CHARACTERIZATION OF SULFUR FLOWS IN FARM DIGESTERS at EL-VI FARMS

Prepared for

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Section 1
DESCRIPTION

EL-VI Farms are located on Pelis Rd a few miles south of Newark, NY. A schematic of the layout of the barns, reception pit, hard covered digester, separator, boiler and compost area is attached in the Appendix, Figure A-1. Raw manure from the freestall barns was scraped and pumped to a reception pit in the manure processing building. From here all the manure was pumped to the separator. The solid portion was elevated to a truck which took the solids to a covered compost area next to the processing building. Liquid from the separator flowed to another pit. From there a fraction of the liquid was pumped to a modified stainless steel bulk milk tank for heating. The influent was heated externally to eliminate the need for an internal heating system. Since the study was started, a second heater, a shell & tube design, was added to assist in heating the influent. When each batch was heated to the desired temperature the heated influent flowed by gravity to the digester. Because of the batch process the mass flow of influent to the digester was well documented. The separated liquid that was not sent to the digester flowed to a long-term storage pond as did the digester effluent. With this arrangement there was no way to quantify the amount of manure flowing from the freestall barn.

Copper sulfate [$CuSO_4 \bullet 5H_2O$] was used in the cow foot bath. All of this sulfur would find its way into the manure leaving the freestall barns.

All the biogas flowed through a *Roots* temperature compensated meter. There is no flare. The biogas was piped to a boiler near the milking center on the west side of the freestall barns. Hot water from the boiler was circulated back to the manure processing building for heating the influent. The biogas meter was modified with two "Pete's Plugs" which permitted the insertion of a bimetal stem thermometer to monitor gas temperature and an adaptor so that gas pressure at the meter. An analog pressure gage made by *Dwyer Instrument, Inc.* was installed near the gas meter.

Two tests were conducted during this study, a 24 hr and a 30 day. These tests were intended to characterize the flow of sulfur to the engines on farms with digesters.

Section 2

RESULTS – 24 HOUR TEST, APRIL 10-11, 2007

Three times during the 24 hr test the biogas was tested for carbon dioxide and hydrogen sulfide. The test for hydrogen sulfide was run with *Gastec* gas tubes and for carbon dioxide *Gastec* tubes and a *Bacharach* unit were used. Table 2-1 gives the results of these tests.

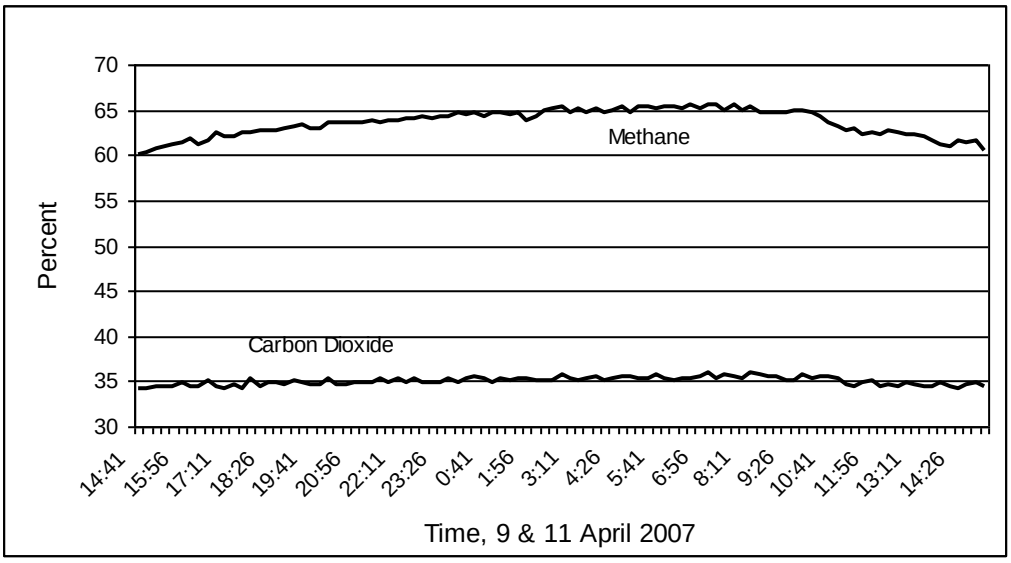
Table 2-1. Concentration of Carbon Dioxide and Hydrogen Sulfide.

Test Number	CO2		H2S
	Tubes, %	Bacharach, %	
No. 1	34	33	7200
	34.5	30	7200
		32	7000
No. 2	36	32	7500
	36	33	7800
		32	7600
No. 3	36	33	7200
	36	33	7500
		33	7600
Average	35.4	32	7400
Standard Dev.	0.92	1.00	260
Confidence Int ±	0.25	0.2	58.4

The concentration of the carbon dioxide as measured with the Gastec tubes was 35.4 ± 0.25, a range from 35.2 to 35.6%. The results from the tests with the Bacharach unit showed an average of 32% with a confidence interval of 0.2, producing a range of 31.8 to 32.2, lower than the test results from the tubes.

During the 24 hr test the carbon dioxide and methane were measured every 15 minutes with a *GEM 2000* instrument. The results of these tests are shown in Figure 2-1. The value of methane varied 5.5% during the 24 hr period even though the digester is fed several time throughout the 24 hours. At the same time the carbon dioxide varied less than 2%. Carbon dioxide plus methane was low at the beginning of the test, 94% and then reached a maximum of 101% at about 8:00 am.

Figure 2-1. Methane and Carbon Dioxide Concentration is Biogas.



The results of a statistical analysis of the 24 hr data are shown in Table 2-2.

Table 2-2. Statistical Analysis of 24 Hour Data at EL-VI Farms.

Parameter	Average	Std Deviation	Confidence Interval
Methane	63.6	0.15	0.29
Carbon Dioxide	35.0	0.43	0.086

The three methods for analyzing for CO2 and CH4 were compared; gas tubes, Bacharach and GEM 2000. The results are shown in Table 2-3. The GEM 2000 measures the gases in terms of a dry biogas. The sum of CH_4 and CO_2 was 96.3% implying that there was 3.7% trace gases. The gas tubes and Bacharach unit refer to a wet biogas. In-other-words, for gas tubes and Bacharach unit the biogas is made

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

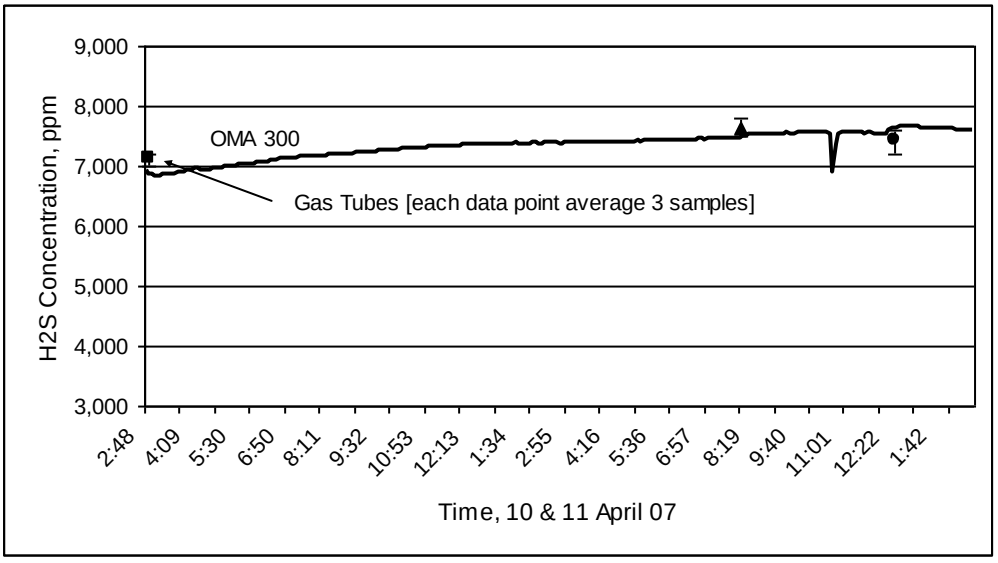
	CO_2 %	CH_4 %		
	Measured	(100 - CO_2)		
GEM2000	35.0		61.3	*
Gas Tubes (24-hr) [9 samples, Dave L.]	35.4	64.6	62.3	**
Bacharach (24-hr) [9 samples, Dave L.]	32.3	67.7	65.4	**
Bacharach (30-day) [180 samples, operator]	32.2	67.8	65.5	**

* Measured directly
**based on avg biogas temp 67°F with 2.3% water vapor (table)
methane = 100 - CO_2 - water vapor

up of CO_2, CH_4, water vapor plus trace gases (ignored here). Determining the percent methane is generally done by measuring the percent carbon dioxide with a Bacharach unit and subtracting that value from 100. This approach will always give elevated values for percent methane because it ignores the water vapor.

During the 24 hour test the biogas was tested for hydrogen sulfide using an OMA 300 instrument. This unit samples the biogas every 5 minutes. The results of this test are shown in Figure 2-2. Also shown in Figure 2-2 are the results of tests done with gas tubes. The dip in concentration at 10:40 was due to a hose being disconnected to remove condensation.

Figure 2-2. Results of Test for Hydrogen Sulfide at EL-VI Farms.



Three times during the 24 hr period tests were made for H_2S with three replicates. The average of the three tests is shown along with an error bar for the three tests. These tests showed an increase in the

concentration of H_2S during the test, in agreement with the OMA 300 results. There is no explanation for the increase in concentration over the 24 hr period. All the tests showed this increase regardless of when the test was started during the 24 hour period.

The results of three tests conducted on the concentration of hydrogen sulfide in the biogas at EL-VI Farms are shown in Table 2-4. The tests run during the same 24 hr period showed similar results, average and standard deviation. The magnitude of the confidence interval is highly dependent on the number of samples. One would expect the standard deviation to be greater over a 30 day period and a 24 hr period.

Table 2-4. Comparison of Various Tests for Hydrogen Sulfide.

Test	No. Samples	Average	Std Deviation	Confidence Interval
OMA 300/24 hr test	284	7,300	210	25
Gas tubes/24 hr test	9	7,400	260	170
Gas tubes/30 day test*	178	6,700	510	70

* described later

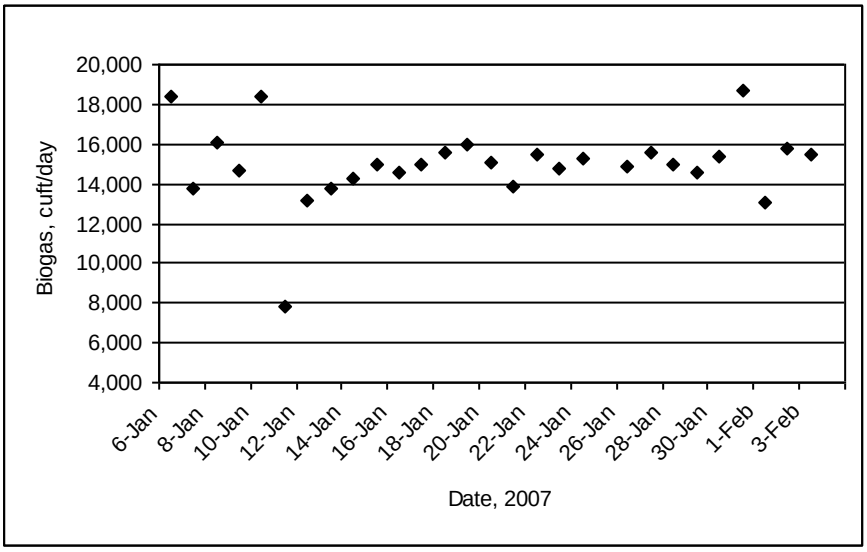
Section 3

RESULTS – 30 DAY TEST, JANUARY 6 to FEBRUARY 4, 2007

During the 30 day test the operator recorded the following data three times per day [morning, noon and evening]: biogas temperature and pressure at meter and the meter reading. At these times the biogas was samples twice (2) for carbon dioxide using a Bacharach unit and for hydrogen sulfide using gas tubes. Raw data is listed in the Appendix, Table A-1.

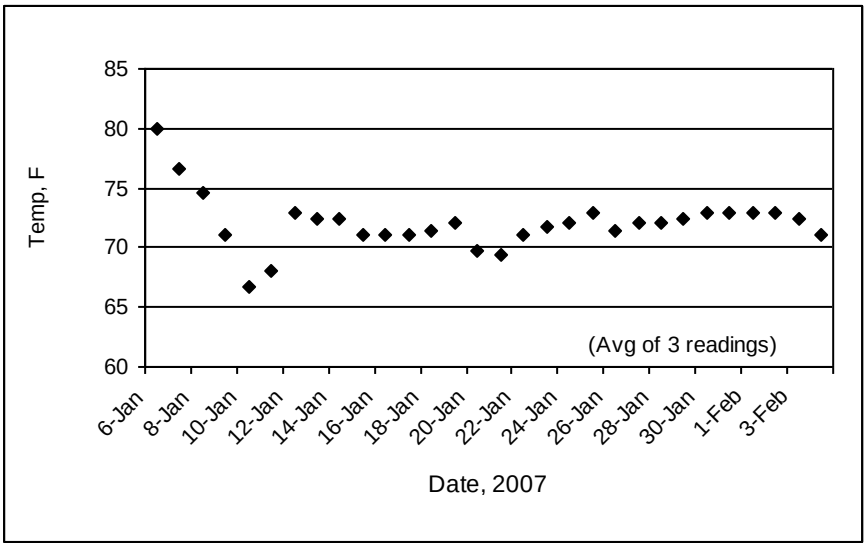
The daily production of biogas during the 30 day test is shown in Figure 3-1. The average daily production was 14,700 ft^3 with a maximum of 18,700 and a minimum of 7,800 ft^3. Some of the variation in daily gas production was due to the slight variations when readings were taken. Comments made on days 4, 5 and 6 showed problems with the blower and feed pump.

Figure 3-1. Biogas Production at EL-VI Farms During 30 Day Test.



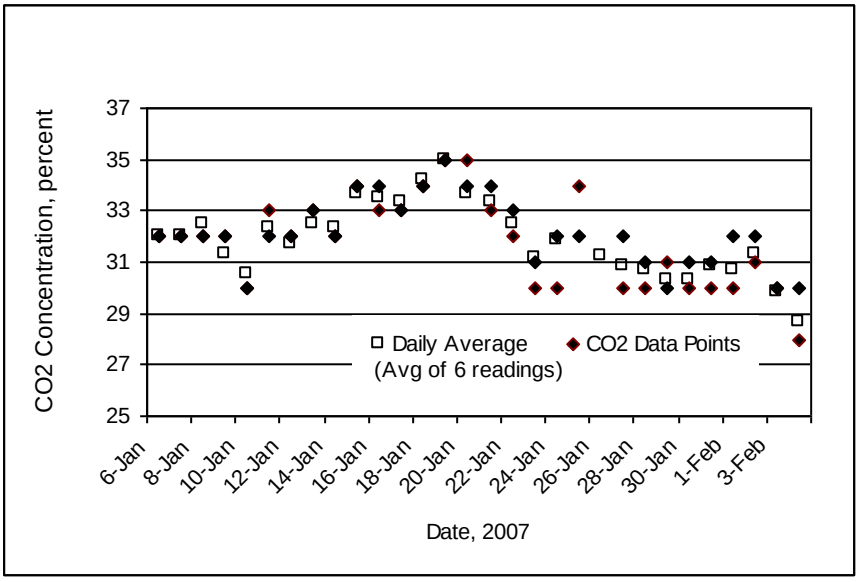
The average daily temperature of the biogas at the meter is plotted in Figure 3-2. The temperature of the biogas at the meter varied more than expected during the 30 day test. The temperature of the biogas is a function of the temperature of digester liquid and perhaps to a lesser degree the outdoor temperature since the digester has a hard cover. A note was made that the heat exchanger was cleaned on day 5 when the temperature of the biogas was declining. The gas production was also decreasing.

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



The level of carbon dioxide in the biogas was measured with a Bacharach unit by the operator. There were 178 samples analyzed, 6 samples per day (2 missing). The concentration of carbon dioxide is plotted in Figure 3-3, daily average in hollow squares and individual data points. [There are not 178 data points (diamonds) in Figure 3-3 because of the arrangement of the spreadsheet.] There were no indications as to why the level of carbon dioxide varied over the 30 days. The production of CO_2, being an indication of biological activity, would indicate that the digester is fed irregularly or the digester temperature was not "constant".

Figure 3-3. Concentration of Carbon Dioxide Measured with Bacharach Unit, 30 Day Test.



However with the mass in the digester, there is considerable "buffer" to changes. The concentration of hydrogen sulfide also varied considerably over the 30 days. The concentrations are plotted in Figure 3-4.

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

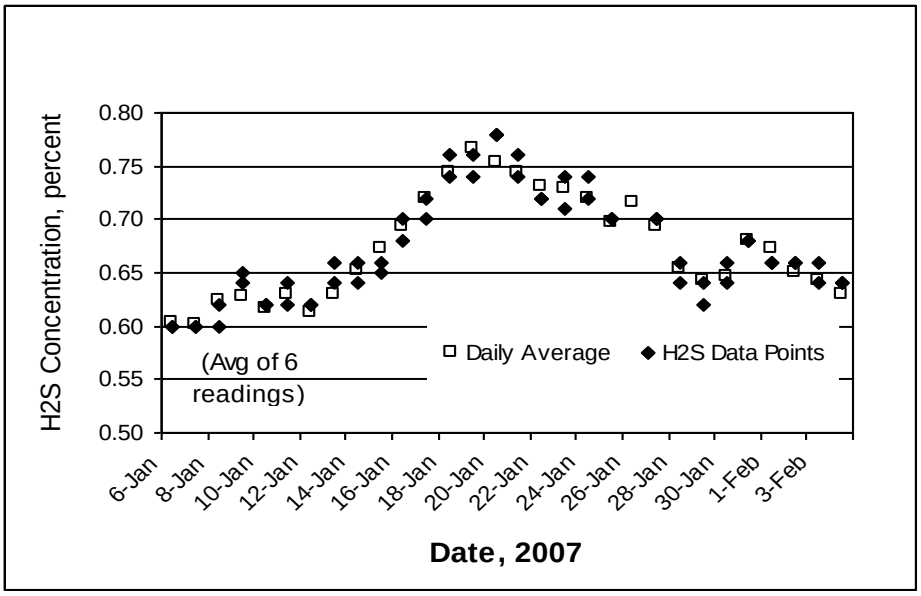


Table 3-1 below lists the average values for each parameter along with standard deviation, confidence intervals and the number of raw data point.

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

	Biogas at Meter					
	Temp	Press.	Flow	H_2S	CO_2	Influent
	° F	(in water)	cu ft/day	%	%	gal/day
average	72.0	6.1	15,000	0.67	31.9	7,700
Standard Dev.	2.67	5.10	1,971	0.051	1.55	981
confidence Int ±	0.55	1.05	730	0.007	0.23	357
(# of samples)	90	90	28	178	174	29

Some of variation in the daily production of biogas and perhaps the concentration of CO_2 and H_2S may be due to the apparent variation in the amount of influent added to the digester each day. This was discussed earlier. With an HRT of 30 days, the delayed impact of changes in amount of influent is unknown.

Section 4
MASS FLOW OF SULFUR

The flow of sulfur through the manure handling system at EL-VI Farms was incomplete because not all the manure was fed to the digester. As discussed earlier, all the manure was delivered to the separator and only a fraction of the separated liquid being fed to the digester.

TOTAL MIXED RATION

The sulfur at the EL-VI Farms originates with the TMR (total mixed ration), drinking water and the copper sulfate in the foot bath. There are three groups of cows in the freestall barns; milking, close-up and far-out each receiving a unique TMR. Table 4-1 lists these three groups along with the amount of TMR feed to each group and the sulfur content of this TMR. The TMR fed to the animals is weighed and the TMR not eaten by the cows is also weighed. The total sulfur in the TMR averaged 97.5 lbs/day.

Table 4-1. Sulfur in TMR at EL-VI Farms.

	Far Out Group				
Date	lbs/day Delivered	lbs/day consumed (95%)	Sample	S % (as fed)	lbs S/day
1/5/2007	3,600	3,420	EVFO	0.07	2.39
1/25/2007	3,660	3,477	EVFO1 EVFO2	0.07 0.07	2.43
3/27/2007	3,890	3,696	EVFO1 EVFO2	0.09 0.09	3.13
		Average		0.083	**2.7**
		Standard Dev			0.41
		Confidence Integral ±			0.47

Close Up Group					
Date	lbs	lbs	Sample	S % (as fed)	lbs S/day
1/5/2007	9,080	8,626	EVCU	0.09	7.76
1/25/2007	7,500	7,125	EVCU1 EVCU2	0.07 0.06	4.63
3/27/2007	8,655	8,222	EVCU1 EVCU2	0.09 0.07	6.58
		Average		0.073	**6.72**
		Standard Dev			1.58
		Confidence Integral ±			1.79

Milking Herd Group					
Date	lbs/day Delivered	lbs/day consumed (97.5%)	Sample	S % (as fed)	lbs S/day
1/5/2007	98,300	95,843	EVMH	0.09	86.26
1/25/2007	99,000	96,525	EVMR1 EVMR2	0.09 0.1	91.70
3/27/2007	103,865	101,268	EVMR1 EVMR2	0.09 0.09	91.14
		Average		0.093	**88.1**
		Standard Dev			3.0
		Confidence Integral ±			3.4

Total sulfur **97.5** lbs/day

DRINKING WATER

The concentration of sulfur in the drinking water was measured. The average concentration was 285 mg/l or ppm. These results are presented in Table 4-2. The number of animals was 1,174. Using the American Society of Agricultural & Biological Engineers (ASABE) equations for manure production, there were

1,009 equivalent milking cows. The water consumption was assumed to be 25 gallons per cow-day or 25,000 gal/day. The sulfur contributed by the drinking water was 19.9 lb/day.

Table 4-2. Sulfur in Drinking Water at EL-VI Farms.

DRINKING WATER				
Date	Sample	mg Sulfate/L	lbs S/1000 gal	lbs S/day
1/5/2007	EVWater1	288	0.81	20.16
1/25/2007	EVWater1	288	0.81	20.16
	EVWater2	280	0.78	19.60
3/27/2007	EVWater1	283	0.79	19.81
		average	0.797	**19.9**
		Standard Dev		0.28
		Confidence Int ±		0.31

conversion factor; mg sulfate/l to lb sulfur/1000gal 0.0028
Water Consumption, 25,000 gal/day (assumed)

FOOT BATH

Copper sulfate [$CuSO_4 \bullet 5H_2O$] is used in the foot bath. The usage averages 40 pounds per day. The molecular weight of copper sulfate is 249.5 while the sulfur is 32. The sulfur accounts for 12.8% of the total weight. Combining this information, 5.1 lbs of sulfur are added to the manure each day.

MANURE

The assumption was made that nearly all outputs of sulfur from the dairy barn will be in the manure and milk. The characteristics of the manure, digester influent and digester effluent are given in Table 4-3.

Table 4-3. Properties of the Digester Influent and Effluent at EL-VI Farms.

	Influent (separated liquid)			Effluent		
Date	Sample	% TS	% S	Sample	% TS	% S
1/5/2007	EVI1	5.23	0.045	EVE1	3.85	0.03
	EVI2	5.45	0.045	EVE2	4.10	0.025
1/25/07	EVDI1	5.08	0.035	EVDE1	4.11	0.03
	EVDI2	5.09	0.04	EVDE2	3.98	0.03
3/27/2007	EVDI1	4.81	0.025	EVDE1	4.04	0.03
	EVDI2	5.08	0.04	EVDE2	3.80	0.03
	EVDI3	4.86	0.04	EVDE3	3.76	0.01*
	Average	5.09	0.0386		3.95	0.03
	Stand Dev	0.216	0.007		0.130	0.002
	Conf Int ±	0.160	0.005		0.096	0.002

*value discarded

Raw Manure to Separator			Separated Solids		
Sample	lbs S/ 1000 gal	S lbs/day	Sample	%	S lbs/day
EVR1	3.4	35.3	EVSS	0.06	13.43
EVRM1	3.7	38.4	EFSS1	0.05	11.19
EVRM2	3.6	37.3	EFSS2	0.06	13.43
		37.0			**12.7**
		1.6			1.3
		1.8			1.5

The flow of separated liquid to the digester was recorded for each day during the 30 day test. The average flow was 7,700 gal/day as given in Table 3-1. Using the volume and characteristics of biogas and the concentration of total solids in the influent and effluent, the mass flow of manure in and out of the digester and the "loss" of sulfur in the digester is given in Table 4-4. The calculated influent flow was 7,870 gpd and an effluent flow of 7,760 gpd. This agrees favorably with the measure amount given above. The loss of sulfur during digestion of a portion of the separated liquid was calculated to be 7.0 lb S/day. For the separated liquid influent with a sulfur content of 27.5 lb/day, the sulfur loss was 26 % of the input.

Table 4-4. Calculation of Sulfur "Lost" During Digestion

Vo =	15,024	ft3/day, dry			Volume of biogas
CH4 =	0.644				Concentration of methane
CO2 =	0.322				Concentration of carbon dioxide
IPTS =	5.09	%			Percent total solids in influent
EPTS =	3.85	%			Percent total solids in effluent
IPS =	0.039	%			Percent sulfur in influent
EPS =	0.029	%			Percent sulfur in effluent
B =	1,025	lb biogas/day dry			Weight of biogas
T =	72	F			Biogas temperature at meter
T =	22.2	C			
bVS =	923	90%*			Volatile solids consumed
bW =	103	10%*			Mass of water consumed
Dw =	0.00104	lb water/ft3 biogas			
We =	15.7	lb water/day			Water in saturated biogas
ITS =	0.0509	ITW=	0.949		Total solids in influent
ETS =	0.0385	ETW=	0.962		Total solids in effluent
ITM =	71,195	lb/day	8,376	gpd	Total mass of influent
ETM =	70,154	lb/day	8,253	gpd	Total mass of effluent
Δ TM =					
Δ	923	lb/day			Total solids "lost"
Sulfur In	27.5	lb/day			Sulfur in influent
Sulfur Out	20.50	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.

MILK

The literature stated that the sulfur (S) content of milk is 0.03%. The data needed to calculate the sulfur in the milk is shown in Table 4-5. The output of sulfur in the milk was 18.5 lb/day.

Table 4-5. Sulfur in Milk at EL-VI Farms.

RHA lbs/cow-yr	lbs/cow day	# of Cow	Sulfur* %	S lbs S/cow day	Total lbs S/day
25,000	68.5	900	0.03	0.021	**18.5**

* based on data from Trace Minerals Research

BIOGAS

Analysis of the biogas was done to compute the amount of sulfur in the gas in terms of pounds/day. This analysis is shown in Table 4-6. The weight of sulfur in the biogas averaged 8.3 lb/day over the 30 day period.

Table 4-6. Analysis of Biogas at EL-VI Farms.

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

Input Data - yellow area		
Biogas temp @ meter	72.0	F
Pressure in gas line	5.8	in H_2O
Biogas flow (meter)	15,000	cuft/day
Elevation of meter	541	ft
H_2S (dry basis)	6,730	ppm
CO_2 (dry basis)	31.9	%
P_{elev}	14.409	psia
P_m	0.210	psig
P_{line}	14.619	psia
Volume of water vapor	2.63	%
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	72.0	F	15,429	cuft/day
Biogas flow (dry) at	72.0	F	15,024	cuft/day
Concentration of methane, CH_4			67.4	%
Volume of CH_4 @	72.0	F	10,130	ft^3/day
Volume of CH_4 @ STP			9,319	ft^3/day
Weight of CH_4			**416**	**lb/day**
HEATING VALUE (low)			8,943,626	Btu/day
			372,651	Btu/hr
Raw biogas			580	Btu/ft^3
			109	kW
Volume of H_2S @	72.0	F	101.1	ft^3/day
Volume of H_2S @ STP			93.0	ft^3/day
Weight of H_2S			8.8	lb/day
Weight of Sulfur (S)			**8.3**	**lb/day**
Volume of water vapor	72.0	F	405	ft^3/day
Weight of water vapor			0.0465	lb/ft^3
Water			19	lb/day
			2.3	gal/day

A summary of the sulfur flow at the EL-VI Farm is given in Table 4-7. The digester influent contained 26% of the sulfur in the raw manure from the barn. There was a discrepancy between the calculate loss of sulfur in the digester and the sulfur in the biogas. The biogas contained 8.3 lb S/day while the change in sulfur within the digester was 7.0 lb S/day, a difference of 1.3 lb S/day or the sulfur in the biogas was 19% greater than the change in sulfur within the digester. This relationship held for all the farms except one. For that farm the total production of biogas was estimated based on data taken several years ago when more food waste was feed.

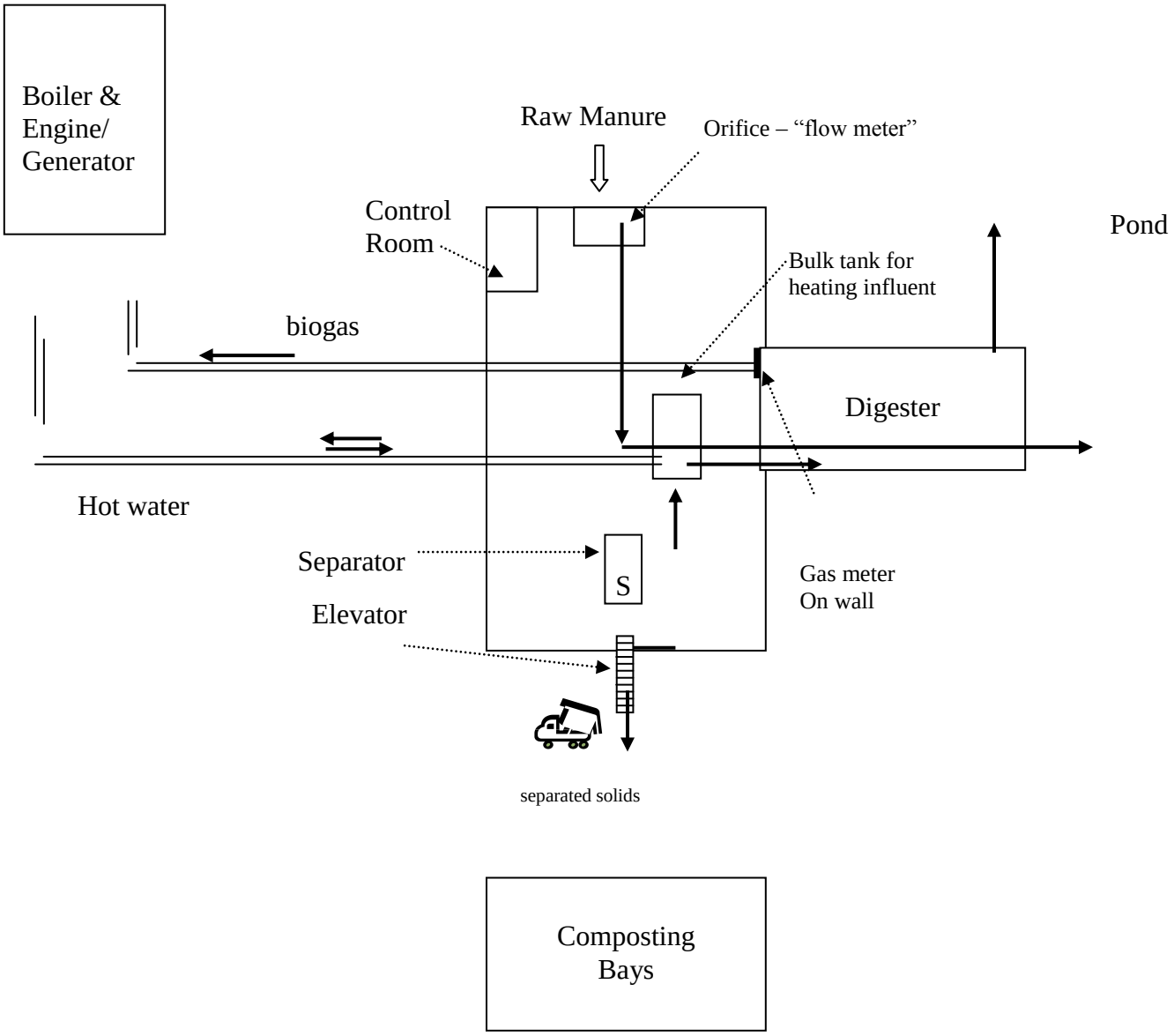
Table 4-7. Summary of Sulfur Flow at EL-VI Farms.

Parameter	Value	Units & Comments
Cow Equivalents*	948	
Sulfur to cow: TMR	97.5	lb S/day
Drinking water	19.9	"
Total	117.4	"
Milk	- 18.5	"
Manure from cow	98.9	"
Copper sulfate	+ 5.1	"
Sulfur from Barn: Manure	104	"
Digester influent	27.5	" (separated liquid)
Digester effluent	20.5	"
Change	7.0	"
Biogas	8.3	"
Discrepancy	1.3	"
Raw Manure	37.0	
Separated Solids	12.7	
* based on ASABE equations, see Appendix, Table A-2		

This summary is presented in a Mass Flow Diagram in the Appendix, Figure A-2.

APPENDIX

Figure A-1. Schematic Drawing of the EL-VI Farms.



Not to scale

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

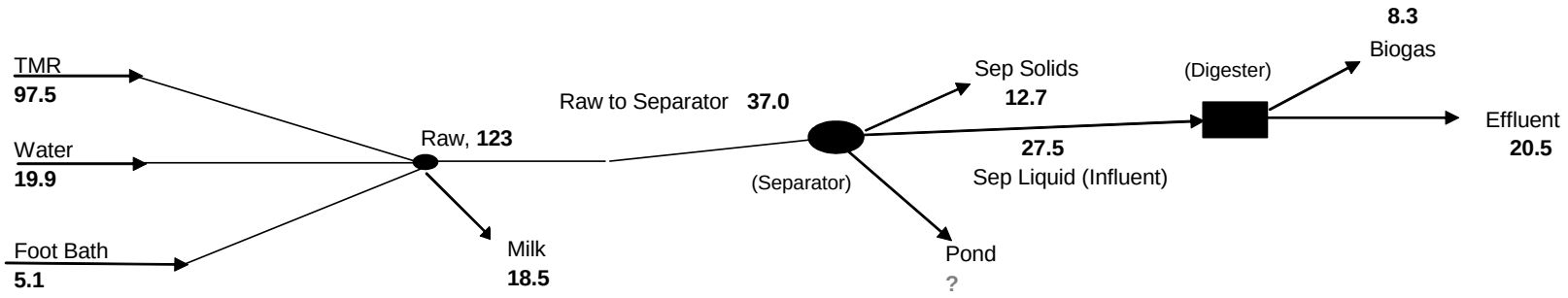


Table A-1. 30-Hour Test Data, EL-VI Farms.

Day #	Date 2007	Time	Biogas Meters				Biogas/ day	Manure, Gal	H2S ppm, %		Avg/ day	CO2 ppm, %		Average	Comments
			Temp	Temp Avg	Press	Reading			#1	#2		#1	#2		
1	6-Jan	7:45am	82		41.5	83,511			0.6	0.6		32	32		
		2:00pm	80		15	83,558	18,400	8,250	0.6	0.6		32	32		
		10:00pm	78	80	13.5	83,610			0.6	0.62	0.603	32	32	32.00	
2	7-Jan	8:00am	76		13	83,695			0.6	0.6		32	32		
		2:30pm	77		13	83,719	13,800	7,350	0.6	0.61		32	32		
		10:00pm	77	76.7	13	83,782			0.6	0.6	0.602	32	32	32.00	
3	8-Jan	7:30am	77		13	83,833			0.62	0.6		32	32		
		1:30pm	74		13	83,872	16,100	7,050	0.62	0.64		33	33		
		8:00pm	73	74.7	14	83,917			0.62	0.64	0.623	32	33	32.50	
4	9-Jan	8:00am	72		12.5	83,994			0.65	0.64		32	32		
		3:00pm	70		11	84,040	14,700	6,000	0.62	0.62		32	31		
		10:00pm	71	71.0	11	84,082			0.62	0.62	0.628	31	30	31.33	
5	10-Jan	7:45am	71		11	84,141			0.62	0.62		30	30		Clean heat tank . No feed
		3:00pm	66		6	84,181	18,400	6,900	0.64	0.62		31	31		several hours. Turn off
		10:00pm	63	66.7	11	84,207			0.6	0.6	0.617	30	31	30.50	blower, turn on blower
6	11-Jan	7:45am	63		5	84,325			0.64	0.62		33	32		Blower off
		3:00pm	70		2.5	84,325	7,800		0.64	0.62		33	32		
		10:00pm	71	68.0	3	84,346			0.64	0.62	0.630	32	32	32.33	
7	12-Jan	7:30am	72		3.5	84,403			0.62	0.62		32	32		Digester feed pump
		2:00pm	73		3	84,440	13,200	5,400	0.6	0.62		31	32		disabled 6 hrs
		10:00pm	74	73.0	6.4	84,483			0.6	0.62	0.613	31	32	31.67	
8	13-Jan	8:00am	73		7.5	84,535			0.64	0.66		33	33		
		2:00pm	69		2	84,568	13,800	7,050	0.64	0.64		32	32		
		10:00pm	75	72.3	3	84,612			0.6	0.6	0.630	32	33	32.50	
9	14-Jan	8:00am	75		3	84,673			0.66	0.64		32	32		
		4:30pm	71		4	84,722	14,300	7,050	0.66	0.67		33	32		
		10:00pm	71	72.3	4	84,754			0.64	0.64	0.652	33	32	32.33	
10	15-Jan	8:00am	72		4	84,816			0.66	0.65		34	34		
		2:00pm	70		4	84,852	15,000	8,580	0.7	0.7		33	33		
		10:30pm	71	71.0	5	84,908			0.66	0.66	0.672	34	34	33.67	
11	16-Jan	8:00am	71		4	84,966			0.7	0.68		33	34		
		1:30pm	71		3	85,001	14,600	8,250	0.7	0.68		33	34		
		10:00pm	71	71.0	3.5	85,053			0.7	0.7	0.693	34	33	33.50	

Table A-1. 30-Hour Test Data, EL-VI Farms, Cont.

Day #	Date 2007	Time	Biogas Meters Temp	Temp Avg	Press	Reading	Biogas/ day	Manure, Gal	H2S ppm, % #1	H2S ppm, % #2	Avg/ day	CO2 ppm, % #1	CO2 ppm, % #2	Average	Comments
12	17-Jan	8:00am	71		4	85,112			0.7	0.72		33	33		Change Fyrite
		3:00pm	71		4	85,151	15,000	9,450	0.7	0.68		33	33		
		9:00pm	71	71.0	4	85,196			0.74	0.78	0.720	34	34	33.33	
13	18-Jan	8:00am	71		4	85,262			0.74	0.76		34	34		
		2:00pm	71		4	85,300	15,600	8,850	0.76	0.74		35	34		
		10:00pm	72	71.3	7	85,352			0.72	0.74	0.743	34	34	34.17	
14	19-Jan	8:00am	72		5	85,418			0.74	0.76		35	35		
		2:00pm	72		5	85,454	16,000	9,600	0.76	0.76		34	35		
		10:00pm	72	72.0	5	85,512			0.8	0.78	0.767	35	36	35.00	
15	20-Jan	8:00am	71		6	85,578			0.78	0.78		35	34		Turn off generator,
		2:30pm	68		13.5	85,620	15,100	6,300	0.76	0.76		33	33		all gas to boiler
		10:00pm	70	69.7	12	85,666			0.72	0.72	0.753	33	34	33.67	
16	21-Jan	8:00am	69		12	85,729			0.76	0.74		33	34		Turn on generator,
		3:00pm	69		11	85,772	13,900	7,920	0.76	0.74		33	34		gas to both
		9:00pm	70	69.3	4.5	85,807			0.72	0.74	0.743	32	34	33.33	turn off blower
17	22-Jan	7:34am	71		5.5	85,868			0.72	0.72		32	33		
		2:00pm	71		4.5	85,906	15,500	8,250	0.72	0.74		32	33		
		9:50pm	71	71.0	5	85,954			0.74	0.74	0.730	32	33	32.50	
18	23-Jan	8:15am	72		5	86,023			0.74	0.71		30	31		
		2:00pm	71		4.5	86,080	14,800	8,550	0.74	0.76		31	32		
		9:50pm	72	71.7	4.5	86,107			0.68	0.74	0.728	31	32	31.17	
19	24-Jan	7:45am	72		4.5	86,171			0.72	0.74		30	32		
		2:00pm	72		4.5	86,210	15,300	8,100	0.72	0.74		31	32		
		10:00pm	72	72.0	4.5	86,261			0.7	0.7	0.720	34	32	31.83	
20	25-Jan	7:45am	72		4	86,324			0.70	0.70		34	32		
		2:00pm	72		4.5	19		8,100	0.70	0.70					
		10:00pm	75	73.0	4.5	69			0.68	0.70	0.697				
21	26-Jan	8:15am	71		5	136									
		4:00pm	70		4	190	14,900	8,550	0.72	0.74		31	32		
		9:50pm	73	71.3	4	219			0.70	0.70	0.715	30	32	31.25	
22	27-Jan	7:45am	73		4.5	285			0.7	0.7		30	32		
		4:00pm	72		4.5	343	15,600	7,500	0.68	0.72		32	30		
		10:00pm	71	72.0	3.5	375			0.68	0.68	0.693	31	30	30.83	
23	28-Jan	8:00am	72		3.5	441			0.64	0.66		30	31		
		3:00pm	72		4	491	15,000	7,920	0.66	0.66		31	31		
		10:00pm	72	72.0	3.5	535			0.66	0.64	0.653	30	31	30.67	

Table A-1. 30-Hour Test Data, EL-VI Farms, Cont.

Day #	Date 2007	Time	Biogas Meters Temp	Temp Avg	Press	Reading	Biogas/ day	Manure, Gal	H2S ppm, % #1	H2S ppm, % #2	Avg/ day	CO2 ppm, % #1	CO2 ppm, % #2	Average	Comments
24	29-Jan	8:00am	72		3	591			0.64	0.62		31	30		
		2:00pm	72		3	628	14,600	7,200	0.64	0.64		31	30		
		9:30pm	73	72.3	3	613			0.66	0.66	0.643	30	30	30.33	
25	30-Jan	7:45am	73		3	737			0.64	0.66		30	31		
		2:00pm	73		3.5	777	15,400	7,200	0.64	0.66		30	30		
		10:00pm	73	73.0	4	826			0.64	0.64	0.647	30	31	30.33	
26	31-Jan	8:15am	73		3.5	891			0.68	0.68		30	31		
		4:00pm	73		3.5	931	18,700	8,700	0.68	0.68		32	31		
		9:50pm	73	73.0	4	982			0.68	0.68	0.680	30	31	30.83	
27	1-Feb	7:45am	73		4	1,078			0.66	0.66		30	32		
		4:00pm	73		4	1,087	13,100	7,650	0.66	0.68		31	30		
		10:00pm	73	73.0	4	1,141			0.68	0.7	0.673	30	31	30.67	
28	2-Feb	7:30am	73		3.5	1,209			0.66	0.66		31	32		
		4:00pm	73		3.5	1,265	15,800	6,900	0.64	0.66		30	31		
		9:30pm	73	73.0	3.5	1,303			0.62	0.66	0.650	32	32	31.33	
29	3-Feb	7:45am	72		4	1,367			0.64	0.66		30	30		
		3:00pm	72		4	1,413	15,500	6,900	0.64	0.64		30	31		
		8:30pm	73	72.3	4.5	1,443			0.64	0.64	0.643	29	29	29.83	
30	4-Feb	7:30am	72		4	1,522			0.64	0.64		28	30		
		2:30pm	70		4	1,566		7,050	0.62	0.64		28	28		
		9:00pm	71	71.0	4	1,609			0.62	0.62	0.630	28	30	28.67	

Average	72		6.1	14,677	14,996	7,675		0.673		31.89
Standard Dev.	2.67		5.10		1,971	981		0.051		1.55
confidence Int ±	0.55		1.05		730	357		0.01		0.23
(# of samples)	90		90		28	29		178		174

Table A2. Cow Manure Production, Based on ASABE Equations.

		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	68.5	900	139.0	125,126	17.7	15,942	12.7%	5,818,913
Dry Cows, Body Weight	1500	140	80.9	11,332	10.1	1,411	12.5%	308,998
Heifers, average Body Weight	800	0	53.5	0	7.0	0	13.0%	0
Total				136,458		17,353	12.7%	6,127,911
				17,057	gal/day			

Milking Center Wastewater		Gal/cow-day	Gal/day	Lb/day		
		8	7,200	60,048		
	Total			196,506	23675	gal/day

*Rolling Herd Average, lb/cow-yr	25,000		
Days per year	365	equivalent cows	948
Days in freestall per year	365		
Days - freestall & corral	0	Total Solids Content, manure	0.127
Days - corral	0	Total Solids Content, all	0.088
Percent of Manure Collected			
Freestall	100%		
Freestall & corral	80%		
Corral	60%		