Cornell CALS
College of Agriculture and Life Sciences

Dairy Environmental Systems Program
425 Riley-Robb Hall, Ithaca, NY 14853
cag26@cornell.edu | (607) 255-2088
www.manuremanagement.cornell.edu

PRO DAIRY Education & Applied Research

Hydrogen Sulfide Removal at Sunnyside Farms, Inc.: Case Study

Timothy Shelford, Ph.D., Jason Oliver, Ph.D. & Curt Gooch
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Contents:

- Hydrogen sulfide scrubber overview
- Farm overview
- Scrubber system
  - System description
  - Process description
- Scrubber performance
- Economics
  - Capital costs
  - Operation and maintenance costs
- Lessons learned
- Contact information

Figure 1. Sunnyside biological trickling filter

Hydrogen Sulfide Scrubber overview

H_2S scrubber type	Biological Trickling Filter
Scrubber designer	American Biogas Conditioning (out of business)
Year commissioned	2015
Number of dairy animals	4,200 cows, 2,700 heifers
Dimensions (height, diameter)	42 ft, 11.5 ft.
Internal volume	3,992 ft^3
Media volume	2,851 ft^3
Water use	2,500 gallons per day
Vessel material	Fiberglass
Design temperature	90°F
Biogas utilization	2, Guascor 500 kW engine-generators (total 1 MW)
Monitoring results available	Yes
Hydrogen Sulfide removal efficiency	94.5%

Farm overview

- Sunnyside Farms, Inc., managed by Neil and Greg Rejman, is located in Scipio Center, New York.
- The farm milks ~4,200 cows.
- Digester was commissioned in May 2009.
- See “Anaerobic Digestion at Sunnyside Farms, Inc.: Case Study” for more information:

http://www.manuremanagement.cornell.edu/Pages/General_Docs/Case_Studies/SunnySide_case_study.pdf

Why the H_2S Scrubber?

A new scrubber at Sunnyside Farms (Figure 1) was retrofitted into the existing biogas handling system, to reduce biogas H_2S concentrations with the overall goal to lower the operation and maintenance costs of the farm's two, 500 kW Guascor engine-generator sets. Before the scrubber was installed oil in the engine-generator sets was changed every 750 hours of operation. With the scrubber, the frequency has dropped to every 1,200 and 1,400 hours (one engine-generator was installed in 2009, and the other in 2012). The current scrubber is the third scrubber system to be installed on farm, the previous two systems failing due to poor design.

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 42' tall and 11.5' in diameter. It is constructed out of fiberglass, with access holes at the top, side and bottom. The vessel is insulated with 2" of spray foam insulation. The interior volume of the reactor is approximately 4,000 ft^3.

<u>Media</u>

The media on which the biofilms form is a plastic honeycomb material available commercially, and occupies a volume of 2,800 ft^3 within the reactor. The media requires a thorough cleaning twice per year, during which water is blasted in to dislodge accumulated elemental Sulfur and biomaterial. It is estimated that the media will require replacement every 4 years at a cost of $13,000.

<u>Air Injection</u>

Oxygen (from ambient air) is introduced into the biogas stream to a concentration of 2% through 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 reactor volume containing the plastic media by means of a 10 HP pump at a design rate of 100 GPM. The vessel is divided into an upper and lower stage, with a separate trickling system installed at the top of each stage.

<u>Reservoir</u>

The base of the reactor vessel acts as a reservoir that collects the water/nutrient mixture that trickles through the media. The pH of the water is automatically 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 triggered to increase the pH.

<u>Nutrients</u>

Supplemental nutrients, are pumped into the reservoir as necessary from a concentrated 275-gallon supply tote. Approximately three totes per year are used at a cost of $1,100 per tote.

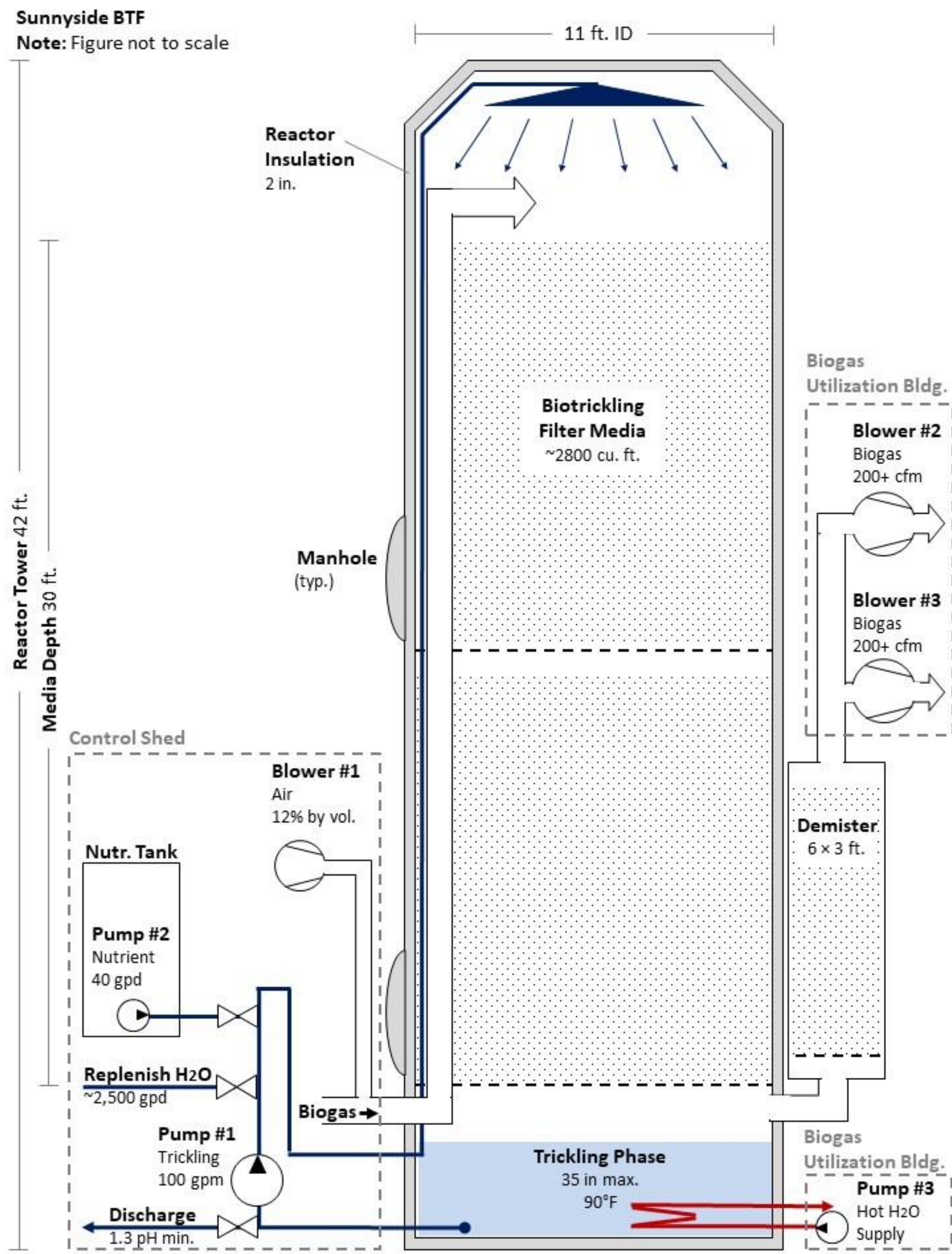

Figure 2. System diagram of Sunnyside biological trickling filter system

System Heat

To maintain the system at 90 F, hot water (190 F) is piped to the vessel in a closed loop 1.5" 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.

Demister

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 an internal pipe to the top of the vessel. 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 at the base, the biogas flows through a demister to remove larger drops of water. Moisture removed by the demister flows back into the reactor vessel.

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 1.3, or every two hours (lasting 5 minutes for the upper and 10 minutes for the lower stage). Approximately 2,500 gallons of fresh water are used per day to flush out the system. Flushed water is piped to the digester effluent long-term 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 February 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.

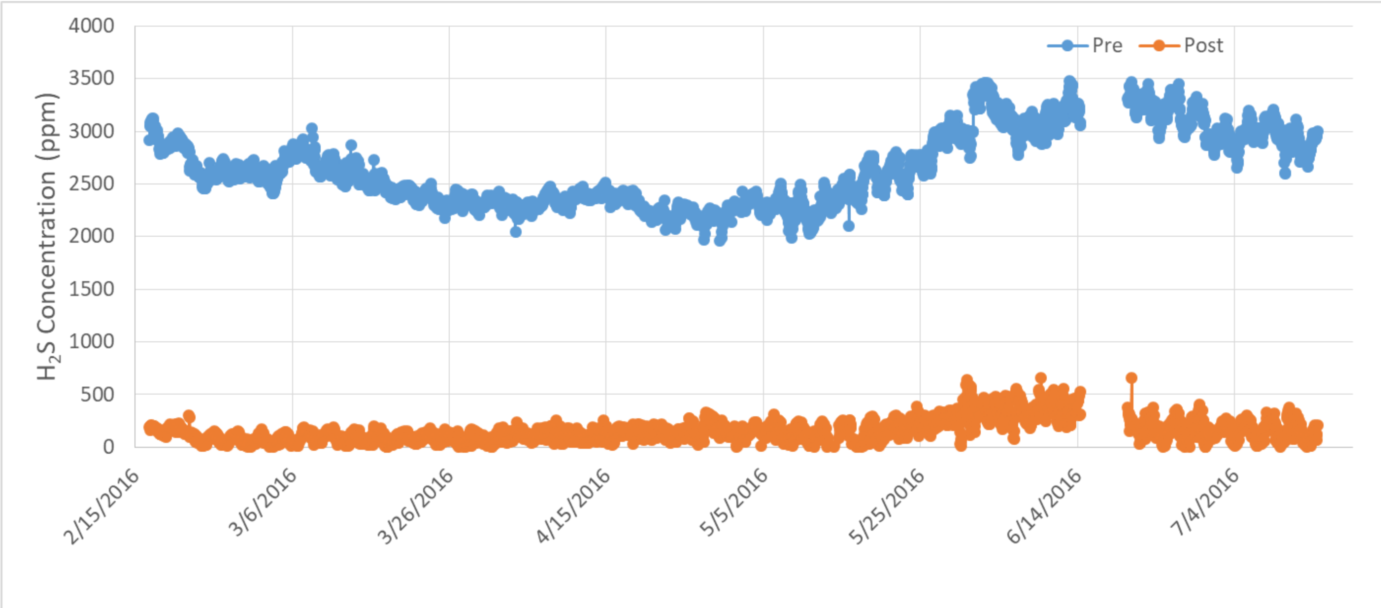

Figure 3. Sunnyside biogas H_2S concentrations pre and post Biological Trickling Filter

Table 1. Biological Trickling Filter Performance Summary

Average Pre BTF H_2S Concentration (ppm)	2,640 +/- 350
Average Post BTF H_2S Concentration (ppm)	150 +/- 110
Average H_2S Removal Efficiency (%)	94.5
Average H_2S removed from biogas per hour (lbs./hr.)	5.22
Engine-Generator Capacity Factor	0.93

Over the course of the monitoring period illustrated in Figure 3, the concentration of H_2S in the raw (untreated) biogas averaged 2,640 ppm with a standard deviation of 350 ppm. This is a fairly typical value compared to other local anaerobic digestion systems.

Post treatment concentrations averaged 150 ppm with a standard deviation of 110 ppm. Increases in concentration in the treated biogas were observed following the frequent flush cycling as well as a gradual overall increase, leading to a system shutdown and cleanout from 6/14 to .6/20.

Overall system H_2S removal efficiency was calculated to be 94.5% over the course of the monitoring period (February 15, 2016 to July 15, 2016).

Biogas flow through the BTF is maintained during engine maintenance due to the two separate engine-generator sets. While one engine-generator is worked on, the other continues to operate and consume biogas.

Economics

Capital Costs

The total capital cost of the BTF system was approximately $412,020 itemized as follows.

- Reactor vessel: $242,900
- Shipping/construction/installation of the BTF system (foundation and system installation): $107,000.
- Trickle Media: $13,000
- Gas Analyzer: $25,000
- Pumps, plumbing and blowers: $25,000

The capital costs have been annualized (Table 2) to illustrate the yearly capital cost of the BTF ($39,085).

Table 2. Component annual capital cost

Component	Purchase Cost ($)	Installation Cost[1] ($)	Useful life (yrs.)	Salvage Value ($)	Annual Cost[2] ($)
Scrubber Foundation	0	18,043	20	0	451
Reactor Vessel	242,124	88,853	20	24,212	24,218
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	5,625
Total					**39,085**

[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 6 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 156 hours was spent maintaining the scrubber equipment, for an annual cost of $5,772. In addition to regular maintenance and repairs, an additional $4,551 per year was spent on cleaning out the reactor vessel (2 cleanouts per year taking approximate 61 hours of labor per cleanout) for a total annual labor cost of $10,323.

Nutrient Solution

Three totes of nutrient solution were used per year, at a cost of $1,100 per tote (~$4 per gallon) for an annual cost of $3,300.

Replacement Parts/Supplies

Parts and supplies for use in maintaining the equipment totaled $5,600 per year. Additionally, the H_2S sensor requires annual replacement at a cost of $750 per year.

Utilities

Over the course of a year the biogas scrubber used approximately 45,000 kWh of electricity, and 340 MMBtus of hot water. The hot water was provided from the heat recovered from the engine-generator sets (from the hot water reservoir), and distributed to the scrubber through a hot 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 $1,800 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 $8,840 per year.

Total Annual Cost

The yearly operation and maintenance costs were $21,773, and the yearly capital costs were $39,085. The total annual cost to own and operate the scrubber was $60,858 for a year period spanning 2016/2017.

Before Sunnyside installed the BTF, they spent $23,896 per year on oil changes (750 hours between changes). After the installation of the BTF, $13,868 per year was spent (1,200 and 1,400 hours between changes) for a savings of $10,028 per year. The savings from reduced oil changes alone does not economically justify the BTF, however it is expected that more significant savings will be realized through increased intervals between more costly engine rebuilds/overhauls. 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

The original BTF system included a Union Instruments (model INCA 4003) gas monitoring system, which monitored and recorded concentrations of CO_2, CH_4, H_2S, and O_2 in the biogas, both before and after the BTF. Though not actually used for control of the BTF process, this data is useful for monitoring BTF performance, 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 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.

During a typical system cleanout, the vessel is usually filled with water to flush out accumulated elemental sulfur. During a cleanout in 2017, the vessel was filled with water, but unfortunately the fiberglass internal column through which biogas flows up to the top of the vessel, was closed off at the top. With the vessel filled with water, the buoyancy of the internal column was such that it separated from the side of the vessel and cracked in the process. For future cleanouts, a clear description of the procedure including when to open and close valves has been developed.

Due to the cracking, all of the media had to be removed from the system when it was discovered that the buildup of elemental sulfur was more extensive than expected, requiring intense manual labor to chip out and remove the encrusted media. To assist with future cleanouts, an additional access manhole was added to the side of the vessel (2017) to allow easier access and inspection of the media during cleanouts.

Contact Information

- Neil Rejman, Vice President, Sunnyside Farms Inc., Office: 315-364-5841
- Curt Gooch, P.E., Dairy Environmental Systems Engineer, PRO-DAIRY Program, Biological and Environmental Engineering, Cornell University, Phone: 607-255-2088, Email: cag26@cornell.edu

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