# CHARACTERIZATION OF SULFUR FLOWS IN FARM DIGESTERS at AA DAIRY

Prepared for

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## Section 1
## DESCRIPTION

AA Dairy is located near Candor, NY. A schematic of the layout of the barns, reception pit, digester, separator and engine/generator room is attached in the Appendix, Figure A-1. Raw manure from approximately 430 lactating cows, housed in a freestall barn was added to the digester. The digester was originally designed with an HRT (hydraulic retention time) of 20 days with an anticipated herd size of some 800 cows. With the current number of cows, the theoretical HRT is near 40 days. Mr. Amen estimates the current HRT to be 30 days due to settled solids. Alley scrapers bring the manure to a central cross alley during this study. The manure from the freestall barn and the holding area flows by gravity to a reception pit [W = 14 ft, L = 44 ft for an area of 616 sq ft (384 gal/inch of depth)]. During this test the distance to the manure surface in the reception pit was always greater than 6 ft which meant the cross alleys to the freestall barn and the holding area would not increase the effective surface area.

Once each day a piston pump moves the manure from this reception pit to the digester. The operation of pump was recorded from 21 Feb to 23 Mar 07. The average pump operation was 201 minutes per day with a range of 78 to 389 minutes per day.

The effluent from the digester is sent to a separator. The solid fraction is piled in windrows and turned to promote heating (composting). A portion of the composted solids are sold. The liquid for the separator is sent to a storage pond for land spreading.

The biogas from the digester is piped directly to a Roots gas meter and then to the engine. The flare was not operative during this test. Prior to testing, temperature compensation (60° F) kits were installed on the *Roots* gas meters at the farm. At the same time, 2 “Pete’s Plugs” were installed in each biogas meter. This permitted the use of a bimetal stem thermometer to monitor the temperature of biogas at the meter and for attaching pressure gages to monitor pressure. An analog pressure gage (*Dwyer Instrument, Inc.*) was installed near the gas meter.

## Section 2

## RESULTS – 24 HOUR TEST, APRIL 9, 2007

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

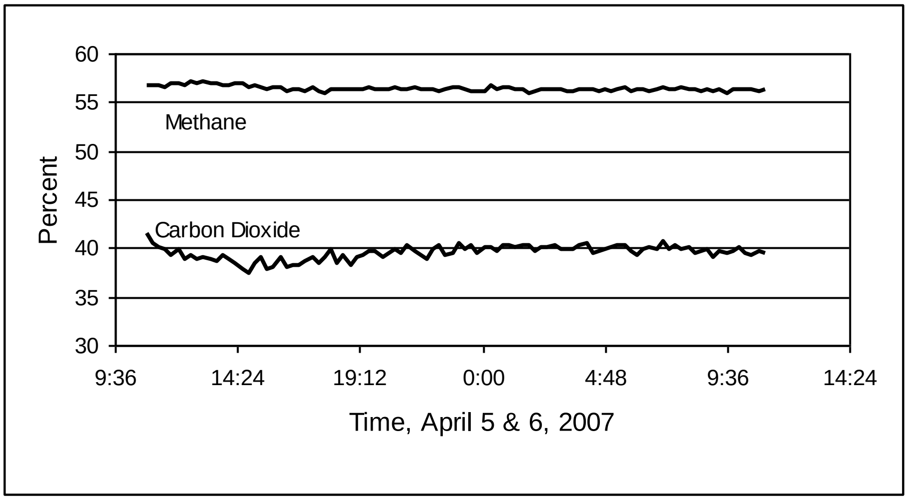
Table 2-1. Concentration of Carbon Dioxide and Hydrogen Sulfide.

| Test Number | $CO_2$ | | $H_2S$ |
|---|---|---|---|
| | Tubes, % | Bacharach, % | |
| No. 1 | 40 | 37.5 | 4,000 |
| | 40 | 37.5 | 4,200 |
| | 40 | 36 | 3,500 |
| No. 2 | 38 | 35 | 3,800 |
| | 38 | 34 | 3,600 |
| | 38.5 | 33 | 4,000 |
| No. 3 | 38 | 36 | 3,800 |
| | 38 | 36 | 4,500 |
| | 38 | 39 | 3,800 |
| Average | 38.7 | 36.0 | 3,900 |
| Standard Dev. | 0.97 | 1.9 | 306 |
| Confidence Int ± | 0.2 | 0.4 | 69 |

The carbon dioxide concentration measured by the gas tubes was 38.7 ± 0.2, with a range of 38.5 to 38.9%. The results from the Bacharach unit had a standard deviation of nearly twice the gas tubes and a confidence interval twice as large. The range of 35.6 to 36.4% was below that for the gas tubes. There seems to be more opportunity for variation with the Bacharach unit than the gas 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 given in Figure 2-1.

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




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

Table 2-2.  Statistical Analysis of 24 Hour Data at AA Dairy.

| Parameter | Average | Std Deviation | Confidence Interval |
|---|---|---|---|
| Methane | 57.4 | 0.3 | 0.06 |
| Carbon Dioxide | 39.1 | 1.0 | 0.19 |

A comparison was done on the three methods of analyzing for $CO_2$ and $CH_4$, the GEM2000, gas tubes and Bacharach unit.   See Table 2-3.  The GEM2000 measures the gases in terms of a dry biogas.  The sum of $CH_4$ and $CO_2$ is 96.5% implies that there was 3.5% trace gases.  The gas tubes and Bacharach unit refer to a wet biogas.  In-other-words, for gas tubes and Bacharach units the biogas is made up of $CO_2$, $CH_4$, water vapor plus the trace gases (ignored here).  Determining the percent methane is generally done by measuring the percent carbon dioxide with a Bacharach unit and then subtracting that value from 100.

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

| | $CO_2$ | $CH_4$ + | $CH_4$ | |
|---|---|---|---|---|
| *GEM2000* (24 hr) 98 samples | 39.1 | | 57.4 | * |
| Gas Tubes [9 samples] | 38.7 | 61.3 | 59.6 | ** |
| Bacharach (24-hr) [9 samples] | 36 | 64 | 62.3 | ** |
| Bacharach (30-day) [180 samples, operator] | 33.1 | 66.9 | 65.2 | ** |

+ Methane by difference, 100 - $CO_2$

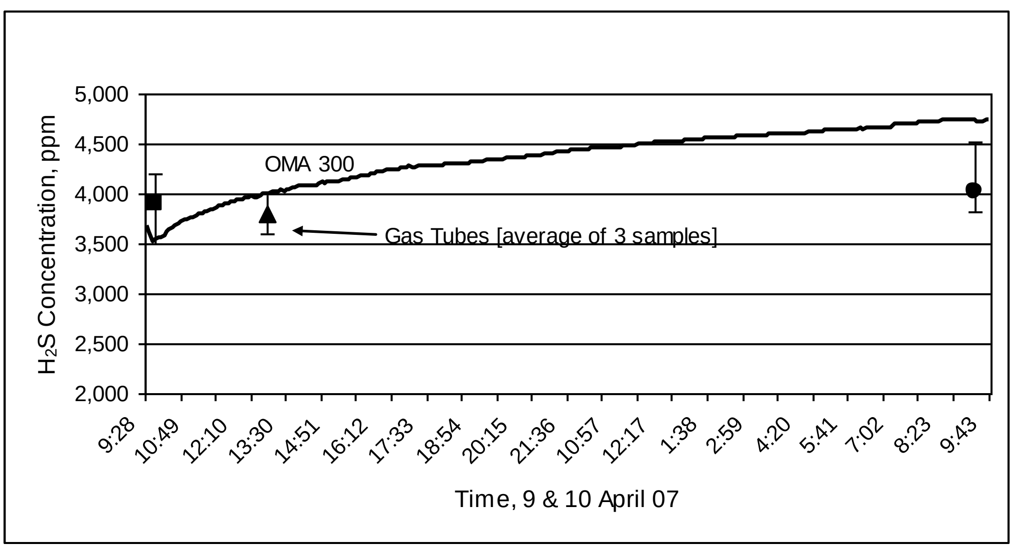
* Measured directly

**Methane calculated based on avg biogas temp 60°F &
1.74 % water vapor (table)
methane = 100-water vapor-CO2

This approach will always give elevated values for percent methane.

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 are the results of three tests during 24 hr period each with three test for hydrogen sulfide using gas tubes. The average value is plotted along with error bars for the three tests.

**Figure 2-2. Results of Test for Hydrogen Sulfide at AA Dairy.**




There is no explanation for the continuous rise in the alleged concentration of $H_2S$ for the OMA-300 other than instrument error. Apparently the instruments need to be blanked every few hours. The average value for $H_2S$ for samples taken during the 24 day test was 3,900 ppm and during the 30 day test (to be discussed later) the average was 4,100 ppm.

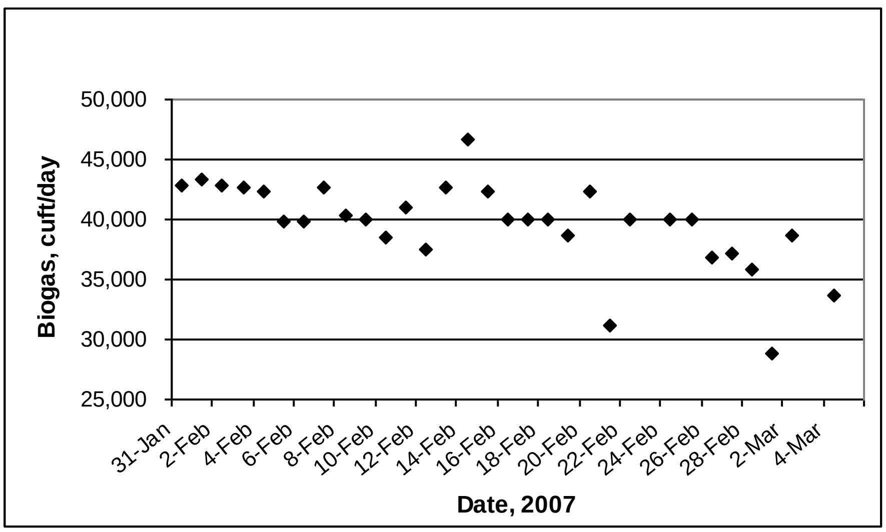
## Section 3

## RESULTS – 30 DAY TEST, JANUARY 31 to MARCH 6, 2007

During the 30 day test the operator recorded the following data. The following items were recorded three times per day: biogas temperature and pressure at meter, reading from biogas meter(s), two samples each for hydrogen sulfide (gas tubes) and carbon dioxide (Bacharach unit). The raw data taken is listed in the Appendix, Table A1.

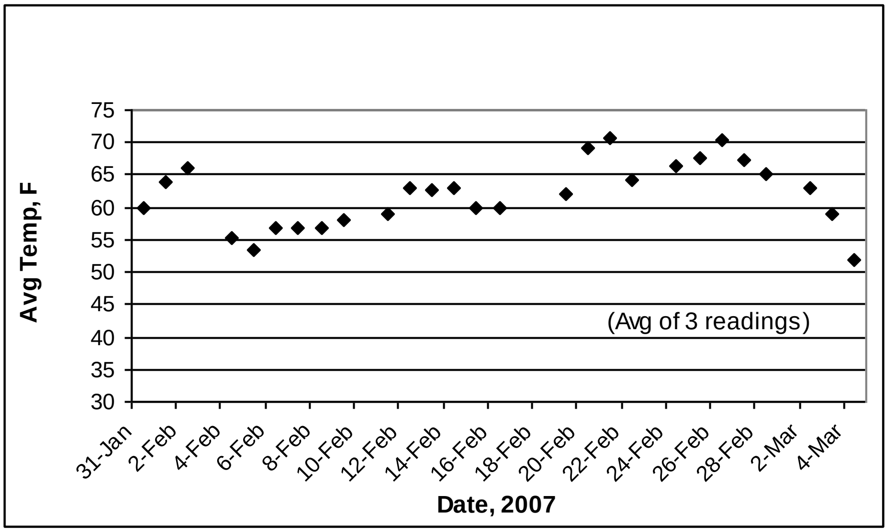
The production of biogas during the "30 day test" (28 days) averaged 39,700 $ft^3$/day with a maximum of 46,600 and a minimum of 28,800. The daily production is plotted in Figure 3-1. The "length of day" varied slightly due to a variation in time when the readings were taken. A comment on the data sheet for March 2 stated "Very little gas – digester bag flat in AM".

**Figure 3-1. Biogas Production at AA Dairy During 30 Day Test.**



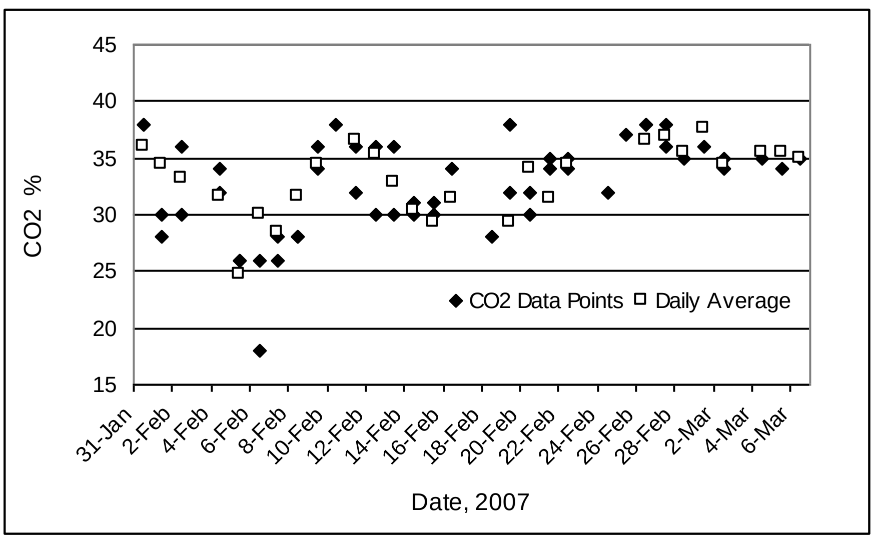

The temperature of the biogas at the meter varied more than expected during the 30 day test. The average daily temperature of the biogas is plotted in Figure 3-2.

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



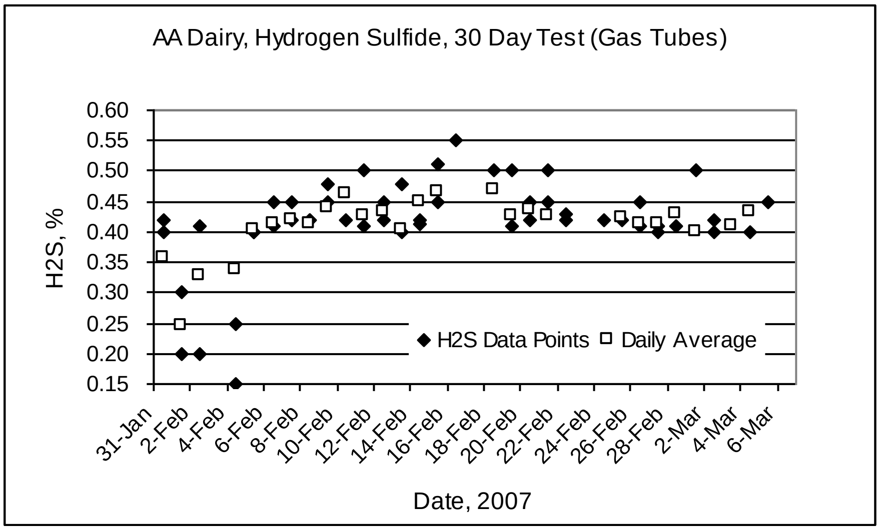

The level of carbon dioxide in the biogas was measured with a Bacharach unit by the operator. There were 144 samples tested out of a possible 168. There are not 144 points shown in Figure 3-3 due to the way the data was arranged in the *excel* File. There were multiple equal values on a given date. There was considerable variation in the concentration during the test period. Some of the variation is due to technique used by the operator. The average $CO_2$ concentration was 33%, 6% below the value from the GEM 2000. The maximum value was 40 (not shown) and a low of 18%. The average concentration for each day is plotted as a hollow square.

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




The hydrogen sulfide in the biogas was tested using gas tubes. Two samples were analyzed three times each day. There were 142 data points. The results of these tests are plotted in Figure 3-4. Again not all points are plotted due to the arrangement of the data in the spreadsheet. The maximum value of 0.55% (5,500 ppm) and minimum value of 0.15% (1,500 ppm) are shown. The average value for all 142 points was 0.41% or 4,100 ppm.

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




The daily average concentrations (an average of up to 6 data points) are plotted in Figure 3-4 as hollow squares.

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 AA Dairy.

| | Temp F | Press. in water | Biogas/day cu ft | H2S % | CO2 % |
|---|---|---|---|---|---|
| Average | 62 | 1.2 | 38,400 | 0.41 | 33 |
| Standard Dev. | 5.1 | 0.58 | 4,400 | 0.06 | 3.9 |
| Confidence Int ± | 1.2 | 0.13 | 1,600 | 0.01 | 0.6 |
| # of samples | 72 | 72 | 33 | 142 | 144 |

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

Samples of 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 by Dairy One, Inc. in Ithaca, NY for total solids and sulfur. The amount of TMR fed to the dairy cows was obtained from the owner for each sampling date. Drinking water was analyzed by Community Science Institute also of Ithaca, NY.

### TOTAL MIXED RATION

The results of the analysis of sulfur in the TMR are shown in Table 4-1. The owner estimated that 6 lb of TMR were not eaten per cow-day. This was taken in account when calculating the pounds of sulfur consumed per day. The TMR samples taken on March 23 had 36% less sulfur than the samples taken in January and February. This was brought to the attention of the owner but as yet no explanation

Table 4-1. Sulfur in TMR at AA Dairy.

| | FEED | | | |
|---|---|---|---|---|
| | TMR for Milking Herd | | | |
| Date | Feed, lbs/day | Sample | % S (as fed) | lbs S/day |
| 1/31/2007 | 40,850 | AAMH1 | 0.12 | 45.92 |
| | | AAMH2 | 0.12 | 45.92 |
| 2/22/2007 | 42,140 | AAMH1 | 0.11 | 42.10 |
| | | AAMH2 | 0.11 | 42.10 |
| 3/23/2007 | 41,000 | AAMH1 | 0.07 | 26.79 |
| | | AAMH2 | 0.08 | 30.62 |
| | | AAMH3 | 0.07 | 26.79 |
| Average | 41,330 | | 0.097 | 37.2 |
| Standard Dev. | | | 0.023 | 8.76 |
| Confidence Int ± | | | 0.017 | 6.49 |

**Total sulfur 37 lbs/day**

for this reduction has been received. Because the first two sample dates were within the 30 day test, the average of these samples (44.0 lb S/day) will be used in calculating sulfur contributed by the TMR.

### DRINKING WATER

Samples of the drinking water were taken on three occasions for analysis for sulfur. The results of these tests are given in Table 4-2. The conversion factor for mg $SO_4$/l to lbs S/1000 gal is 0.0028. The amount of water consumed by the dairy cows was assumed to be 25 gal/cow-day or 10,750 gal/day. Only 0.44 lb S was consumed by the dairy cows in their drinking water.

Table 4-2. Sulfur in Drinking Water at AA Dairy.

| DRINKING WATER | | | | |
|---|---|---|---|---|
| Date | Sample | Sulfate mg/L | Sulfur lbs/1000 gal | lbs S/day |
| 1/15/2007 | AAWater (cow drinking) | 13.8 | 0.039 | 0.41 |
| | *AAWater (milking ctr) | 14.5 | 0.041 | 0.44 |
| 2/21/2007 | *AA Water1 (milking ctr) | 15.3 | 0.043 | 0.46 |
| | AA Water2 (cow drinking) | 14.8 | 0.041 | 0.44 |
| | | | | |
| 3/23/2007 | AA Water (cow drinking) | 15.0 | 0.042 | 0.45 |
| | *not in average | | | |
| Average | | 14.7 | 0.04 | 0.44 |
| Standard Deviation | | | | 0.02 |
| Confidence Interval ± | | | | 0.02 |

The sulfur consumed by the dairy cows averaged 37.6 lb per day.

**MANURE**

The properties (percent total solids and sulfur) for the influent and effluent are given in Table 4-3. The concentration of TS decreased about 2% during digestion, 8.88 to 6.81percent.

Table 4-3. Properties of the Digester Influent and Effluent at AA Dairy.

| | Influent | | | Effluent | | |
|---|---|---|---|---|---|---|
| Date | Sample | % TS | % S | Sample | % TS | % S |
| 1/31/2007 | AAI1 | 8.81 | 0.035 | AAE1 | 7.11 | 0.035 |
| | AAI2 | 8.65 | 0.045 | AAE2 | 7.18 | 0.035 |
| 2/21/2007 | AAI1 | 9.32 | 0.05 | AAE1 | 6.43 | 0.03 |
| | AAI2 | 9.02 | 0.045 | AAE2 | 6.85 | 0.035 |
| 3/23/2007 | AAI1 | 9.05 | 0.04 | AAE1 | 6.84 | 0.035 |
| | AAI2 | 8.71 | 0.045 | AAE2 | 6.64 | 0.035 |
| | AAI3 | 8.63 | 0.04 | AAE3 | 6.59 | 0.035 |
| Average | | 8.88 | 0.043 | | 6.81 | 0.034 |
| Standard Dev | | 0.25 | 0.0052 | | 0.28 | 0.0020 |
| Conf Int ± | | 0.19 | 0.0038 | | 0.21 | 0.0015 |

To calculate the sulfur "lost" during digestion based on changes in the manure influent and effluent, the flow rate of the effluent must be known. The Mass Balance Method calculates the flow of effluent and the sulfur in the effluent. There is only one influent flow rate and resulting effluent flow rate to satisfy the measured concentration of TS in the influent and effluent and the biogas produced, volume and concentration of methane and carbon dioxide. The analysis used here assumed that there was no settling in digester. Using the data in Table 4-3, the results of this analysis showed a loss of sulfur in the digester to be 9.2 lb S per day. See Table 4-4 for more details.

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

| | | | | | |
|---|---|---|---|---|---|
| Vo = | 40,310 | ft3/day, dry | | | Volume of biogas |
| CH4 = | 0.666 | | | | Concentration of methane |
| CO2 = | 0.331 | | | | Concentration of carbon dioxide |
| IPTS = | 8.88 | % | | | Percent total solids in effluent |
| EPTS = | 6.81 | % | | | Percent total solids in influent |
| IPS = | 0.043 | % | | | Percent sulfur in influent |
| EPS = | 0.034 | % | | | Percent sulfur in effluent |
| B = | 2,835 | lb biogas/day dry | | | Weight of biogas |
| | | | | | |
| T = | 62 | F | | | Biogas temperature at meter |
| T = | 13.3 | C | | | |
| bVS = | 2,552 | 90%* | | | Volatile solids consumed |
| bW = | 284 | 10%* | | | Mass of water consumed |
| Dw = | 0.00066 | lb water/ft3 biogas | | | |
| We = | 26.8 | lb water/day | | | Water in saturated biogas |
| ITS = | 0.0888 | ITW= | 0.911 | | Total solids in influent |
| ETS = | 0.0681 | ETW= | 0.932 | | Total solids in effluent |
| | | | | | |
| ITM = | 113,394 | lb/day | 13,340 | gpd | Total mass of influent |
| ETM = | 110,532 | lb/day | 13,004 | gpd | Total mass of effluent |
| Δ TM = | 2,862 | lb/day | | | Change in mass |
| ITS = | 10,074 | lb/day | | | Total solids in influent |
| ETS = | 7,522 | lb/day | | | Total solids in effluent |
| Δ TS = | 2,552 | lb/day | | | Total solids "lost" |
| Sulfur In | 48.6 | lb/day | | | Sulfur in influent |
| Sulfur Out | 37.9 | lb/day | | | Sulfur in effluent |
| Δ Sulfur | 10.7 | 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.

**BEDDING**

Dairy cows are bedded with kiln-dried wood shavings. Data concerning the rate and properties of the bedding are given in Table 4-5.

Table 4-5. Sulfur in Bedding at AA Dairy.

| Type | Amount $yd^3$/4 weeks | Cows | Moisture Content, % | Density (assumed), lb/$ft^3$ | Use | | S* |
|---|---|---|---|---|---|---|---|
| | | | | | lb/day | lb/cow-day | lb/day |
| Kiln Dried Wood Shavings | 110 | 450 | 5 | 10 | 1,060 | 2.36 | 1.0 |

* See references in Appendix

**MILK**

The concentration of sulfur in milk is low but because there are large volumes of milk produced sulfur in milk must be considered. Table 4-6 shows the information concerning sulfur is the milk at AA Dairy.

Table 4-6. Sulfur in Milk at AA Dairy.

| RHA lbs/cow-yr | lbs/cow day | # of Cow | Sulfur* % | S lbs S/cow day | Total lbs S/day |
|---|---|---|---|---|---|
| 21,000 | 57.5 | 430 | 0.03 | 0.02 | 7.4 |

* based on data from Trace Minerals Research

**MASS FLOW OF MANURE**

The piston pump [dia = 19 inch, stroke = 46 inch] made 3 strokes/min. The theoretical capacity of the pump was 170 gpm. Using this theoretical capacity of the pump and the average operating time per day (201 min), 34,200 gallons would be pumped per day or 79 gallons per cow-day. This is seems too high. Wastewater from milking center is not added to the manure.

The mass flow of the influent to the digester was also measured by monitoring the change in depth of the manure in the reception pit. An ultrasonic device was used to monitor the change in depth of the manure in the reception pit. The average rate of change in depth when the pump was not operating [15.9 hr], when manure was flowing into the pit, was 0.019 in/min or 7.4 gpm. Assuming the flow of manure from the freestall barn was uniform during the day, the total would be 10,500 gpd or 207 lb/cow-day, assuming 8.5 lb/gal. At a concentration of TS in the influent at 8.88% there are 7,930 lb TS per day. With 1,010 lb TS in bedding, the manure TS is 6,920 lb/day or 16.1 lb TS per cow-day. Using American Society of Agricultural & Biological Engineers (ASABE) equations, the manure production would be 16.7 lb total solids (TS) per cow-day. See worksheet in Appendix, Table A-2. The "mass balance method" predicted 10,050 lb TS/day.

Analyzing the data from the ultrasonic device when the pump was operation showed a change in depth of 0.133 in/min or a flow of 52.1 gpm. At the same time manure continued to flow into the reception pit at 7.3 gpm giving a total pump-out rate of 59.4 gpm. Operating an average of 201 min/day, the calculated influent flow was 11,900 gpd. The volumetric efficiency of the piston pump was 35%.

Table 4-7. Summary of Flow of Influent to Digester.

| Method | Influent to Digester, lb/day | Sulfur Flow in Digester, lb/day |
|---|---|---|
| Flow of Manure & Bedding from Freestall Barn | 89,300 | 38.4 |
| ASABE Equation plus Bedding | 92,800 | 39.9 |
| Mass Balance Method | 115,600 | 49.7 |
| Delivery from piston pump | 101,900 | 43.5 |

**BIOGAS**

The sulfur in the biogas was computed using the data taken during the 30 day test given in Table 4. The biogas, based on the tests conducted during the 30 day test, contained 13.0 pounds of sulfur per day. The results from this analysis are shown in Table 4-8.

Table 4-8. Analysis of Biogas at AA Dairy.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Based on averages from 30 day test, main meter | | | | | | | | | | |
| Biogas meter, Temp compensated (60 F) | | | | | | | | | | |
| **Input Data - yellow area** | | | | | **Calculations** (assume pressure at 1 atm) | | | | | |
| Biogas temp @ meter | 62.0 | F | | | | | | | | |
| Pressure in gas line | 1.2 | in $H_2O$ | | | Biogas flow (wet) at | | 62.0 | F | 41,090 | cuft/day |
| Biogas flow (meter) | 39,690 | cuft/day | | | Biogas flow (dry) at | | 62.0 | F | 40,313 | cuft/day |
| Elevation of meter | 920 | ft | | | | | | | | |
| $H_2S$ (dry basis) | 4,100 | ppm | | | Concentration of methane, $CH_4$ | | | | 66.6 | % |
| $CO_2$ (dry basis) | 33.0 | % | | | Volume of $CH_4$ @ | | 62.0 | F | 26,845 | $ft^3$/day |
| $P_{elev}$ | 14.208 | psia | | | Volume of $CH_4$ @ STP | | | | 24,537 | $ft^3$/day |
| $P_m$ | 0.043 | psig | | | **Weight of $CH_4$** | | | | **1,094** | **lb/day** |
| $P_{line}$ | 14.252 | psia | | | | | | | | |
| Volume of water vapor | 1.89 | % | | | **HEATING VALUE (low)** | | | | 23,547,878 | Btu/day |
| | | | | | | | | | 981,162 | Btu/hr |
| Standard Pres. | 14.696 | psia | | | | Raw biogas | | | 573 | Btu/$ft^3$ |
| Standard Temp. | 0 | ° C | | | | | | | 287 | kW |
| Methane, low heating value | 21,518 | Btu/lb | | | Volume of $H_2S$ @ | | 62.0 | F | 165.3 | $ft^3$/day |
| Weight $CH_4$ at 0º C and 1 atm | 0.0446 | lb/$ft^3$ | | | Volume of $H_2S$ @ STP | | | | 151.1 | $ft^3$/day |
| Weight $CO_2$ at 0º C and 1 atm | 0.1227 | lb/$ft^3$ | | | Weight of $H_2S$ | | | | 14.3 | lb/day |
| Weight $H_2S$ at 0º C and 1 atm | 0.0948 | lb/$ft^3$ | | | **Weight of Sulfur (S)** | | | | **13.5** | **lb/day** |
| | | | | | | | | | | |
| | | | | | | Volume of water vapor | 62.0 | F | 777 | $ft^3$/day |
| | | | | | | Density of water vapor | | | 0.0474 | lb/$ft^3$ |
| | | | | | | Water | | | 37 | lb/day |
| | | | | | | | | | 4.4 | gal/day |

A summary of the flow of sulfur is given in Table 4-9, and is diagramed in the Appendix, Figure A-2.

Table 4-9. Summary of Sulfur Flow at the AA Dairy.

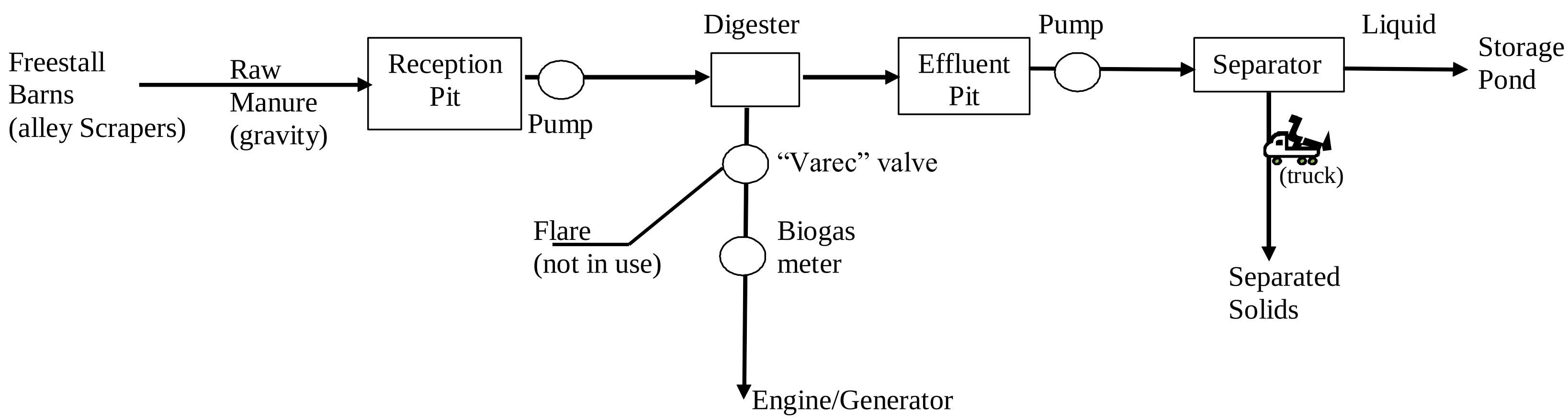
| Parameter | Value | Conditions |
|---|---|---|
| Number of cows | 430 | Given |
| Sulfur, lb/day | | |
| TMR | 44.0 | Measured concentration*, mass given |
| Drinking water | 0.44 | Measured concentration, volume assumed |
| Bedding | 1.0 | |
| Total input | 45.4 | |
| Milk | - 7.4 | Concentration from reference, volume given |
| "Manure" from barn | 38.0 | By difference |
| Digester influent | 49.5 | Mass balance method |
| Digester effluent | 38.6 | Mass balance method |
| Change in digester | 10.7 | "loss" during digestion by difference |
| Biogas | 13.5 | Concentration and volume of biogas, measured |

* Concentration taken as the average of samples collected 1/31 & 2/22/07 (during 30 day test)

The difference between the amount of sulfur in the influent calculated by difference (38.0) and that computed with the mass balance method (49.5) is not known. There is no method for measuring the mass flow of the digester effluent. There was closer agreement in calculating the sulfur loss as hydrogen sulfide in the biogas (13.5) and the mass balance method (10.7). Based on the reliability of the analysis for each method – biogas (gas meters and gas analysis) vs. flow through the digester (mass flows and analysis of manure), the biogas would be deemed the more reliable.

**APPENDIX**

**Figure A-1. Schematic Drawing of AA Dairy.**




Not to scale

**Figure A-2. Mass Flow Diagram of Sulfur, AA Dairy**.

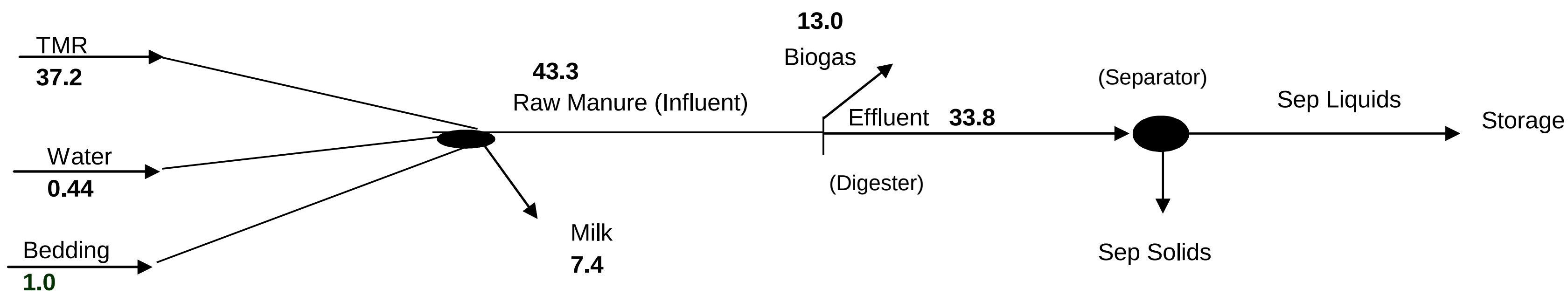


Table A-1.  30-Day Test Data, AA Dairy.

| Day # | Date 2007 | Time | Biogas Meters | | | | | H2S | | | CO2 | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Main | | | | Avg/ day | ppm/% | | Avg/ day | ppm/% | | Avg/ day | |
| | | | Temp | Ave Temp | Press | Reading | | #1 | #2 | | #1 | #2 | | |
| 1 | 31-Jan | 9:00am | 60 | | 2.5 | 3,455 | | 0.42 | 0.40 | | 38 | 38 | | |
| | | 12:00pm | 60 | | 2.0 | 3,542 | | 0.30 | 0.35 | | 38 | 38 | | |
| | | 3:00pm | 60 | 60.0 | 1.8 | 3,630 | 42,800 | 0.32 | 0.35 | 0.36 | 34 | 30 | 36.0 | |
| 2 | 1-Feb | 6:30am | 61 | | 1.8 | 3,883 | | 0.20 | 0.30 | | 30 | 28 | | |
| | | 11:30am | 65 | | 1.8 | 3,971 | | 0.20 | 0.38 | | 40 | 36 | | |
| | | 3:30pm | 66 | 64.0 | 0.6 | 4,040 | 43,300 | 0.20 | 0.20 | 0.25 | 36 | 36 | 34.3 | |
| 3 | 2-Feb | 7:00am | 65 | | 1.5 | 4,316 | | 0.20 | 0.41 | | 36 | 30 | | |
| | | 1:00pm | 67 | | 1.6 | 4,430 | | 0.20 | 0.41 | | 30 | 34 | | |
| | | 4:00pm | 66 | 66.0 | 1.5 | 4,478 | 42,500 | 0.35 | 0.40 | 0.33 | 36 | 33 | 33.2 | |
| | 3-Feb | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | 42,500 | | | | | | | |
| 4 | 4-Feb | 5:30am | 57 | | 0.5 | 5,171 | | 0.15 | 0.25 | | 34 | 32 | | |
| | | 12:00pm | 56 | | 1.0 | 5,262 | | 0.42 | 0.40 | | 34 | 30 | | |
| | | 4:00pm | 53 | 55.3 | 1.0 | 5,348 | 42,300 | 0.40 | 0.40 | 0.34 | 32 | 28 | 31.7 | |
| 5 | 5-Feb | 6:30am | 55 | | 0.5 | 5,594 | | 0.40 | 0.40 | | 26 | 26 | | |
| | | 11:30am | 53 | | 0.5 | 5,678 | | 0.40 | 0.40 | | 24 | 25 | | |
| | | 4:30pm | 52 | 53.3 | 0.4 | 5,759 | 39,800 | 0.41 | 0.40 | 0.40 | 24 | 23 | 24.7 | |
| 6 | 6-Feb | 6:30am | 54 | | 1.3 | 5,992 | | 0.41 | 0.45 | | 26 | 18 | | |
| | | 2:00pm | 58 | | 1.4 | 6,130 | | 0.41 | 0.40 | | 36 | 32 | | |
| | | 3:30pm | 58 | 56.7 | 1.7 | 6,215 | 39,800 | 0.41 | 0.40 | 0.41 | 36 | 32 | 30.0 | |
| 7 | 7-Feb | 6:15am | 56 | | 1.0 | 6,390 | | 0.45 | 0.42 | | 28 | 26 | | |
| | | 12:00pm | 57 | | 1.8 | 6,488 | | 0.41 | 0.42 | | 28 | 30 | | |
| | | 4:00pm | 57 | 56.7 | 1.8 | 6,598 | 42,700 | 0.41 | 0.40 | 0.42 | 30 | 28 | 28.3 | |
| 8 | 8-Feb | 7:00am | 56 | | 0.8 | 6,817 | | 0.42 | 0.42 | | 28 | 28 | | |
| | | 12:30pm | 57 | | 1.7 | 6,915 | | 0.42 | 0.41 | | 32 | 36 | | |
| | | 3:00pm | 57 | 56.7 | 1.7 | 6,958 | 40,400 | 0.40 | 0.41 | 0.41 | 36 | 30 | 31.7 | |
| 9 | 9-Feb | 6:30am | 57 | | 1.0 | 7,221 | | 0.45 | 0.48 | | 36 | 34 | | |
| | | 1:30pm | 59 | | 1.5 | 7,344 | | 0.41 | 0.42 | | 38 | 30 | | |
| | | | | 58.0 | | | 40,000 | | | 0.44 | | | 34.5 | |
| | 10-Feb | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | 38,500 | | | | | | | |

Table A-1. 30-Day Test Data, AA Dairy, Cont.

| Date 2007 | Time | Biogas Meters | | | | | H2S | | | CO2 | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Main | | | | Avg/ day | ppm/% | | Avg/ day | ppm/% | | Avg/ day | |
| | | Temp | Ave Temp | Press | Reading | | #1 | #2 | | #1 | #2 | | |
| | 5:30am | 58 | | 1.5 | 8,016 | | 0.50 | 0.45 | | 36 | 36 | | |
| 11-Feb | 12:00pm | 60 | | 1.6 | 8,120 | | 0.48 | 0.42 | | 36 | 38 | | |
| | | | 59.0 | | | 41,000 | | | 0.46 | | | 36.5 | |
| | 6:30am | 62 | | 1.0 | 8,426 | | 0.45 | 0.42 | | 36 | 38 | | |
| 12-Feb | 12:30pm | 64 | | 0.6 | 8,515 | | 0.42 | 0.41 | | 35 | 32 | | |
| | | | 63.0 | | | 37,500 | | | 0.43 | | | 35.3 | |
| | 5:45am | 62 | | 0.9 | 8,801 | | 0.48 | 0.45 | | 36 | 34 | | |
| 13-Feb | 12:00pm | 63 | | 1.2 | 8,910 | | 0.42 | 0.42 | | 34 | 30 | | |
| | 4:30pm | 63 | 62.7 | 1.3 | 8,985 | 42,600 | 0.42 | 0.41 | 0.43 | 31 | 32 | 32.8 | |
| | 6:00am | 63 | | 1.0 | 9,227 | | 0.41 | 0.41 | | 31 | 33 | | |
| 14-Feb | 12:00pm | 63 | | 1.2 | 9,330 | | 0.40 | 0.40 | | 30 | 30 | | |
| | 4:00pm | 63 | 63.0 | 1.0 | 9,425 | 46,600 | 0.40 | 0.40 | 0.40 | 28 | 30 | 30.3 | |
| | 6:30am | 60 | | 1.5 | 9,693 | | 0.51 | 0.48 | | 30 | 30 | | |
| 15-Feb | 12:00pm | 60 | | 1.3 | 9,781 | | 0.45 | 0.42 | | 28 | 30 | | |
| | 4:30pm | 60 | 60.0 | 1.0 | 9,852 | 42,300 | 0.43 | 0.40 | 0.45 | 28 | 30 | 29.3 | |
| | 7:00am | 60 | | 2.0 | 10,116 | | 0.55 | 0.50 | | 34 | 32 | | |
| 16-Feb | 1:30pm | 60 | | 1.5 | 10,228 | | 0.42 | 0.45 | | 30 | 31 | | |
| | 8:00pm | 60 | 60.0 | 1.3 | 10,298 | 40,000 | 0.42 | 0.45 | 0.47 | 30 | 31 | 31.3 | |
| | | | | | | | | | | | | | |
| 17-Feb | | | | | | | | | | | | | |
| | | | | | | 40,000 | | | | | | | |
| | | | | | | | | | | | | | |
| 18-Feb | | | | | | | | | | | | | |
| | | | | | | 40,000 | | | | | | | |
| | 7:30am | 60 | | 1.3 | 11,318 | | 0.50 | 0.50 | | 32 | 28 | | |
| 19-Feb | 12:00pm | 62 | | 1.5 | 11,386 | | 0.48 | 0.50 | | 30 | 28 | | |
| | 5:00pm | 64 | 62.0 | 1.5 | 11,472 | 38,600 | 0.42 | 0.42 | 0.47 | 30 | 28 | 29.3 | |
| | 6:00am | 64 | | 1.8 | 11,704 | | 0.45 | 0.45 | | 32 | 32 | | |
| 20-Feb | 12:45pm | 72 | | 1.5 | 11,829 | | 0.41 | 0.41 | | 36 | 38 | | |
| | 4:15pm | 71 | 69.0 | 1.8 | 11,882 | 42,300 | 0.41 | 0.42 | 0.43 | 34 | 32 | 34.0 | |
| | 6:30am | 67 | | 1 | 12,127 | | 0.50 | 0.45 | | 35 | 33 | | |
| 21-Feb | 12:00pm | 73 | | 0.4 | 12,219 | | 0.45 | 0.42 | | 31 | 30 | | |
| | 3:00pm | 72 | 70.7 | 1 | 12,265 | 31,100 | 0.40 | 0.40 | 0.44 | 30 | 30 | 31.5 | |
| | 6:30am | 61 | | 0.0 | 12,438 | | 0.43 | 0.45 | | 35 | 34 | | |
| 22-Feb | 12:00pm | 66 | | 0.1 | 12,503 | | 0.42 | 0.45 | | 35 | 34 | | |
| | 3:00pm | 66 | 64.3 | 1 | 12,594 | 40,000 | 0.40 | 0.41 | 0.43 | 34 | 34 | 34.3 | |

Table A-1. 30-Day Test Data, AA Dairy, Cont.

| Day # | Date 2007 | Time | Biogas Meters | | | | | H2S | | | CO2 | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Main | | | | Avg/ day | ppm/% | | Avg/ day | ppm/% | | Avg/ day | |
| | | | Temp | Ave Temp | Press | Reading | | #1 | #2 | | #1 | #2 | | |
| | 24-Feb | | | | | | 40,000 | | | | | | | |
| | 25-Feb | | | | | | 40,000 | | | | | | | |
| 21 | 26-Feb | 7:00am | 65 | | 0.3 | 14,025 | | 0.45 | 0.41 | | 38 | 38 | | |
| | | 12:15pm | 67 | | 0.5 | 14,095 | | 0.42 | 0.42 | | 38 | 34 | | |
| | | 3:00pm | 67 | 66.3 | 1.6 | 14,132 | 36,800 | 0.42 | 0.41 | 0.42 | 35 | 36 | 36.5 | |
| 22 | 27-Feb | 7:00am | 67 | | 1.7 | 14,393 | | 0.41 | 0.42 | | 38 | 38 | | |
| | | 11:30am | 68 | | 2 | 14,468 | | 0.42 | 0.42 | | 36 | 32 | | |
| | | 3:00pm | 68 | 67.7 | 0.5 | 14,525 | 37,100 | 0.40 | 0.41 | 0.41 | 38 | 39 | 36.8 | |
| 23 | 28-Feb | 6:45am | 66 | | 0.8 | 14,764 | | 0.41 | 0.41 | | 35 | 35 | | |
| | | 11:15am | 76 | | 2.3 | 14,845 | | 0.41 | 0.42 | | 35 | 37 | | |
| | | 6:45pm | 69 | 70.3 | 0.7 | 14,955 | 35,900 | 0.40 | 0.42 | 0.41 | 35 | 36 | 35.5 | |
| 24 | 1-Mar | 6:30am | 66 | | 0.3 | 15,123 | | 0.50 | 0.45 | | 36 | 38 | | |
| | | 10:30am | 68 | | 1.8 | 15,190 | | 0.40 | 0.41 | | 40 | 38 | | |
| | | 3:30pm | 68 | 67.3 | 1.5 | 15,265 | 28,800 | 0.40 | 0.41 | 0.43 | 38 | 36 | 37.7 | |
| 25 | 2-Mar | 7:00am | 65 | | 0 | 15,411 | | 0.40 | 0.40 | | 34 | 34 | | Very little gas |
| | | 11:00am | 65 | | 0.2 | 15,441 | | 0.40 | 0.40 | | 34 | 36 | | Digester bag flat in am |
| | | | | 65.0 | | | 38,600 | | | 0.40 | | | 34.5 | |
| | 3-Mar | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| 26 | 4-Mar | 4:30am | 63 | | 0.5 | 15,797 | | 0.40 | 0.42 | | 35 | 36 | | |
| | | | | | | | | | | | | | | |
| | | | | 63.0 | | | | | | 0.41 | | | 35.5 | |
| 27 | 5-Mar | 6:00am | 60 | | 0.3 | 16,134 | | 0.45 | 0.44 | | 34 | 38 | | Generator shut down for repairs |
| | | 12:00pm | 58 | | 1 | 16,147 | | 0.42 | 0.42 | | 35 | 35 | | |
| | | | | 59.0 | | | | | | 0.43 | | | 35.5 | |
| 28 | 6-Mar | 7:00am | 52 | | 0.3 | 13,681 | | | | | 35 | 35 | | H2S - no more tubes |
| | | | | | | | | | | | | | | |
| | | | | 52.0 | | | | | | | | | 35.0 | |
| Average | | | 62 | | 1.16 | | 39,690 | | | 0.41 | | | 32.93 | |
| St Dev. | | | 5.10 | | 0.58 | | 3,510 | | | 0.06 | | | 3.92 | |
| Confidence Interval | | | 1.18 | | 0.13 | | 1,256 | | | 0.01 | | | 0.64 | |
| (# of samples) | | | 72 | | 72 | | 30 | | | 142 | | | 144 | |

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

Calculating Manure Production

| | | Animal | Manure Prod | | Total Solids | | | Total Solids |
|---|---|---|---|---|---|---|---|---|
| | | Number | lb/animal-day | lb/day | lb/animal-day | lb/day | % TS | collected, lb/yr |
| Milking Cows, RHA*, lt | 57.5 | 430 | 132.0 | 56,744 | 16.7 | 7,166 | 12.6% | 2,615,589 |
| Dry Cows, Body Weigl | 1500 | 0 | 80.9 | 0 | 10.1 | 0 | 12.5% | 0 |
| Heifers, average Body | 700 | 0 | 51.8 | 0 | 6.7 | 0 | 13.0% | 0 |
| Total | | | | 56,744 | | 7,166 | 12.6 | 2,615,589 |

| Milking Center Wastewater | Gal/cow-day | Gal/day | Lb/day | | |
|---|---|---|---|---|---|
| | 8 | 3,440 | 28,690 | | |
| Total | | | 85,433 | 10110 | gal/day |

| | | | |
|---|---|---|---|
| *Rolling Herd Average | 21,000 | | |
| Days per year | 365 | equivalent cows | 430 |
| Days in freestall per ye | 365 | | |
| Days - freestall & corra | 0 | Total Solids Content, manure | 0.126 |
| Days - corral | 0 | Total Solids Content, all | 0.084 |
| Percent of Manure Collected | | | |
| Freestall | 100% | | |
| Freestall & corral | 80% | | |
| Corral | 60% | | |