American Society of Agricultural and Biological Engineers

Go Back

Monitoring on-farm Dairy Anaerobic Digestion Biogas H_2S Scrubber Performance and Economics

Timothy Shelford[1], Curt Gooch[1], Stephanie Lansing[2]

[1] Cornell PRO-DAIRY, Dairy Environmental Systems, Cornell University, Ithaca, NY

[2]Department of Environmental Science and Technology, University of Maryland, College Park, MD

This is not a peer-reviewed article.

2017 ASABE Annual International Meeting, Paper No. 1701551, pages 1-7 (doi: 10.13031/aim.201701551). St. Joseph, Mich.: ASABE.

Written for presentation at the
2017 ASABE Annual International Meeting
Sponsored by ASABE
Spokane, Washington
July 16-19, 2017

Abstract. Anaerobic digestion (AD) produces renewable energy in the form of methane (CH4)-enriched biogas. Hydrogen sulfide (H2S) is formed in the produced biogas in trace quantities (up to 8,000 ppm). H2S can cause corrosion damage to biogas-fueled engine-generator sets (EGS), resulting in high maintenance costs and/or lost revenues for farmers. There is a need for thorough understanding of optimal H2S scrubbing operational and maintenance parameters, quantifiable advantages and disadvantages of different types of scrubbing systems, and the capital and operational costs associated with H2S scrubbers, and for this information to be conveyed to farmers using or interested in using AD systems. To address these knowledge deficiencies, the efficacy of H2S scrubbing systems on two dairy farms in NY was being evaluated, with financial analyses conducted on each AD scrubber operation.

Biogas production (cfm) and H2S, CO2 and CH4 concentrations in the biogas were quantified on existing biological H2S scrubbing systems for 7 months. Two continuous biogas monitoring systems (Siemens Ultramat 23) were used to analyze the biogas streams, with data collected and transmitted with Campbell Scientific (CR1000) dataloggers. Data on scrubber and engine-generator maintenance costs (parts and labor) was collected, and indicate that the annual economic savings of reduced oil-change frequencies was not more than the annual cost of owning and operating the biological treatment systems.

Keywords. Anaerobic digestion, Biogas scrubbing, Biogas treatment, H2S.

Introduction

A main operational challenge to on-farm anaerobic digestion systems (ADS) has been operational interruption of biogas-fueled engine-generator sets (EGS) due to damage from hydrogen sulfide (H2S) in biogas, resulting in high maintenance costs and/or lost revenues. The uncertainties associated with biogas scrubber cost and ability to reduce H2S affects profitability, EGS effective lifetime, electricity production, and overall interest by farms in ADS.

According to AgSTAR (AgSTAR, 2017), there have been 200 new on-farm digesters built in the US since 2003, but many ADS lack any biogas scrubbing systems. Biogas scrubbing is perceived by 88% of ADS practitioners, extension specialists, and funding agencies as one of the most important barriers to wider-spread ADS adoption and success in the marketplace, and there is no doubt that the lack of implementation of H2S scrubbing equipment is holding back the biogas industry. Eighty-Five% of farmers indicated they need a better understanding of scrubbing operational and maintenance conditions, quantifiable benefits of different types of scrubbing systems and the costs associated with operating biogas scrubbers. With the increasing use of ADS, more evaluation and guidance information is needed to guide adopters, especially in light of the large capital investment needed for ADS available in the current market. With greater adoption rates, ADS could result in large increases in on-farm energy production, increased opportunities for on-farm GHG reductions, and increased opportunities for nutrient reductions from manure, as digestion allows for post-treatment harvesting and transport off-farm of nutrients or more appropriate application of nutrients on-farm. The goal of this project was to provide famers with unbiased information about the efficacy and economics of biogas scrubbing systems which should in turn increase on-farm energy production on US farms and lead to greater ADS profitability and adoption rates on US dairy farms.

Methods

To measure the efficacy of biological treatment systems (BTS) performance, and to determine the economics of ownership, two farms in NY State with a BTS installed were continuously monitored for over the course of six months, with economic monitoring occurring for 18 months.

Farm Information:

Both farms monitored for the project used a BTS to scrub the biogas produced by their anaerobic digesters. Both farms are also equipped with their own biogas analysis equipment that was operated independently of our monitoring project.

Farm 1 had a herd of 4,200 milking cows feeding their digester, and the biogas was used to power two, 500-kW engine-generator sets. The biogas treatment system was a retrofitted American Biogas Conditioning unit that has been in operation for approximately 24 months (figure 1). System performance was measured by a Union Instruments (model INCA 4003), gas analyzer that measured biogas CH_4, CO_2, O_2 and H_2S concentrations. The instrument measures both pre- and post-treatment biogas concentrations.

Farm 2 had a herd of 1,500 milking cows feeding their digester, and the biogas was used to power a 502-kW engine-generator set. The anaerobic digestion system came with a biogas clean-up unit that was designed and manufactured by Martin Machinery (figure 2); it has been in operation for approximately 36 months. The Martin Machinery unit came with a Geotechnical Instruments (UK, model GA 3000 Plus), biogas analyzer, that measured CH_4, CO_2, O_2 and H_2S concentrations, both pre- and post-treatment.

Figure 1: Farm 1 Biological Treatment System

Figure 2: Farm 2 Biolgocial Treatment System

Monitoring Equipment:

The basis of the biogas monitoring system was the Siemens Ultramat 23 Gas Analyzer, which was capable of measuring up to three infrared absorbing gases and/or oxygen and hydrogen sulfide (H2S). Two units were purchased, configured to measure CO2, CH4, O2, and H2S. Two gas sampling multiplexers which allow automatic switching between two sample streams, were also purchased. As installed on-farm, the first sample stream was pre-treatment (raw) biogas, and the second stream was post-treatment (treated) biogas.

The Ultramat 23 was equipped with an automatic calibration mode, that calibrated the unit with air, every 8 hours, or during significant temperature changes. Calibration for all monitored gasses was carried out with calibration gasses before system installation. In addition, monthly calibration of the H2S sensor was performed.

The Ultramat 23 was only capable of measurement and so Campbell Scientific CR1000 dataloggers, were installed to record the output (measured concentrations) of each Ultramat 23. In addition, each CR1000 monitored the status of the electrical supply to the Ultramat 23, as well as the ambient temperature. If the temperature dropped to a point where freezing of the biogas sample lines was a concern, it turned on a space heater and muffin fans to blow warm air along the sample lines.

The CR1000 was accessed remotely through a Sierra Wireless Raven XT cellular digital modem, and the Campbell Scientific software, Loggernet. Loggernet allowed the user to view real-time data that the CR1000 datalogger is experiencing, and to download previously collected data. All of the instrumentation was located within portable plastic sheds (figure 3).

Data was collected every minute for 15 minutes on each treatment stream before the switch to the other stream. Five minutes of data from the beginning of each 15 minute period was discarded during analysis to provide a period for the measurement to stabilize. The remaining data was then averaged.

Figure 3: Biogas Monitoring Equipment Setup

Economic Data Collection:

To provide data for economic cost-benefit analyses of the two biological treatment systems, daily log sheets were provided to the treatment system operators. One log sheet was used to track the time spent for maintenance of the scrubber systems, as well as any materials or replacement parts that were purchased. The second log sheet was used to track the time spent for maintenance of the engine-generator set as well as any materials or replacement parts that were purchased.

Results

The hourly concentrations of H2S over the course of the monitoring period both pre- and post-treatment for farm 1 and farm 2 are shown in figures 4 and 5, respectively. To correct for drift between monthly H2S sensor calibrations, the percent difference between the measured value and calibration value was applied in a linear fashion to the data set.

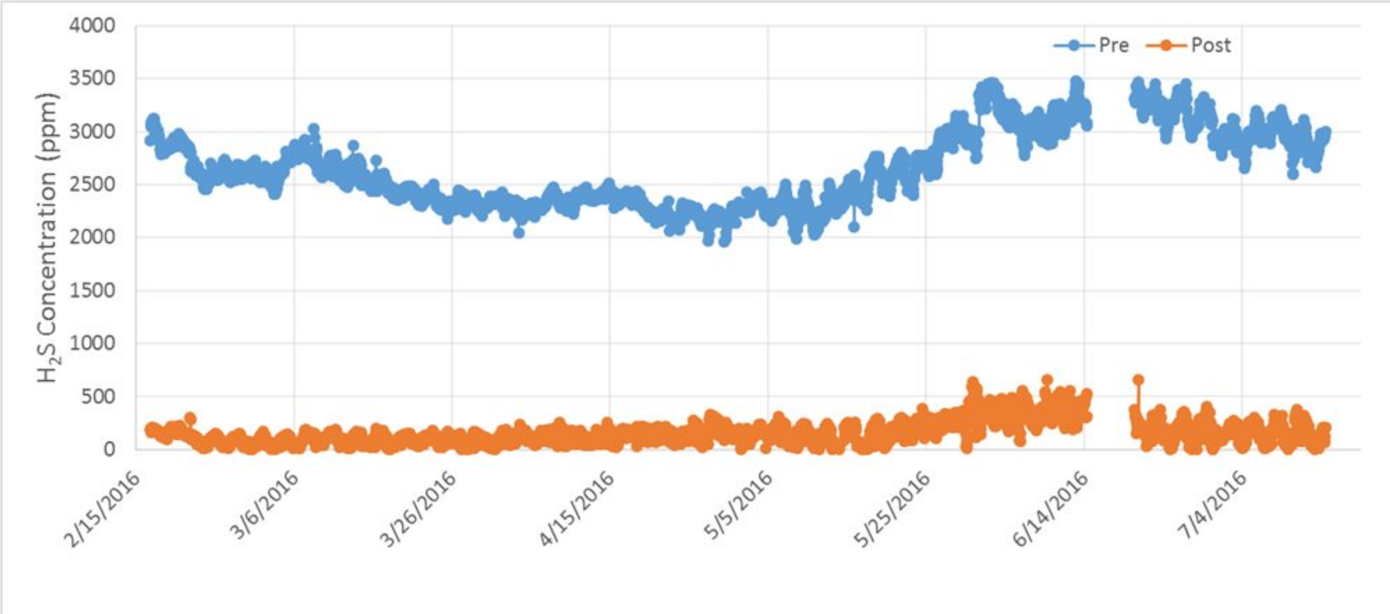

Figure 4: Farm 1 H2S Scrubber Performance over monitoring period

The pre-treatment concentration of H2S at farm 1 averaged 2,640 ppm over the course of the monitoring period. This varied considerably (+/- 350 ppm) over the analysis period. Post treatment performance was consistent throughout the monitoring period, with a gradual increase in concentration, which was likely due to build-up of solid Sulphur on the reactor media. The period with missing data corresponds to a scrubber clean out, during which the reactor vessel was thoroughly flushed. Following cleanout, system performance returned to normal.

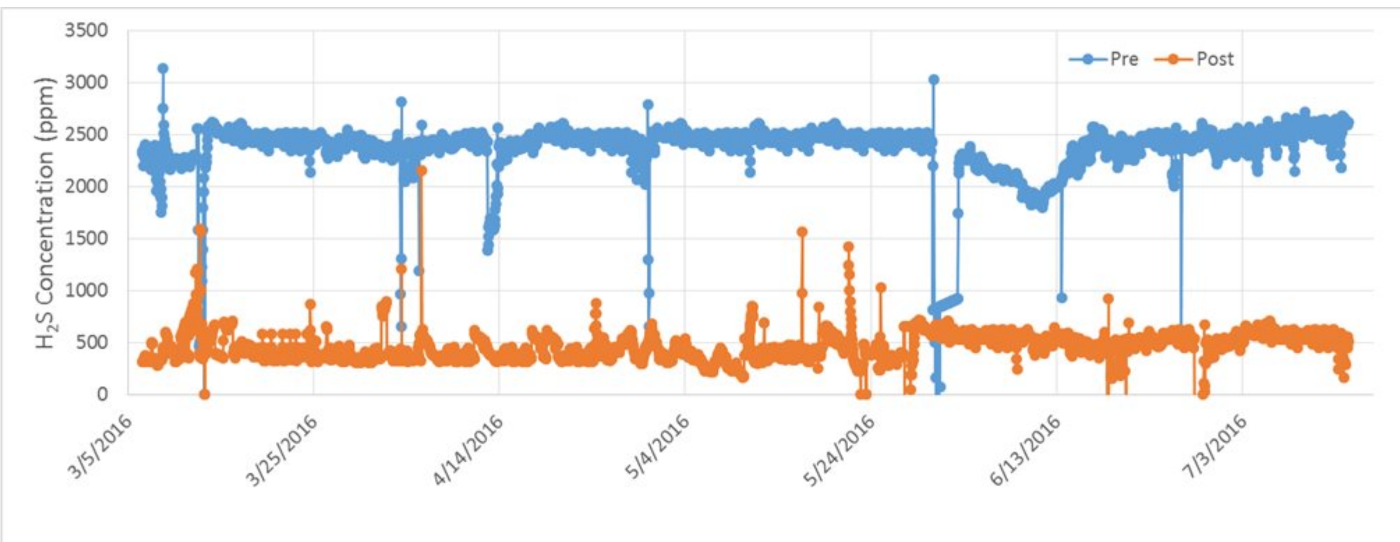

Figure 5: Farm 2 H2S Scrubber Performance

Farm 2 BTS performance was not as good as farm 1. Though the concentration of H2S pre-treatment was on average lower than farm 1, the post-treatment concentrations were approximately 3 times higher than farm 1.

The characteristics, performances and costs of the two NY farm systems over the course of the data collection period, are summarized in table 1.

Table : Summary of NY Farm Systems

Table : Summary of NY Farm Systems

System		Farm 1	Farm 2
Size	Milking Cows (#)	4,200	1,500
	Engine-Generator set capacity (kW)	1,000	502
Performance	Average Untreated biogas H_2S (ppm)	2,640 +/- 350	2,350 +/- 315
	Average Treated biogas H_2S (ppm)	150 +/- 110	450 +/- 190
	Overall removal efficiency (%)	94.5	80.1

	Capacity Factor	0.93	0.68
	H_2S removed per hour, calculated (lbs/hr)	5.22	0.78
Cost	H_2S Scrubber System Capital Cost ($)	342,000	185,000
	H_2S Scrubber yearly Maintenance Labor ($/yr)	5,772	3,120
	H_2S Scrubber yearly Cleanout Labor ($/yr)	4,551	1,220
	H_2S Scrubber yearly Nutrients ($/yr)	3,300	7,800
	H_2S Scrubber yearly Trickle Media replacement ($/yr)	4,195	2,200

Over the course of the monitoring period it was determined that the total annual cost of operating the BTS on farm 1 was $76,640 per year (including the cost of ownership). Costs for labor and supplies alone totaled $21,523 per year. A breakdown of the annual component capital cost for farm 1 is outlined in table 2.

Table : Farm 1 annual component capital cost

Table : Farm 1 annual component capital cost

Component	Initial Cost	Installation Cost[1]	Useful life (yrs)	Salvage Value	Annual Supplies	Annual Cost[2]
Scrubber Foundation	$0	$18,043	20	$0		$451
Reactor Vessel	$242,124	$88,853	10	$24,212		$39,556
Trickle Media	$13,000	$0	4	$0		$3,575
Air Injection (Blower #1)	$3,000	$0	5	$300		$623
Biogas Blower #2	$4,200	$200	5	$420		$917
Biogas Blower #3	$4,200	$200	5	$420		$917
Circulation Pump (Pump #1)	$11,500	$0	5	$1,150		$2,386
Nutrient Pump (Pump #2)	$200	$0	5	$0		$45
Hot Water Supply pump (Pump #3)	$1,500	$0	5	$150		$311
Gas Analyzer	$25,000	$0	5	$0	$750	$6,375

[1] If there is no value for installation cost it is assumed to be a part of the Reactor Vessel installation cost

[2] Interest on investment was assumed to be 5%

Before farm 1 installed their BTS, they spent $23,896 per year on oil changes (750 hours between changes). After the installation of the BTS, $13,868 per year was spent (1,300 hours between changes) for a savings of $10,028 per year.

For farm 2, the total annual economic cost of operating the BTS was $40,404 per year (including the cost of ownership). Costs for labor and supplies alone totaled $14,840 per year. A breakdown of the annual component capital cost for farm 2 is outlined in table 3.

Table : Farm 2 annual component capital cost

Table : Farm 2 annual component capital cost

Component	Initial Cost	Installation Cost[1]	Useful life (yrs)	Salvage Value	Annual Supplies	Annual Cost[2]
Scrubber Foundation	$0	$11,000	20	$0		$275
Reactor Vessel	$94,900	$40,000	10	$9,490		$16,151
Trickle Media	$8,000	$0	4	$0		$2,200
Air Injection (Blower #1)	$2,000	$0	5	$200		$415
Biogas Blower #2	$2,500	$0	5	$250		$519
Circulation Pump (Pump #1)	$3,200	$0	5	$320		$664
Nutrient Pump (Pump #2)	$200	$0	5	$0		$45
Hot Water Supply pump (Pump #3)	$700	$0	5	$70		$145
Gas Analyzer	$22,000	$0	5	$0	$750	$5,150

[1] If there is no value for installation cost it is assumed to be a part of the Reactor Vessel installation cost

[2] Interest on investment was assumed to be 5%

The BTS at farm 2 was installed as part of the original anaerobic digestion system, so there was no data for engine oil costs without a BTS. Currently the engine oil is changed every 900 hours, at an annual cost of $6,911 per year.

Discussion

The two systems operated on the same biological treatment principles, however, it is clear that the system at farm 1 performed better. This is likely due to a number of reasons. On farm 1 there is an advantage in that the digester supplied two engine-generator sets, and so biogas flow through the BTS is maintained even during routine maintenance, as only one EGS is worked on at a time. In addition, the larger farm has a solid cover over their digester. Farm 2 has a flexible cover that posed problems during the winter months when snow and rain would build up on top and restrict the collection and flow of biogas, resulting in system slowdowns or shutdowns. This difference in system performance can be verified by examining the capacity factor (CF) of the two farms. The CF is a measure of how much electricity was actually produced divided by how much electricity could have been produced over the same period. The CF is less than one due to system shutdowns for maintenance or outages, and also due to operating the systems at below design capacity due to inadequate biogas flow or other maintenance problems (overheating of engine heads, etc.)

Throughout the course of the evaluation, frequent calibration and maintenance of the monitoring equipment was essential, particularly for the H_2S sensors. Monthly calibrations were necessary to avoid excessive sensor drift. Though the H_2S sensors are supposed to be replaced yearly, one of the sensors failed after only three months of operation. The H_2S sensors on both of the farmers monitoring equipment were frequently in disagreement with the calibrated values from the Siemens Ultramat 23, indicating that H_2S sensor problems are not manufacturer specific.

Due to the sometime inconsistent nature of the power supply at the two farms, it became necessary to include a monitor for the power supply to the biogas analysis units. Both units were equipped with a UPS to provide a short period of operation without requiring a system reboot. On farm 2 in particular the power supply circuit to the biogas analysis unit was shared with heat tape used to warm the BTS biogas supply lines. During severely cold periods, this circuit could overload. Automatic notification of power loss to the monitoring equipment facilitated restoring power promptly.

Based on the data collected on these two systems, savings from reduced frequency of engine-oil changes alone do not justify the cost of owning and operating a BTS (even when considering only the labor and maintenance costs). One significant non-monetary benefit of the systems was that the treatment system at farm 1 prevented up to 43,000 lbs. of Sulphur emissions (elemental Sulphur, higher mass of SO_x) per year (6,400 lbs. from farm 2).

When biological treatment systems are operating correctly, they can be a highly effective means of removing H_2S from a biogas stream. However, to keep systems operating at peak efficiency requires a dedicated operator who is committed to keeping on top of maintenance of both the BTS and the anaerobic digestion system.

References

References

AGSTAR. (2017) Anaerobic Digestion Project Database. USEPA AGSTAR. Retrieved from: https://www.epa.gov/agstar/livestock-anaerobic-digester-database

American Society of
Agricultural and Biological Engineers

2950 Niles Road, St. Joseph, MI 49085
Phone: +12694290300 Fax: +12694293852