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PRO-DAIRY Education & Applied Research

Hydrogen Sulfide Removal at Spruce Haven Farm, LLC: Case Study

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Figure 1. Spruce Haven biological trickling filter

Hydrogen Sulfide Scrubber overview

H_2S scrubber type	Biological trickling filter
Scrubber designer	Martin Energy Group
Year commissioned	2014
Number of dairy animals	1,850 cows, 1,750 heifers
Dimensions (height, diameter)	20 ft, 7.5 ft.
Internal volume	700 ft^3
Media volume	462 ft^3
Water use	1,500 gallons per day
Vessel material	Fiberglass
Design temperature	100°F
Media	Plastic inserts
Biogas utilization	Guascor 502 kW combined heat and power
Monitoring results available	Yes
Hydrogen Sulfide removal efficiency	80.1%

Farm overview

- Spruce Haven Farm, LLC, managed by Doug Young, is located in Cayuga County, New York.
- The farm herd comprised of 3,360 Holsteins and milks ~1,500 cows.
- Digester construction began in Spring 2014, with the system operating by October 2014.
- See "Anaerobic Digestion at Spruce Haven Farm, LLC: Case Study" for more information: http://www.manuremanagement.cornell.edu/Pages/General_Docs/Case_Studies/Case_Study_Spruce_Haven_2016.pdf

Why the H_2S Scrubber?

The scrubber at Spruce Haven Farm, Inc. (Figure 1) was included as a part of the initial anaerobic digestion system design and was in place when the system was commissioned. The purpose of the scrubber was to remove hydrogen sulfide (H_2S) from the biogas stream to reduce the maintenance costs and prolong the lifespan of the engine-generator equipment. Based on the performance conditions at Spruce Haven Farm, with the H_2S scrubber operational, oil changes for the 502 kW Guascor engine-generator are necessary every 900 hours of operation.

Biological Trickling Filter (BTF) Scrubber system

System description

The scrubber system has several components (see Figure 2) including:

<u>Vessel</u>

The reaction vessel is 20 feet tall, and 7.5 feet in diameter. It's constructed out of fiberglass, with access holes at the top, side and bottom. The vessel is insulated with 2" of spray foam insulation. The total interior volume of the reactor is approximately 770 ft^3.

<u>Media</u>

The media on which the biofilms form is a plastic honeycomb material, occupies a volume of 462 ft^3 within the reaction vessel. The media requires a thorough cleaning twice per year, during which water is blasted in to dislodge accumulated elemental Sulfur and accumulated biomass. It is estimated that the media will require replacement every 4 years at a cost of $8,000.

<u>Air Injection</u>

Oxygen (from ambient air) is introduced into the biogas stream to a concentration of ~2% using an air injection blower. The air injection rate varies based on the measured biogas flowrate (measured with a Sage Prime SIP meter, Sage Metering, Inc.). Though the biogas is at a negative pressure at the inlet where air is introduced, air is introduced with a blower for more precise application rates.

<u>Nutrient Solution Distribution</u>

Water containing essential nutrients for the sulfur fixing microbes, is constantly circulated through the plastic media by means of a 3 HP pump at a design rate of 100 GPM. A single manifold at the top of the reactor distributes the water over the media.

<u>Reservoir</u>

The base of the reactor vessel acts as a reservoir that collects the water/nutrients that trickles through the media. The pH of the water is measured and controlled through sensors located in the reservoir, and is typically 1.5. When the pH of the system drops due to accumulated sulfuric acid a fresh water flush is automatically triggered to increase the pH.

<u>Nutrients</u>

The microbes that fix the sulfur require supplemental nutrients, which are pumped into the reservoir as necessary from a concentrated 275 gallon supply tote. The system uses approximately three totes of proprietary nutrient solution per year at a cost of $2,600 per tote.

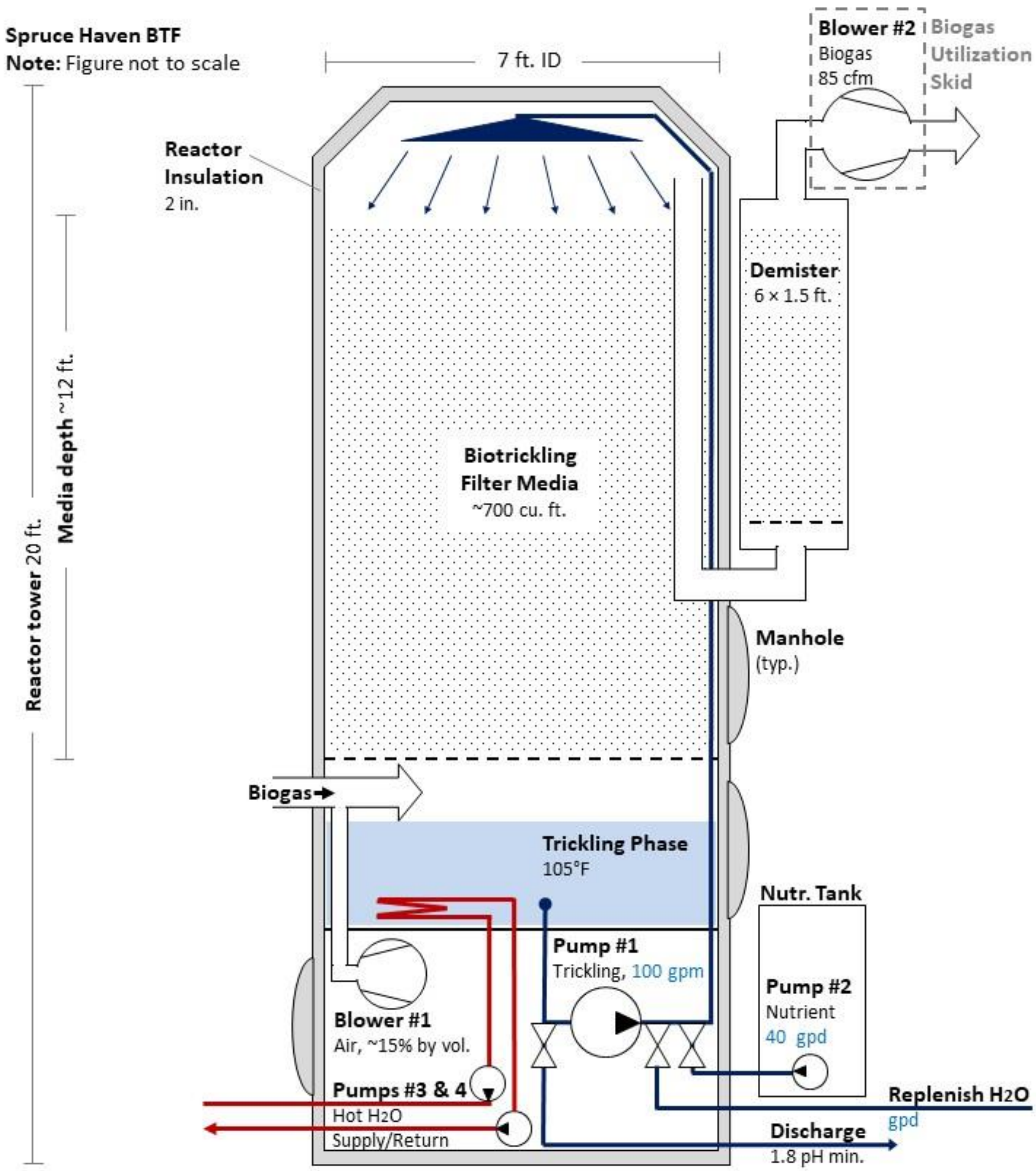

Figure 2. System diagram of Spruce Haven biological trickling filter system

<u>System Heat</u>
To maintain the system at 105 F, hot water (190 F) is piped to the vessel in a closed loop 1” supply hose. Hot water is distributed throughout the vessel using ½” pex tubing (not shown). The hot water source is combustion heat recovered from the biogas-fueled engine-generator set.

<u>Demister</u>
The demister removes water droplets from the biogas stream. Condensed liquid drains back into the main vessel.

Process Description
For a more in-depth description of the biological trickling filter process refer to the biogas cleanup Fact sheet series, available on the Dairy Environmental Systems website (http://www.manuremanagement.cornell.edu).

Biogas is drawn into the scrubber vessel at the base, and flows upward through the column of media. The biogas blower placed on the outlet of the reactor vessel creates a vacuum of 0.7-0.8 in. WC within the unit. Within the vessel, sulfur oxidizing bacteria metabolize the H_2S in the biogas and convert it to sulfate and elemental sulfur. After leaving the reactor, the biogas flows through a demister to remove water droplets from the biogas. Moisture removed by the demister drains to the scrubber vessel reservoir.

The elemental sulfur builds up on the media, which must be cleaned several times per year (and/or replaced when the buildup is such that effective cleanup isn’t practical). Sulfate is water soluble and dissolves in the tricking water, which transports it to the sump. The sulfate forms sulfuric acid which automatically triggers a flush of the system when the pH drops below a target of 1.5. Approximately 1,500 gallons of fresh water are used per day to flush out the system. Flushed water is piped to the long-term digester effluent storage for eventual field application.

Scrubber Performance
Under a project funded by Northeast Sustainable Agriculture Research and Education, (NESARE) the concentrations of H_2S were measured from March to July 2016, with a Siemens Ultramat 23 Biogas Analyzer equipped with a multiplexer which allowed the system to switch sampling between the inlet (pre BTF) and the outlet of the BTF (post BTF). Results are shown in Figure 3 and summarized in Table 1. Further details on the monitoring project can be found in Shelford and Gooch, 2018.

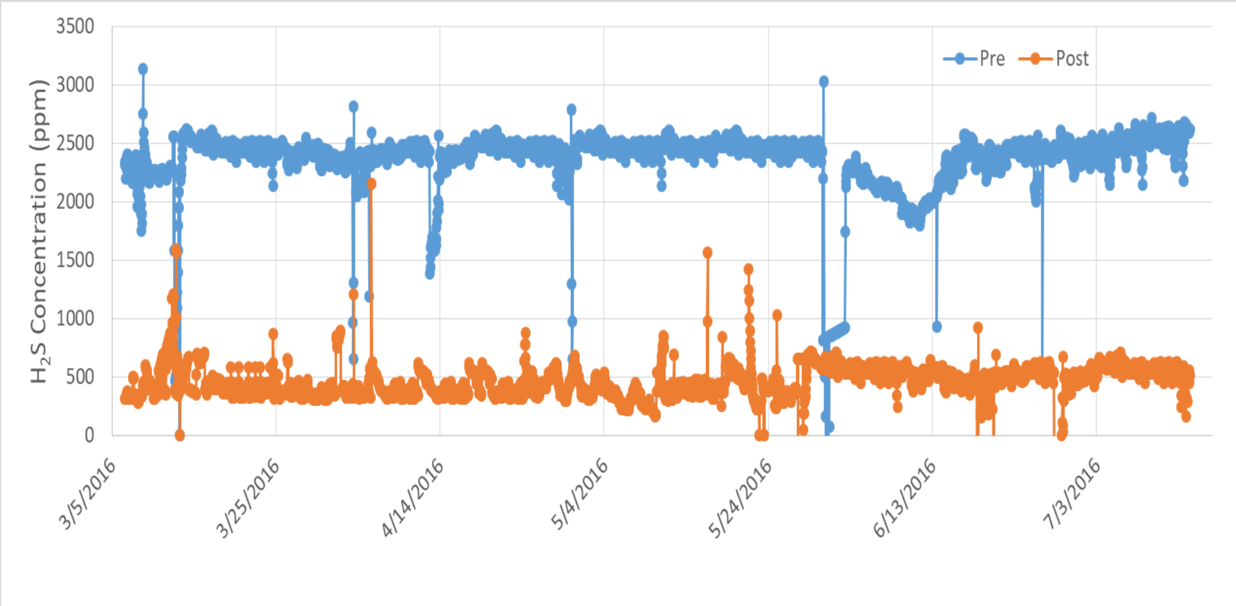

Figure 3. Measured Spruce Haven biogas H_2S concentrations before and after the Biological Trickling Filter

Table 1. Biological Trickling Filter (BTF) performance summary

Average Pre BTF H_2S Concentration (ppm)	2,350 +/- 315
Average Post BTF H_2S Concentration (ppm)	450 +/- 190
Average H_2S Removal Efficiency (%)	80.1
Average H_2S removed from biogas per hour (lbs./hr.)	0.78
Engine-Generator Capacity Factor	0.68

Over the course of the monitoring period illustrated in Figure 3, the concentration of H_2S in the raw (untreated) biogas averaged 2,350 ppm with a standard deviation of 315 ppm. This is a fairly typical value compared to other local anaerobic digestion systems.

Post treatment concentrations averaged 450 ppm with a standard deviation of 190 ppm. This average is higher than other BTF systems we have examined, but still below the target threshold target for engine-generator operation (500 ppm). Overall system H_2S removal efficiency was calculated to be 80.1% over the course of the monitoring period.

Part of the reason for the lower overall system removal efficiency was due to issues with the supply of biogas due to complications with the cover of the anaerobic digester, and operation of the digester in general (the farm uses sand bedding, and the sand/manure separator operational issues complicate digester operation). The engine-generator capacity factor of 0.68 indicates that the system was not operating near system electricity production potential and biogas flow to the BTF was variable.

Economics

Capital Costs

The total capital cost of the BTF system was approximately $184,500 itemized as follows.

- Reactor vessel: $94,900
- Construction/installation of the BTF system (foundation and system installation): $51,000.
- Trickle Media: $8,000
- Gas Analyzer: $22,000
- Pumps, plumbing and blowers: $8,600

The capital costs have been annualized (Table 2) to illustrate the yearly capital cost of the BTF ($18,543).

Table 2. Component Annual capital cost

Component	Purchase Cost ($)	Installation Cost[1] ($)	Useful life (yrs.)	Salvage Value ($)	Annual Cost[2] ($)
Scrubber Foundation	0	11,000	20	0	275
Reactor Vessel	94,900	40,000	20	9,490	9,880
Trickle Media	8,000	0	4	0	2,200
Air Injection (Blower #1)	2,000	0	5	200	415
Biogas Blower (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 pumps (Pump #3 and 4)	700	0	5	70	145
Gas Analyzer	22,000	0	5	0	4,400
Total					**18,543**

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

[2]Lost opportunity cost was assumed to be 5%

Operation and Maintenance Costs

As part of the NESARE grant, scrubber performance was monitored for 5 months and operation and maintenance costs were monitored over the course of 18 months (2016 to 2017). Operation and maintenance included labor, nutrient solution, replacement parts, supplies and utilities.

<u>Labor</u>

Over the course of a year, approximately 78 hours was spent maintaining the scrubber equipment, for an annual cost of $3,120. In addition to regular maintenance and repairs, an additional $1,220 per year was spent on cleaning out the reactor vessel (2 cleanouts per year taking approximate 16 hours of labor).

<u>Nutrient Solution</u>
Three totes of nutrient solution were used per year, at a cost of $2,600 per tote (~$9.50 per gallon) for an annual cost of $7,800.

<u>Replacement Parts/Supplies</u>
Parts and supplies for use in maintaining the equipment totaled $1,600 per year. Additionally, the H_2S sensor requires annual replacement at a cost of $750 per year.

<u>Utilities</u>
Over the course of a year the biogas scrubber used approximately 11,000 kWh of electricity, and 85 MMBtus of hot water. The hot water was provided from the heat recovered from the engine-generator set (from the hot water reservoir), and distributed to the scrubber through a closed glycol/water loop.

The farm is typically paid by the utility at a rate equal to the utilities avoided cost of production, which is typically about $0.04 per kWh. At this rate, it cost the farm $440 per year for electricity.

Since the heat in the hot water is over and above what is required to operate the digester excess heat is dumped to the ambient with large heat dump radiators, no annual cost was assigned for the heat needed to operate the BTF in this analysis. If fuel oil at $26 per MMBtu had been used to supply the heat, it would represent an additional cost of $2,210 per year.

<u>Total Annual Cost</u>
The yearly operation and maintenance costs were $14,930, and the yearly capital costs were $18,543. The total annual cost to own and operate the scrubber was $33,473 for a year period spanning 2016/2017.

The BTF has been in operation since commissioning of the digester and so a comparison of the oil-change frequency with and without a scrubber system is not possible. Assuming that the frequency of oil change would be 500 hours vs. the current 900 hours with the BTF, the annual savings on oil changes would be $5,500. However a major consideration in including the BTF in the AD system is to delay the need to rebuild the engine-generator, which is estimated to cost $80,000. Added benefits include a significant reduction in sulfur emissions from the engine-generator (SO_X) and increased sulfur recovery for use in crop fertilization (through field distribution of the recovered and stored BTF flush water).

Lessons Learned

Monitoring project lessons learned
Originally a Landtec GA 3000 gas analyzer was used to monitor the post treatment concentrations of CO_2, CH_4, H_2S, and O_2 in the biogas (monitoring and reporting system performance was a requirement of NYSERDA who partially supported the purchase of the AD system). Though not actually used for control of the BTF process, this data is useful for monitoring the performance of the BFT, and to detect when the system may require a cleanout. Unfortunately the H_2S sensors have proven quite problematic in that they have routinely failed well before their expected lifespan of one-year. At approximately $800 each they represent a significant annual cost. Other biogas monitoring equipment such as Siemens gas analyzer also suffer from this issue (to the point where

Siemens is no longer offering "high range" (0 to 5,000 ppm) H_2S sensing capability). The original Landtec GA 3000 has since been replaced with a Union Instruments (model INCA 4003) gas monitoring system, which monitors and records concentrations of CO_2, CH_4, H_2S, and O_2 in the biogas, both before and after the BTF.

Farm lessons learned

The operation of the anaerobic digester itself has proven challenging for a number of reasons, which has translated into engine-generator down-time (no biogas flow) which in turn has affected the performance of the BTF. Unlike the digester, the volume of the BTF reactor is primarily biogas, and so there is much less thermal mass to help maintain temperature during periods when heat supply is interrupted.

Spruce Haven uses a deep bed of sand for freestall bedding and bedding sand is reclaimed by a sand-manure separation (SMS) system. The SMS poses additional maintenance and operational challenges for the digester system. Being a relatively smaller system, it is also more difficult to dedicate staff full time to system operation, and the time that is dedicated is usually spent maintaining the SMS system.

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