

EXPERIENCE WITH THREE ON-FARM DIGESTER SYSTEMS USING ADDITIONAL OFF FARM ORGANIC SUBSTRATES

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INTRODUCTION

One strategy to improve economics of on-farm anaerobic digester systems is to add off-farm organic substrates in order to increase Biogas production. This co-digestion strategy also has the potential advantage of receiving a tipping fee at the farm. This paper will discuss use of this strategy on three farms, while also examining issues such as; expected Biogas production per dairy cow, engine-generator set efficiency at several digester systems, methods of measuring methane content of Biogas, and hydrogen sulfide levels in Biogas at eight operating digester systems in New York State.

SUBSTRATES POTENTIAL

A study by Labatut et al. (2011) determined the specific biomethane potential and biodegradability of an array of substrates, including mono and co-digestion samples using a biochemical methane potential (BMP) assay, a bench-scale anaerobic digestion test. This test is designed to determine methane yield and biodegradability of organic materials. The results of about 175 individual BMP assays indicated that substrates rich in lipids and easily degradable carbohydrates possess the highest methane potential, while more recalcitrant substrates, with a high fraction of lignocellulosic components have the lowest. Results also showed that co-digestion of dairy manure with easily degradable substrates increases the specific methane yield when compared with manure-only digestion methods.

EXPERIENCES WITH SUBSTRATES

The University of Maine experimented by adding organic substrates to their 250 cow anaerobic digester in the 1980's. First experience was with cheese whey and no specific results were reported; only the general report that Biogas production did increase. Their second experience with added organics was much more interesting to the University, as food service waste from dining halls was collected and run through a grinder prior to being added to the raw manure pit. The food service waste added to Biogas production, but more importantly eliminated tipping fees to the local landfill. The University dairy herd was downsized in 1991, and digester operation ceased.

Recent experience has been with two farms in central Pennsylvania (330 cows & 420 cows) and one farm (560 cows) in central New York. Both Pennsylvania systems were designed with added substrates in mind, with consideration to both added revenue and future expansion. The complete mixed digesters were designed for 17 days retention time for substrates plus the current cow numbers, and the engine-generator set was specified to produce double the electricity expected from the current herd. Both farms

wanted to design for possible expansion, and this design concept anticipates that added substrates will be reduced as cow numbers increase, keeping Biogas production essentially constant and the engine operating at high efficiency.

As an example calculation, from prior experience anaerobic digestion of dairy manure is expected to yield 80 cubic feet of Biogas per cow per day, with methane content of 60%, and heat value of 550 BTU per cubic foot. For a 330 cow operation, expect about 25 gallons of 11% dry matter liquid manure per day, or 8,250 gallons per day. Organic substrates added at 25% of total volume would thus equal 2,750 gallons per day, and total input volume would be 11,000 gallons per day. It was expected that high yield organic substrates added at 25% of total volume could as much as double electricity production compared to dairy manure alone.

A total system designed to handle off-farm substrates should have separate containment for substrates, with mixing system and feed pump to allow for periodic addition of completely mixed substrates to the main manure reception pit. The main manure reception pit should also have a mixer and feed pump to periodically feed completely mixed manure and substrates to the digester. Consistent feeding is essential to good digester performance, so substrates need to be as consistent as possible, both in terms of quality and quantity. This need for consistency of feeding leads to the desirability of a separate holding tank and subsequent dosing system. Both Pennsylvania farm systems were designed with separate holding tanks for substrates, while the New York farm was not initially designed for substrates. On a trial basis, substrates were added to the manure reception pit at the barn on the New York farm.

In all cases when substrates are added an effective digester mixing system will be required within a digester. Mixing will keep solids from settling, but most important function is to eliminate upper crust formation. When too much liquid is added to as-produced dairy manure the fibers are washed and subsequently float to the top of a digester or manure storage. Without mixing, this crust will continue to form within a digester, causing outflow plugging and requiring eventual shut-down of the digester for cleaning, a difficult and costly operation. Crusts as much as 4 feet in depth have been experienced in digesters, and mechanical removal is extremely difficult.

Waste material from a local poultry processing plant was delivered to the 330 cow dairy farm, while wash water from a molasses plant was added to the 420 cow operation. Whey from a yogurt plant was added to the 560 cow digester system. In all three cases substrates came from a single, local source, an important factor related to the desire for consistent quantity/quality substrates. Poultry processing plant waste increased Biogas production from 26.4 CFM to 39.0 CFM and doubled resulting electricity production at the 330 cow dairy, from 50 KW to 100 KW. Conversion from Biogas energy to electrical energy efficiency increased from 19.6% (at 50 KW) to 26.5% (at 100 KW) as a result of the engine operating near full capacity. Farm was paid a tipping fee, and agreement also involved land spreading a portion of the digester effluent.

Molasses plant wash water (sugar water) was added to the 420 cow digester at an approximate rate of 7% of digester infeed for a period of several months, resulting in an increase of electricity production from 90 KW to 120 KW. Frequency of mixing was also

increased to eliminate the possibility of crust formation. Biogas meter was not functioning properly during this period, so Biogas production figures are not available. Subsequent tests with Biogas meter in place indicate that conversion from Biogas energy to electrical energy efficiency was 24.6% when operating at 90 KW (maximum rated load is 120 KW). Use of this sugar water ceased when the molasses plant would no longer pay a tipping fee.

Whey from a yogurt plant at approximately 25% of total volume added to the 560 cow digester increased Biogas production from 40.3 CFM to 41.7CFM, with little change in electrical output as the engine-generator set had been at near capacity with manure alone. Small increase in gas production may have been due to retention time being decreased from 17 to 13 days due to increased input volume. Separation prior to the digester took place at this farm to guarantee adequate quantity and quality separated/composted manure solids would be produced for bedding of cow stalls. Conversion from Biogas energy to electrical energy efficiency was 28.4% when operating at 96 KW (maximum rated load is 108 KW). Use of cheese whey ceased when yogurt plant would no longer pay a tipping fee.

Manure separation subsequent to anaerobic digestion is very common for on-farm systems, as separated solids are a source of bedding and/or a potential cash crop. The addition of organic substrates to manure does not appear to be detrimental to operation of manure separators. Expect approximately 1.0 cubic feet of separated manure solids per cow per day when separation takes place after digestion. If separation takes place prior to digestion, as in the case of the 560 cow farm, expect 1.5 cubic feet of separated solids per cow per day. Separated solids will shrink about 50% during complete composting, so consider that factor when considering cash crop value. Depending on location, value of separated manure solids for either bedding or cash sale may well exceed value of electricity produced by the engine-generator set. Economics thus depends upon electricity prices, cost of other types of bedding, and market for fresh or completely composted separated manure solids.

When adding substrates, consideration must be given to long-term manure storage capacity. Added nutrients brought in with substrates must be land applied in accordance with the Nutrient Management Plan for the farm.

HYDROGEN SULFIDE AND BIOGAS

Ludington, et al. (2011) studied the flow of elemental sulfur (S) in the manure treatment system at eight dairy farms with anaerobic digesters in New York State from January 2007 to March 2008. The dairies ranged in size from 430 to 948 milking cows. Digesters on five farms were traditional plug flow, two were horizontal and mixed, and one was vertical with a mixer. Food waste was imported at two farms, and there was pre-digester separation of solids at two farms. The sources of sulfur in the manure treatment system included the total mixed ration (TMR), drinking water, bedding, foot bath and food waste.

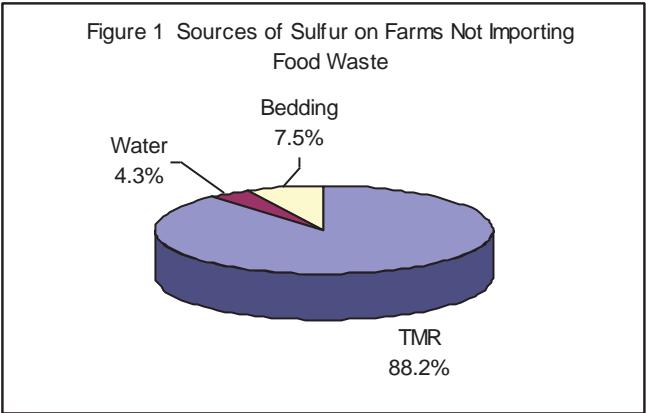
The major source of sulfur in the digester influent originated with the total mixed ration (TMR) as shown in the table below, 11.3 lb S/100 cow-days. The low standard deviation

shows the uniformity between farms. This was not true for water and bedding. Two farms had high sulfur drinking water (2.9 lb S/100 cow-days) while the other 6 were in the normal range (0.26 lb S/100 cow-days).

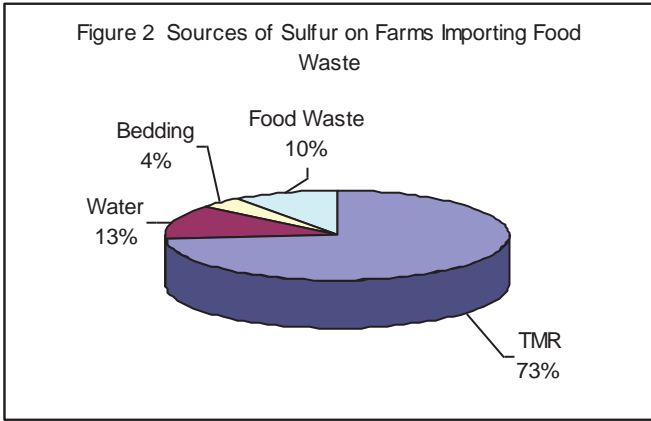
Summary of Mass Flow Inputs*	Farms	lb S/100 cow-days
TMR (8 farms)	8	11.3 ± 1.7
Water, "normal sulfate"	6	0.26 ± .22
Water, "high sulfate"	2	2.9 ± 1.2
Bedding, wood shavings	3	2.1 ± 0.5
Bedding, separated solids	5	5.3 ± 1.3
Food Waste	2	1.5

* Sulfur in milk was subtracted from these inputs to determine output from barn.

Five farms used separated solids (SS) which contains more than twice the sulfur as wood shaving (0.01 vs. 0.28 % S dry weight). At the same time farmers using SS used more bedding. As shown in the table, three farms using wood shavings for bedding averaged 2.1 lb S/100 cow-days while the 5 farms using SS averaged 5.3 lb S.



The sources of sulfur on the 5 farms not importing food waste are shown in the pie chart, Figure 1 with 88% from TMR. For the 2 farms importing food waste, the food waste contributed only 10 % of the sulfur.



The farm with the highest concentration of sulfur in the drinking water [420 mg SO₄/l] also imported food waste. This is the reason for the higher average contribution of S in the water (13%) on the two farms that import food waste.

The pre-digester separation reduced the sulfur content of the digester influent by about 40%.

Two farms used copper sulfate in the foot bath. At one 900 cow dairy the foot bath contributed 5 lbs S/day (5 lbs out of total of 104 lb S/day). At the second farm, only 1 lb S/day for 1,060 cows was contributed (1 lb out of a total of 140 lb S/day). Both farms used cupric sulfate· pentahydrate, where sulfur (S) amounts to only 12.8 percent of the molecular weight. The exact amount of sulfur that entered the digester from the foot bath is not known. Because of the copper, the foot bath was not emptied into the digester.

For the six farms not importing food waste the digesters produced an average of 79 ft³ (wet biogas at 60 F) per equivalent milking cow-day. An “equivalent milking cow” is based on the total solids from all animals and bedding. Considering the destruction of volatile solids, the average production of biogas was 15.5 ± 0.5 ft³ per lb of VS destroyed.

The concentration of hydrogen sulfide in the biogas averaged 3,860 ± 1,880 ppm for all 8 farms with a range of 1,020 to 6,730 ppm. (90 tests were made at each farm over a one month period) Approximately 28 % of the sulfur in the digester influent was released in the biogas, with a range from 17.5% to 46.1%. The mass flow of sulfur in the biogas averaged 2.57 ± 0.37 lb S per 100 cow-days. With roughly 80 % of the sulfur originating in the TMR, efforts to reduce sulfur would likely focus on TMR.

Three methods for determining the concentration of CO₂ and CH₄, 1) GEM 2000 unit, 2) Gastec gas tubes, and 3) Bacharach unit were compared. The GEM 2000 measures the gases in terms of dry biogas, while the Gastec and Bacharach units refer to wet biogas. The GEM 2000 measures CO₂ and CH₄ directly, while the Gastec and Bacharach units measure CO₂ only, with CH₄ assumed to be 100 minus the CO₂ reading. This subtraction method ignores water vapor present in the biogas. Comparing these three methods yielded average CH₄ readings of 59.8% for the GEM 2000, 63.9% for the Bacharach, and 63.0% for the Gastec unit. The Bacharach and Gastec units will always indicate elevated values for percent methane.

ENGINE-GENERATOR SET PERFORMANCE

As noted above, engine-generator set performance and conversion efficiency will depend on Biogas quality and quantity. Engine efficiency drops rapidly when loaded below 75% of full load, so engine-generator set selection is very important. The Bacharach CO₂ tester is a cost effective method for measuring CO₂, but an adjustment of 4% (add 4% to the CO₂ reading) needs to be made to account for water vapor in the Biogas. The two best measures of digester performance are CO₂ level and gas production. A gas meter is an essential instrument for all digester systems. Consistent

feeding and good temperature control are essential for digester operation, as taking care of a digester is similar to care for any other living creature.

Continuous operation is probably the main criteria for good engine performance, as Biogas contains both water vapor and hydrogen sulfide which can form sulfuric acid when engines are shut down and water vapor condenses. Hydrogen sulfide scrubbing continues to be an issue, with engine oil selection, oil change interval, and oil analysis all important factors to consider.

A good example of nearly continuous operation is the 330 cow farm digester discussed above, with 13,106 operating hours and 187 hours down, a run time of 98.6% of available hours. The 420 cow farm digester has 11,681 operating hours with 171 hours down time, a run time of 98.6% of available hours. The 560 cow farm digester is in its fifth year of operation and last year it had 8,554 operating hours with 206 hours down time, a run time of 97.6% of available hours. Hydrogen sulfide content in the Biogas on these farms ranged from 1,200 to 2,400 ppm. All three systems are a testament to good design, maintenance, and oversight. A good on-site operator is always the most critical contributor to success.

REFERENCES

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