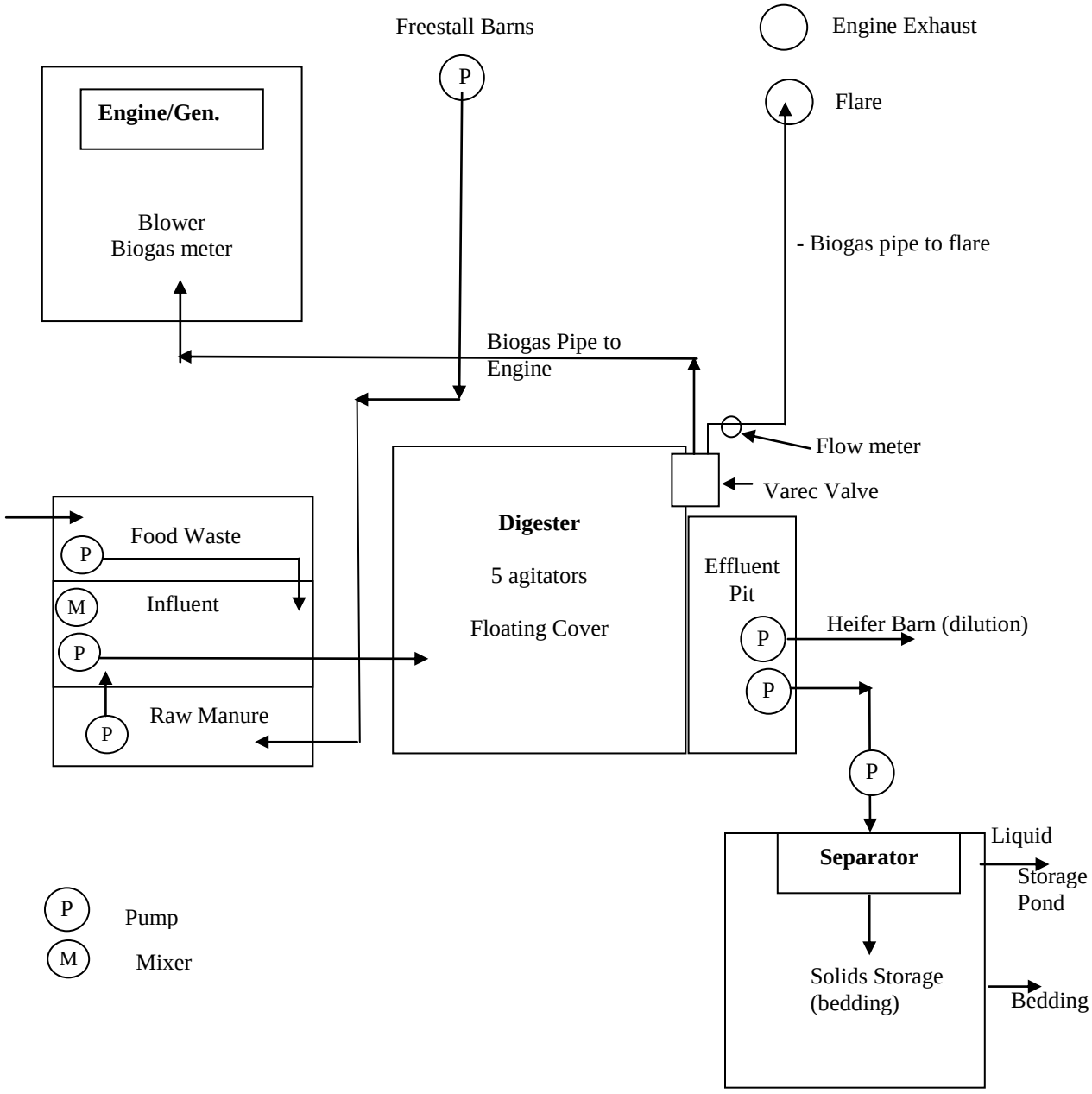
A summary of the sources of sulfur and the magnitude of each source is given in Table 4-11. How the mass flow of sulfur was arrived at is also given. The sulfur in the manure leaving the barn plus the sulfur in the food waste equals 198 lb S/day. Analysis of pumping capacity and concentration of sulfur in the influent yielded 213. The mass balance method predicted 194 lb S/day. The 77 lb sulfur in the biogas per day ranged from 36 to 40 of the sulfur entering the digester.

Table 4-11. Summary of Sulfur Flow at Patterson Farms.

Parameter	Value	Comments
Number of Cows	1,049	Equivalents, based on production of TS
Source	Sulfur, lb/day	
TMR	146	Mass given, measured concentration
Drinking Water	41	Volume calculated, measures concentration
Bedding	12.5	Estimate mass, measured concentration
Milk	16.1	Mass given, concentration from reference
Raw manure leaving barn	183	146 + 41- 16.1 + 12.5 = 183
Food Waste	15.3	
Digester influent	198	183 + 15.3 = 198
Digester influent	213	Pump operation and measured concentration
Digester influent	194	Mass balance method
Digester effluent	104	Mass balance method
Sulfur “lost” in digester	90	By difference
Sulfur in biogas	77	Measured concentration and mass flow

APPENDIX

Figure A-1. Patterson Farms Flow Diagram.



Not to scale

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

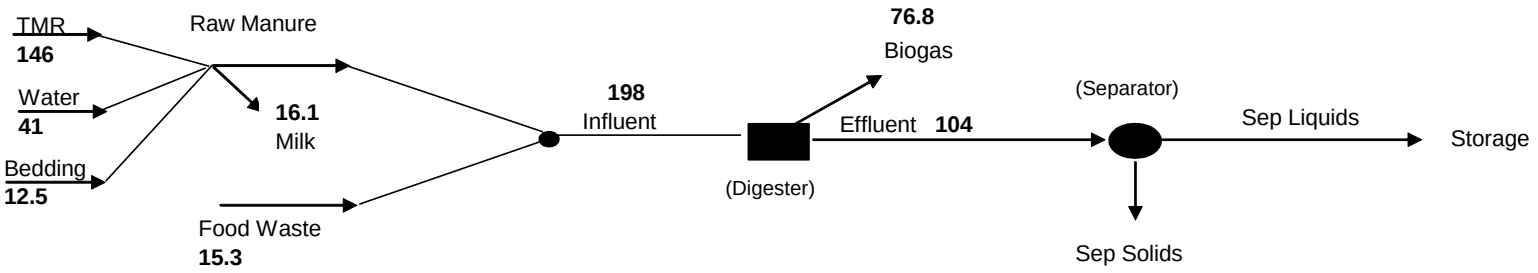


Table A-1. 30 Day Test Data, Patterson Farms.

Day #	Date 2007	Time	# of Hrs	Biogas Meters							Total Biogas		H2S ppm%			CO2 ppm/%			Comments
				Meter 1					Flare										
				Temp	Avg	Press (")	Reading	avg cuft/day	Reading	Avg cuft/day	cuft	Avg cuft/day	#1	#2	H2S/ day	#1	#2	Avg/ day	
1	26-Apr																		Put 7,000g of Bunk Juice in east Drain Barn Pit
		4/26/07 12:05 PM		69			8,725		1,472,342		1,481,067		0.61	0.62		38	38		
		4/26/07 3:15 PM		73	71		17,980		1,498,380		1,516,360		0.61	0.61	0.61	40	40	39	
2	27-Apr	4/27/07 7:35 AM		70			80,121		1,627,841		1,707,962		0.65	0.68		40	40		Dumped some liquid; Check CO2 meter
		4/27/07 10:00 AM		71			89,970		1,645,494		1,735,464		0.38	0.65					
		4/27/07 4:30 PM	21.92	76	72		119,199	88,968	1,699,949	57,451	1,819,148	146,419	0.63	0.63	0.60	42	42	41	
3	28-Apr	4/28/07 7:25 AM		70			185,867		1,842,601		2,028,468		0.70	0.68		45	43		Shut down for oil change
		4/28/07 2:25 PM		72			203,824		1,919,388		2,123,212		0.62	0.65		43	41		Drained all condensat traps
		4/28/07 6:00 PM	28.42	69	70		215,157	96,158	1,958,072	93,461	2,173,229	189,620	0.65	0.62	0.65	40	40	42	
4	29-Apr	4/29/07 9:50 AM		68			286,918		2,091,464		2,378,382		0.62	0.64		40	40		
		4/29/07 3:50 PM		76			313,511		2,140,307		2,453,818		0.58	0.58		43	41		
		4/29/07 6:25 PM	25.42	76	73		324,790	103,573	2,159,696	72,301	2,484,486	175,874	0.65	0.67	0.62	47	47	43	
5	30-Apr	4/30/07 7:17 AM		73			382,301		2,273,959		2,656,260		0.58	0.59		41	43		Shut down 2 times for southern research
		4/30/07 12:55 PM		73			403,200		2,326,227		2,729,427		0.59	0.60		42	41		
		4/30/07 7:55 PM	21.08	65	70	-19	414,829	102,097	2,408,689	63,442	2,823,518	165,538	0.59	0.60	0.59	43	42	42	
6	1-May	5/1/07 7:45 AM		65		-20	469,100		2,501,366		2,970,466		0.60	0.60		42	41		Southern research testing
		5/1/07 2:45 PM		72		-19	500,726		2,554,972		3,055,698		0.59	0.59		42	42		
		5/1/07 6:00 PM	25.83	71	69	-20	514,985	90,605	2,580,620	79,181	3,095,605	169,786	0.60	0.61	0.60	44	42	42	
7	2-May	5/2/07 8:00 AM		67		-19	578,317		2,682,790		3,261,107		0.59	0.60		39	39		Southern research testing
		5/2/07 6:30 PM		75		-18	623,323		2,753,240		3,376,563		0.56	0.56		40	38		
		5/2/07 7:30 PM	27.75	74	72	-18	627,458	106,030	2,759,734	66,089	3,387,192	172,119	0.60	0.61	0.59	39	39	39	
8	3-May	5/3/07 9:15 AM		67		-19	690,490		2,847,297		3,537,787		0.60	0.59		38	38		
		5/3/07 4:00 PM		75		-17	711,500		2,899,590		3,611,090		0.30	0.30		35	35		
		5/3/07 9:00 PM	21.50	73	72	-18	732,600	98,430	2,931,355	49,010	3,663,955	147,440	0.60	0.58	0.50	37	37	37	
9	4-May	5/4/07 11:10 AM		72		-18.5	793,722		3,008,998		3,802,720		0.50	0.60		36	36		
		5/4/07 5:00 PM		77		-19	819,519		3,042,932		3,862,451		0.59	0.57		36	36		
		5/4/07 7:45 PM	25.00	76	75	-19	831,529	103,698	3,059,955	45,869	3,891,484	149,568	0.42	0.57	0.54	36	36	36	
10	5-May	5/5/07 9:50 AM		69		-19	894,930		3,137,341		4,032,271		0.60	0.61		36	36		
		5/5/07 8:00 PM		74		-19	940,488		3,196,968		4,137,456		0.60	0.60		36	36		
		5/5/07 8:30 PM	27.00	73	72	-20	942,533	107,528	3,198,887	51,345	4,141,420	158,873	0.61	0.60	0.60	36	36	36	
11	6-May	5/6/07 9:20 AM		66		-19.5	999,884		3,137,341		4,137,225		0.61	0.60		36	36		
		5/6/07 12:30 PM		72		-19.5	1,014,389		3,281,588		4,295,977		0.60	0.59		36	35		
		5/6/07 3:00 PM	16.50	75	71	-19.5	1,025,320	107,492	3,295,365	28,604	4,320,685	136,096	0.61	0.60	0.60	36	36	36	
12	7-May	5/7/07 9:40 AM		67		-20	1,109,134		3,407,567		4,516,701		0.70	0.70		40	40		
		5/7/07 2:00 PM		72		-20	1,121,499		3,451,103		4,572,602		0.60	0.60		42	42		
		5/7/07 3:24 PM	25.50	78	72	-19.5	1,127,381	100,809	3,460,768	56,245	4,588,149	157,054	0.60	0.61	0.64	42	42	41	
13	8-May	5/8/07 12:10 PM		85		-18.5	1,217,819		3,591,466		4,809,285		0.59	0.59		40	39		
		5/8/07 7:00 PM		88		-18	1,247,652		3,633,560		4,881,212		0.59	0.59		38	38		
		5/8/07 9:00 PM	29.00	84	86	-18	1,256,061	104,402	3,645,389	51,116	4,901,450	155,519	0.59	0.59	0.59	43	37	39	

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

Day #	Date 2007	Time	# of Hrs	Biogas Meters							Total Biogas		H2S ppm%			CO2 ppm/%			Comments
				Meter 1					Flare										
				Temp	Avg	Press (")	Reading	avg cuft/day	Reading	Avg cuft/day	cuft	Avg cuft/day	#1	#2	H2S/ day	#1	#2	Avg/ day	
14	9-May	5/9/07 8:30 AM		78		-19.5	1,308,604		3,713,054		5,021,658		0.60	0.61		38	40		
		5/9/07 3:30 PM		90		-18	1,338,180		3,753,390		5,091,570		0.57	0.59		38	38		
		5/9/07 8:15 PM	20.50	86	85	-18	1,358,000	105,984	3,782,850	33,968	5,140,850	139,952	0.58	0.59	0.59	38	39	39	
15	10-May	5/10/07 12:30 PM		80		-17.5	1,410,864		3,859,359		5,270,223		0.59	0.59		39	38		
		5/10/07 4:00 PM		78		-18	1,426,100		3,878,086		5,304,186		0.58	0.60		40	38		
		5/10/07 9:00 PM	24.50	80	79	-19	1,446,725	86,126	3,902,592	37,723	5,349,317	123,849	0.59	0.60	0.59	38	38	39	
16	11-May	5/11/07 10:30 AM		78		-19.5	1,506,977		3,973,970		5,480,947		0.63	0.61		40	38		
		5/11/07 2:38 PM		83		-19	1,526,331		3,997,427		5,523,758		0.61	0.62		40	40		
		5/11/07 7:00 PM	22.63	83	81	-19	1,544,926	106,283	4,022,760	35,215	5,567,686	141,499	0.67	0.62	0.63	40	40	40	
17	12-May	5/12/07 8:00 AM		70		-20	1,602,300		4,083,816		5,686,116		0.72	0.70		42	40		
		5/12/07 11:20 AM		75		-19	1,617,190		4,110,917		5,728,107		0.70	0.70		39	39		Food waste:1/2 &1/2 slop
		5/12/07 6:00 PM	20.70	80	75	-19		105,344		36,317	-	141,661	0.65	0.40	0.65	39	39	40	and concentrate
18	13-May	5/13/07 10:30 AM		70		-19	1,722,500		4,209,716		5,932,216		0.65	0.61		37	38		
		5/13/07 5:30 PM		75		-19	1,752,747		4,237,228		5,989,975		0.62	0.65		40	38		
		5/13/07 6:30 PM	30.17	75	73	-19	1,756,099	107,846	4,238,453	41,338	5,994,552	149,185	0.62	0.62	0.63	38	38	38	
19	14-May	5/14/07 9:00 AM		66		-20	1,822,940		4,299,697		6,122,637		0.74	0.70		38	38		
		5/14/07 5:30 PM		82		-19.5	1,859,323		4,339,201		6,198,524		0.60	0.62		38	38		
		5/14/07 9:00 PM	24.00	79	76	-19.5	1,874,060	106,576	4,355,924	32,344	6,229,984	138,920	0.62	0.63	0.65	40	38	38	
20	15-May	5/15/07 2:30 PM		86		-18.5	1,951,251		4,438,616		6,389,867		0.60	0.62		38	38		
		5/15/07 7:30 PM		84		-19	1,972,787		4,464,804		6,437,591		0.65	0.63		43	40		
		5/15/07 8:30 PM	26.00	84	85	-19	1,976,999	104,736	4,470,813	35,604	6,447,812	140,340	0.70	0.68	0.65	40	40	40	
21	16-May	5/16/07 9:00 AM		78		-20	2,032,745		4,543,550		6,576,295		0.72	0.70		41	41		
		5/16/07 7:00 PM		72		-20	2,076,261		4,595,928		6,672,189		0.75	0.79		42	40		
		5/16/07 8:30 PM	23.50	70	73	-20	2,083,945	105,676	4,604,466	42,913	6,688,411	148,589	0.75	0.76	0.75	45	42	42	
22	17-May	5/17/07 3:30 PM		64		-18	2,146,520		4,722,798		6,869,318		0.72	0.73		38	38		Shut down to charge radiator
		5/17/07 4:30 PM		68		-18.5	2,150,791		4,727,872		6,878,663		0.72	0.75		38	38		11 am-3 pm
		5/17/07 7:30 PM	21.50	72	68	-19.5	2,164,781	83,196	474,426	46,568	2,639,207	129,765	0.72	0.79	0.74	40	38	38	Drained condisat traps
23	18-May	5/18/07 7:30 AM		63		-20	2,218,176		4,802,490		7,020,666		0.78	0.79		37	38		
		5/18/07 1:15 PM		68		-19	2,243,994		4,831,715		7,075,709		0.72	0.75		36	36		
		5/18/07 6:15 PM	20.75	73	68	-19	2,266,030	107,801	4,859,237	36,650	7,125,267	144,452	0.72	0.72	0.75	36	36	37	
24	19-May	5/19/07 9:30 AM		38		-18.5	2,335,311		4,937,273		7,272,584		0.62	0.62		36	35		Radiator looks like it's
		5/19/07 1:15 PM		76		-18.5	2,351,421		4,956,031		7,307,452		0.60	0.62		34	34		leaking (Connie)
		5/19/07 5:45 PM	24.00	78	64	-18	2,370,600	107,427	4,979,579	46,619	7,350,179	154,046	0.62	0.62	0.62	34	34	35	Overflow
25	20-May	5/20/07 8:45 AM		73		-18.5	2,437,488		5,059,388		7,496,876		0.60	0.62		34	34		
		5/20/07 11:45 AM		73		-18.5	2,450,199		5,074,327		7,524,526		0.60	0.62		34	34		
		5/20/07 8:00 PM	22.50	71	72	-19	2,487,708	105,363	5,122,628	39,250	7,610,336	144,613	0.68	0.65	0.63	36	35	35	
26	21-May	5/21/07 9:00 AM		67		-19.5	2,545,081		5,197,161		7,742,242		0.65	0.68		35	35		
		5/21/07 8:00 PM		75		-19	2,594,400		5,266,745		7,861,145		0.61	0.61		35	35		
		5/21/07 9:15 PM	32.25	75	72	-19.5	2,599,347	107,312	5,273,723	63,844	7,873,070	171,156	0.70	0.65	0.65	36	36	35	

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

Day #	Date 2007	Time	# of Hrs	Biogas Meters									H2S			CO2			Comments
				Meter 1					Flare		Total Biogas		ppm%			ppm/%			
				Temp	Avg	Press (")	Reading	avg cuft/day	Reading	Avg cuft/day	cuft	Avg cuft/day	#1	#2	H2S/ day	#1	#2	Avg/ day	
		5/22/07 9:45 AM		69		-19	2,655,458		5,344,961		8,000,419		0.62	0.62		35	35		
27	22-May	5/22/07 11:00 AM		73		-19	2,661,723		5,353,455		8,015,178		0.59	0.60		35	34		
		5/22/07 7:30 PM	15.00	81	74	-19	2,697,474	107,717	5,405,970	27,996	8,103,444	135,713	0.57	0.58	0.60	34	33	34	
		5/23/07 9:25 AM		74		-19	2,759,091		5,489,822		8,248,913		0.57	0.57		33	33		Shut valve
28	23-May	5/23/07 9:00 PM		86		-19	2,808,945		5,565,670		8,374,615		0.57	0.56		32	32		
			34.00		80			103,921		63,665	-	167,586			0.57			33	
		5/24/07 4:30 PM		94		-17	2,892,090		5,687,184		8,579,274		0.50	0.55		32	32		
29	24-May	5/24/07 6:00 PM		91		-17	2,899,697		5,698,762		8,598,459		0.57	0.53		32	32		
		5/24/07 8:15 PM	21.00	90	92	-17	2,908,167	103,717	5,712,681	34,846	8,620,848	138,562	0.57	0.59	0.55	32	32	32	
		5/25/07 7:30 AM		41		-17.5	2,957,481		5,787,052		8,744,533		0.59	0.59		33	34		
30	25-May	5/25/07 1:20 PM		49		-17	2,982,111		5,828,277		8,810,388		0.58	0.58		34	34		
		5/25/07 5:40 PM	19.33	73	54	-17	3,000,299	102,307	2,561,055	57,209	5,561,354	159,516	0.58	0.58	0.58	33	34	34	
		5/26/07 11:40 AM		85		-18	3,086,559		6,010,138		9,096,697		0.59	0.60		32	32		Shut down for service
31	26-May	5/26/07 3:30 PM		87		-18	3,094,548		6,022,913		9,117,461		0.58	0.59		34	34		
			26.17		86			103,127		54,317	-	157,444			0.59			33	
		5/27/07 11:30 AM		85		-18	3,177,605		3,174,321		6,351,926		0.60	0.61		35	36		
32	27-May																		
			0.00																

Average	74.3		-18.8		102,342		49,350		151,692		0.62		38	
Standard Dev	8.98		0.84		6,703		15,730		14,990		0.07		3.2	
Confidence Interval	1.85		0.19		2,399		5,629		5,364		0.01		0.47	
(# of samples)	91		78		30		30		30		182		180	

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

Patterson Farms

Calculating Manure Production, ASABE

		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	63.0	881	135.5	119,371	17.2	15,144	12.7%	5,527,492
Big Heifers, Body Weight	1400	323	78.8	25,437	9.7	3,126	12.3%	684,703
Small Heifers, Body Weight	800	112	53.5	5,997	7.0	780	13.0%	284,578
Total				150,806		19,050	0.126	6,496,773

Milking Center Wastewater		Gal/cow-day	Gal/day	Lb/day
*Rolling Herd Average, lb/cow-yr	23,000		equivalent cows	1,108