Overview Of US Experiences With Farm Scale Biogas Plants

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Abstract
Farms are increasingly being required by their nutrient management plans to store manure, spread it close to the crop growing season, and utilize more fields to limit application to agronomic appropriate rates. These practices each increase the potential for odor conflicts with neighbors. While reducing their risk for water pollution, farms are facing increased opposition from those who object to the smell. Farms need a treatment method to obtain odor control that is effective, economical, and sustainable. Anaerobic digestion has been used and continues to be proposed as one method to treat manure to reduce odors and recover by-products. These systems have met with varying degrees of success on farms. Different types of anaerobic digesters have been researched and proposed as appropriate technology for on-farm use. Many farms are considering the application of anaerobic digestion to reduce odor that over time may provide a positive return to the farm. Each dairy farm is different and anaerobic digestion systems vary both in cost and in function.

This paper provides an overview of some of the digestion experiences in the US. Emphasis is placed on dairy farm systems in the Northeast US. Economic results, treatment parameters, and energy production are shown for five digesters with documented results. Barriers and opportunities for adoption of this technology are discussed.

Introduction
Changes to the rural landscape are occurring. However, although the price of milk received by dairy farms varies, the average price has not increased much in the last 20 years. Other production costs such as land prices, equipment, and labor have increased. Cost control is increasingly seen as an important aspect to successful dairying. From 1997 to 2001 the average net income per cow in the Northeast ranged from $42 to $440 per year. This is forcing farms to adopt methods to cut costs.

Society has recognized that animal agriculture can lead to excess nitrates in the ground water, pathogens in the drinking water and excess nutrients, BOD, and sediment in surface water. To avoid these problems manure will increasingly be spread on dry soils, in fields where the chance of runoff and leaching are low. Environmental agencies are prescribing these changes. There are now many state, provincial, and federal regulations on the timing and amounts of manure spreading. To hold the manure until the appropriate time to spread manure storage will be a standard practice on most farms. Only 10% of the dairy farms in New York State have more than 6 months of storage.

Concentrated Animal Feeding Operations (CAFOs) are specifically defined as point sources subject to the NPDES permits program. The definition of a point source in the Clean Water Act of 1972 includes a concentrated animal feeding operations from which pollutants are or may be discharged. Farms that have more than 200 cows or 300 heifers and the potential to discharge should get a permit in New York State. Those farms with fewer animal units may be designated as needing a permit if they are found to be polluting. Smart farmers have begun to plan for these requirements.

Manure from storages is already generating many complaints about odor. When manure is stored, it starts to decompose anaerobically. The by-products of incomplete anaerobic decomposition are very smelly. Society objects to bad odors as much, if not more, than to dirty water. Therefore treatment for odor control will become much more common as farms are forced to convert to storing their manure.

There are a wide variety of farms. They vary in their resources and their environmental concerns. Some farms have access to more capital, skilled labor, management ability, land resources, water resources, and markets than other farms. Different manure treatment and handling methods will be needed to match the resources and needs of different farms. Anaerobic digestion is one possible solution for farms.

Anaerobic digestion may be a viable manure treatment and handling method for dairy farms. This process produces renewable energy, helps to control water pollution, reduces odors, and reduces the emissions of greenhouse gases. Methane production and then the irrigation of the odorless effluent through irrigation systems during the growing season is a method of manure handling that has a beneficial impact on the environment. These systems combined with a nutrient management plan will also improve neighbor relations and will help provide for sustainable development of the dairy industry.

Anaerobic Digestion for methane production can almost completely control odors from manure. It requires skilled operation and management to run the biological process, the material handling, and the energy utilization. It helps to have a use for extra heat since as much as 75 % of the energy produced is wasted as heat. Many of the existing systems have a high capital cost and may be dependent on above market prices for energy to be profitable based on electric production alone. Liquid manure of uniform consistency unmixed with runoff should be used as the feed to a digester.

Anaerobic digesters for typical dairy manure are plug flow systems. Manure is added to one end of an insulated impermeable container. The added manure forces out an equal amount of effluent from the other end of the digester. With a typical 20-day retention time, manure that enters will leave, neglecting dispersion, 20 days later as digested effluent.

Mixed systems may also be used. These systems use agitators to mix the incoming manure (and other substances) with the material in the digester. This agitation is used to keep the material in a consistent slurry. Material leaving the digester will contain a fraction of the just-added manure. Their retention time is also about 20 days. Mixed digesters can handle material and moisture contents (that may occur when adding food waste) that would settle out or crust over in plug flow digesters. Table 2 shows the advantage of adding food wastes to the on-farm digester systems.

Anaerobic digestion can occur in lagoons, which are popular in warmer climates. Because lagoons operate at an ambient temperature rather than at an elevated temperature, they breakdown solids more slowly than anaerobic digesters. Recently there have been a number of impermeable covers put on anaerobic lagoons that will trap the biogas produced.

The cover floats on top of the lagoon, capturing methane that is produced and sometimes preventing the dilution of the manure with rainwater. This is a less expensive way to build and operate an anaerobic digester. Some existing manure storage facilities can be retrofitted with a cover, thus making the addition of methane generation and odor control less costly. The covers have to be substantial to withstand the rigors of weather.

When lagoon temperature is high enough, the proper mix of bacteria will break down solids and produce methane and carbon dioxide, both odorless gases. However, because the bacteria won't function properly at low temperatures, neither does the lagoon. The result of an improperly functioning lagoon is an accumulation of solids, an overloaded lagoon, and potential odor problems when lagoon temperatures rise in the spring. Treatment lagoons have not been popular north of the Mason Dixon Line partially because they require a large land area and treatment is seasonal. There may be some covered anaerobic lagoon systems installed in northern latitudes. Time will tell if their operation over the winter will be adequate.

The nutrients are not removed by anaerobic digestion. There is a shift of about 30% of the organic nitrogen to ammonia. This may be a benefit to crop production if the effluent is applied right away. During storage the ammonia may volatilize. Nutrients (and solids) will tend to settle out of the anaerobic effluent. There may be as much as 5 to 8 times less nutrients in the top layers of the effluent storage compared to the bottom sludge. There is a loss of solids in this treatment process resulting in a 2 -3 % increase in the moisture content of the effluent compared to the raw manure entering the system.

Since the early 1900s municipal treatment systems have been collecting biogas from anaerobic sludge digestion. Many wastewater treatment plants continue to do this around the world. In Asia, countries with a low labor cost and relatively high-energy cost use many large and small-scale anaerobic digestion systems to produce energy to heat homes and cook. Europe has a number of large digestion systems that combine many sources of organic material and process it anaerobically to produce energy.

During and immediately after the energy crisis caused by the oil embargo in 1973, many anaerobic systems were built to produce energy. At least 71 were installed on commercial livestock or poultry operations. With lower energy prices many of these systems were abandoned. Of the 71 only 25 were still operating in 1995 (EPA). Now stricter environmental standards including the need for odor control are bringing a resurgence of anaerobic digestion on livestock farms again.

Biogas

The biogas produced is expected to be about 60% methane and 40% carbon dioxide (see table 1). Pure methane has a heating value of 912 BTU/ft^3 (at standard temperature and pressure). Since biogas is only 60% methane its heating value is 40% lower at about 540 BTUs/ft^3. Biogas is not easily compressed. Even at 2000 lbs. per in^2. It takes about 14 gallons of compressed biogas to equal the energy value of one gallon of diesel fuel. It would be very difficult to use the biogas for anything but continuous on site consumption. Biogas from dairy manure typically contains 0.2-0.4% hydrogen sulfide H_2S. This is very corrosive at low temperatures since it converts to sulfuric acid. Engine systems need to be adopted for this low energy density and potentially corrosive fuel.

In a well-run plug flow digester, biogas production of at least 1.5 ft^3/day/ft^3 of digester volume can be expected (Koelsch et al). Production of biogas is dependent on the retention time and the energy in the raw manure. Biogas production has also been related to volatile solids (VS) with ranges from 3-7 ft^3/lb. VS being reported with 6 ft^3/lb. VS being typical for a plug flow digester (EPA).

Five Examples

Five farms in NY have been part of a research project over the last three years (Wright et al 2004). Descriptions of these farms can be obtained at the website: www.manuremanagement.cornell.edu Manure samples were taken monthly at key locations for each system. The data reported for Farms DDI, NH, and ML include times when the digesters, due to start-up conditions or other operating upsets, may not have been operating as designed. Care should be taken when using this data and comparing these analyses since the operating conditions on each farm are different. Table 1 shows some of the information collected from these farms. Among the five farms, Farm ML is the only one that adds food waste to its digester. Many of the comparison parameters in table 1 reflect this difference. As expected the fecal coliform in the food waste was very low. The volatile acids in the food waste were much higher, indicating that the digestibility would be high as well. The pH of the food wastes was lower, which could be a problem if the food waste was digested alone, since methanogenic bacteria are susceptible to low pH; however, the manure in the digester buffers the pH of the food waste.

The nutrient levels in the food waste imported by Farm ML were not very different compared to the nutrients in the raw manure on all five farms. Food wastes can vary from load to load, but in general they have a larger available energy to the digester with about the same proportion of nutrients compared to raw manure. Overall, Farm ML has the highest solids reduction rates compared to all the other farms (see table 3), which probably means the digester is much more efficient at reducing odor and producing biogas, due to the mixture of food waste with the manure.

Farm ML produces 250,400 $ft^{3/}$day of biogas as calculated by the VS reduction that occurs. The methane percentage also tends to be higher compared to digesters that only receive manure. For example, on Farm ML the average methane content of the biogas is 70%, whereas on Farms AA and NH the average methane content is 62% (see table 3). Little research has been done to explain the effect of food waste on biogas production in manure digesters. Farmers need to be cautious with the amount and types of food wastes they add to manure digesters until these systems are better understood.

The level of fecal coliform in effluent from Farm AA is significantly lower than the rest of the farms, probably because the Farm AA digester has the longest retention time (about double the others). The sampled characteristics in Table 1 are averages and will vary from day to day.

Table 1. Digestion comparisons of five different manure digestion systems. (Wright et al 2004)

Farm	AA	DDI	NH	ML	FA
No. of Milking Cows	500	850	1,100	740	100
Digester Type	Plug flow, soft top, manure infeed	Plug flow, soft top, manure infeed	2 parallel Plug flow, hardtop, Manure infeed	Mixed, soft top, manure and food waste infeed	Fixed Film, concrete tank separated liquids infeed
BiogasProductionft^3/ cow-day	85	41	64	*[1]	24*[2]
% CO_2 / % Methane	38% / 62%	32% 68%	38% / 62%	30% / 70%	33% / 67%*[2]
Hydraulic Retention Time	40 days	21 days	25 days	21 days*[1]	4 days*[2]
Gas Use	Caterpillar engine generator 130 kW	Capstone microturbines 60 kW*[3]	Caterpillar engine & Marathon generator 130 kW	Waukesha engine & Marathon generator 145 kW	Smith cast iron boilers
Fecal Coliform Reduction (%)	99%	99%	98%	94%	98%*[2]
Effluent Volatile Acids mg/kg	496	1,413	Digester 1 = 520 Digester 2 = 590	386	929*[2]
Total Solids Reduction (%)*[4]	27	23	24	62	22*[2]
Volatile Solids Reduction (%)	32	23	31	67	26*[2]
Increase in Ammonia (%)	37	27	Digester 1 = 36 Digester 2 = 30	37	11*[2]
Increase in Otho-P (%)	17	13	Digester 1 = 60 Digester 2 = 45	3	15*[2]

*[1] 250,400 ft3/day of biogas was calculated as the average daily production. Since most of the biogas is from food waste, per cow figure is not appropriate.

*[2] For the period 6/2/02 to 4/25/03 when the digester was performing as a fixed film digester. Separated manure liquids only.

*[3] Problems with biogas pre-treatment have resulted in poor performance of the microturbines.

*[4] Reduction in solids from the influent to the effluent of the digester.

Potential pathogen reduction was above 94% for all digesters, and the average was near 99%. On the other hand, the reduction rate varies for other parameters, generally in accordance with the retention time. Since Farms DDI and NH were both still in a start-up period and had operating issues during the time data was being collected, their performance characteristics are expected to improve. The effluent volatile acid levels in the DDI, NH and FA Farms are above the recommended 500-ppm for odor control.

There was a shift in the effluent on all farms toward more nitrogen in the ammonia form and more phosphorus in the Ortho-P form; however, the total amounts of N and P remained about the same. These inorganic forms of N and P are more available to plants, and also more easily lost to the environment compared to organic forms. Nutrient management planners can use these results to better plan the rates and timing of manure applications so as to maximize the amount of nutrients available to the plant, and to minimize losses to the environment. Since the odor is reduced, it is possible to apply the effluent closer to planting time, or even during the growing season, without causing odor problems with neighbors. Actively growing plants make the best use of manure nutrients.

Economics

A complete economic analysis is needed for anaerobic digester systems so a producer can make an informed business decision regarding their use. Producers who make a capital investment in an anaerobic digester need to understand the economics of the system; otherwise, they risk making poor investment choices. The capital and estimated operating costs for the five farms are shown in table 2. The available data for the capital costs shown have not been adjusted to reflect the grant funds each farm received.

Table 2. Estimated net income or loss for the five digester systems. (Wright et al 2004)

	Farm				
	AA	**DDI**	**NH**	**ML**	**FA**
Number of Cows	500	850	1,100	740	100
Capital Costs					
Digester Set	$192,000	$442,200*[4]	$339,400	$298,149	$80,183
Separator Set	$50,000	$89,000	$61,000	$61,689	$44,013
Gas Utilization Equipment	$61,000	$138,200	$287,300	$130,431	$13,135
Total Capital Cost	$303,000	$669,400	$687,700	$490,269	$137,331
Total Capital Cost Per Cow	$606	$788	$625	$663	$1,373
Annual Projected Capital Cost	$25,468	$52,978	$63,274	$49,016	$13,396
Annual Projected Capital Cost Per Cow	$51	$62	$58	$66	$134
Total Estimated Annual Cost*[1]	$37,540	$79,317	$103,960	$70,880	$21,497
Total Estimated Annual Cost Per Cow*[1]	$75	$93	$95	$96	$215
Total Estimated Annual Revenues	$56,445	$60,400*[3]	$77,680	$287,685	$10,900
Total Estimated Annual Revenues Per Cow	$113	$71*[3]	$71	$389	$109
Total Estimated Annual Cost or Benefit*[1] *[2]	$18,906	-$18,917 *[2] *[3]	-$26,280*[2]	$216,805	-$10,597*[2]

Total Estimated Annual Benefit Per Cow*[1] *[2]	$38	-$22*[2] *[3]	-$24*[2]	$293	-$106*[2]

*[1] Does not include system electrical use.

*[2] Negative numbers mean the farm incurs a net loss from the digester system.

*[3] The electrical savings for DDI assumes the price of electricity is 10 cents/ Kw. This farm actually incurs a lower cost due to a specific business initiative. Since this is not typical of most dairy farms, the higher price is used.

*[4] This cost assumes the microturbines were purchased new.

Total capital costs vary because each digester is specifically designed for each farm. For example, Farm DDI has microturbines; Farm FA doesn't generate electricity; and the three other farms use engine-generators. Farm AA's capital cost is less than its electricity-generating counterparts because it was built in June of 1998. The total annual cost or benefit calculation is considered to be the cost the farm pays for odor control when values are less than zero. Farm ML has high earnings because of the annual tipping fee they receive. Total annual cost per cow is not correlated with the total number of cows, again showing that site-specific systems have highly variable costs.

Engines-generators

Most anaerobic digestion systems use the biogas to either run a boiler or to run an engine generator. Large engines have been adopted for biogas use produced from landfills. Researchers have produced long lasting engines that can use poor quality gas. They are experimenting with adding diesel fuel to make the engine both more responsive to electric demand and to add needed fuel to the methane to fully utilize the engine's capacity. These same adaptations of the spark plugs and carburetors work with smaller engines that are found on on-farm engine generators. There may be a slight decrease in the output of these engines with a low BTU fuel.

The engine will need to run a generator. Induction generators run off the signal from the utility and are used to allow parallel hook up with the utility. A synchronous generator could be run independently of the utility but matching the utilities power signal would be very difficult so these types of generators would be used if the system were not connected to the utility grid.

The electric production depends on the amount and quality of gas as well as the efficiency of the engine generator. Typically, 33-38 kWh/day will be produced per 1000 ft^3/day of biogas produced (Koelsch et al and EPA). An operation and maintenance cost of $0.015 per kWh is estimated for engine generators (EPA).

Safety

There are safety issues of asphyxiation, fire, and explosion associated with the production of biogas. Biogas does not contain any oxygen. Dangerous amounts of ammonia and hydrogen sulfide may also be present. Never enter a digester without extensive mechanical ventilation, using gas detection equipment, and using safe entry procedures. Natural ventilation cannot be trusted, as some gases such as H_2S and CO_2 are heavier than air and can concentrate at the bottom of the empty digester, while NH_3 is lighter than air and could be caught at the top of a structure. Methane can explode when mixed with air in concentrations of 5 to 15%. Certainly a fire hazard exists from leaks in a gas line.

The same hazards associated with large engines and electrical generation are also present at these systems.

Advantages

Environmentally, one of the main advantages of anaerobic digestion is the ability to spread the effluent at different times and different places than was previously socially acceptable. Spreading odor free material during the warm times of the year when the fields are dryer and the nutrient uptake is at a maximum should be an improvement to the water quality. Spreading on fields that were previously too close to residences would allow the manure to be distributed to more fields and reduce the fertilizers imported on to the farm. The effluent from the anaerobic digesters is more likely than manure to be used on non-farmland like golf courses. The effluent will have essentially the same nutrients as the raw manure with a shift from organic N to NH_4.

The decrease in solids content during digestion will provide a more liquid effluent that will be easier to handle in liquid systems. The separation process would also decrease the amount of solids that would be sent through the spreading systems. This would decrease the problems of plugging and extra power requirements of handling a stiffer liquid.

Anaerobic digestion is an excellent way to reduce the odor in the manure. The larger the farm, the greater the economic feasibility of anaerobic digestion. Methane production has efficiencies of scale that turn positive at around 500 cow farm sizes. Anaerobically digested manure has a significantly limited odor. Most easily digested organic matter will be broken down in the anaerobic digestion process. The gas production is controlled and burned so no odors escape. The resulting effluent is mostly inert organics and does not develop the objectionable odors that raw manure storage produces.

As the manure is anaerobically digested some of the solids are converted to methane gas, carbon dioxide gas and water. About 4% of the solids are converted reducing the solid content and raising the moisture content of the effluent about 4%. This change, in addition to some breakdown of the fibers in the manure, makes the resulting effluent much easier to pump. Solid separation systems also seem to work better on digested effluent than on the raw manure.

Dairy manure from 500 cows is estimated to produce about 42,000 cubic feet of biogas per day. By using a 70 kW engine and generator, this could produce about 1390 kW/d of electricity and allow significant heat recovery from the engine. It may be difficult to sell the electricity and to use all the heat produced.

There have been a number of anaerobic digesters installed on farms. These systems have a mixed record of success. They are more likely to get the management attention they need to work well where they are not exclusively run to generate a profit from electricity, but are also needed as an odor control system.

Additional monetary benefits can be added to the dairy's cash flow. These benefits may include a monetary value per cow for odor control, bedding material recovered from the digested manure, protein feed grown from the liquid slurry effluent from the digested manure, and a monetary value associated with environmental benefits.

Barriers to Implementation

The large capital costs and generally low rates of return from digesters are the largest hurdle to implementation of this technology. In some European countries where energy prices are higher and green energy prices are even higher, a huge number of digesters have been built and continue to be run overtime. Unfortunately in North America these subsidies and price structures don't exist. A potentially high profit from the digesters from both energy and/or separated solid sales would soon overcome any of the secondary barriers to implementation.

Lack of continued management is one of the main reasons installed digesters fail. This is directly related to the lack of profit from the systems. In general, people recognize where their main income from the farm comes from and concentrate their efforts in that area. Normal maintenance and monitoring of the digester may take about one half hour per day. However when something goes wrong delaying the needed fix will lead to a much more severe problem. A service industry that could help the farms maintain the digesters would certainly develop if there were significant profit from the system.

Digesters don't always run trouble free. With any biological process changes in the feed or the environment can upset the system. Adding different types or amounts of influent can allow the acid formers to out-produce the methanogens. Acidic conditions can then develop which will further decrease the production of the methanogens.

Digesters fed too high of a moisture content (less than 10% DM) may result in settling out or crusting of the solids. Heavier solids will settle to the bottom taking up space so the retention time is reduced. Lighter solids may float, again using up volume so the retention time decreases. Crusting may plug the outlet of the digester. Bedding types and quantities that settle or crusts needs to be avoided. Sand will settle and rapidly fill the digester reducing the retention time.

Foaming can occur if the bubbles that bring the gas to the surface don't pop. Excessive foaming can plug the gas outlet or enter the gas line and gum up pressure regulators or other equipment.

Maintaining the temperature of the digester is critical. Heat pipes, if operated at too high a temperature, can build up cooked-on manure that reduces their heat transfer efficiency. Poorly insulated digesters may lose too much heat in the winter to maintain temperatures. Frozen manure can require so much heat to melt that there is not enough heat to bring the manure up to operating temperatures. With lowered temperatures the gas production drops, resulting in even less heat being available. Cold manure entering the digester, being denser than the manure in the digester, may flow along the bottom of the digester to the outlet, thus short circuiting the biological processes. There may be physical problems in the digester that encourages short-circuiting as well.

The environment inside the digester can be very corrosive. If two different metals are present one will become a cathode and one will become an anode. The metals will then corrode rapidly.

Working with the utility to negotiate and maintain electric sales can be frustrating. In general utilities don't want to be bothered with a non-utility generator the size of on-farm digestion systems. Producing electricity is only part of the problem with making an anaerobic digester cost effective. Meeting the criteria of the electric utility to sell the electricity may be challenging. During the 1970s energy crisis extra power production was welcomed and encouraged. Lately the price paid to non-utility generators has been under $0.025 per kW. Specific requirements for insurance, demand charges for the use of electricity when the on site generator is down, and other rules may be difficult to meet.

Various designs for digesters are still being explored with no clear reason for a producer to chose one design over another. Designs continue to create production and maintenance problems for the farm as new design entities continue to enter the market. Designs that don't allow for easy clean out (or mechanisms to prevent settling) will leave a farm struggling when the HRT is reduced. Gas collection, handling and cleaning systems have also provided challenges to farms and their engine generator.

Not all environmental issues are solved with digestion. Since the digested effluent has been reduced only 4% from digestion and the effluent still contains all the nutrients, it will need to be stored, on most farms, until the appropriate time to spread. Separating the solids out prior to storage can reduce the liquid storage amount by about 20%. With the moisture content reduced and the odors substantially eliminated it may be possible to store the anaerobically digested effluent further from the barn, closer to the fields where it will be applied, and closer to neighbors. There may be additional ammonia losses from anaerobically digested manure as it is stored and applied.

Odor control is now a necessity on many large farms. Farms are looking for a way to achieve odor control without a large annual cost. There are larger farms with economies of scale where a digester would have a lower annual cost. On farms, the ability to manage biological systems has increased. The electric demand on some large farms is steadier than in the past. The effluent from the digester is conducive to solid separation. This equipment as well as liquid manure handling systems are more advanced than 30 years ago.

Digesters that survived over time did so because the system worked well, the operator had technical skills available, and/or the operation realized either monetary (from by-product sales) or odor control benefits.

Energy Production

There were 7,644 dairy farms and 686,000 milk cows in New York State (New York Agricultural Statistics Service, 2000). Multiplying the total number of cows with the methane production from dairy manure, it can be shown that the methane potential was

288806 tons/year or 15023.4 million ft^3/year if all of dairy manure in New York was collected and processed in anaerobic digester system to produce biogas.

Since methane is the major component (95%) of natural gas, with which people are more familiar, it is useful to translate the methane potential into natural gas equivalent and also show the energy savings based on natural gas price. Based on calculations, after the methane potential from dairy manure was converted to natural gas equivalent, it is 15,814 million ft^3/year, which is roughly the same as the marketed production of natural gas – 17,757 million ft^3/year in New York State (EIA, 2000). In 2000, the total consumption of natural gas in New York was 1,256,683 million ft^3. That means the biogas methane can only possibly meet 1.26% of this total consumption, which is ranked 4th among all states.

Opportunities for Improvement

Fixed-film digesters may be a technology to help overcome the limitations of conventional digesters. After liquid solid separation, an anaerobic digester with interior surfaces (fixed-film) can be used so that microbes cling to the surfaces, and are not flushed from the digester. This increases the microbial population, and decreases the digestion time when compared to conventional digesters. Removing the large solids prior to digestion will reduce biogas production, but this fixed-film system might make odor control practical for smaller farms. Building on research results from the University of Florida, it is expected that the digester vessel will be 1/5 the size of a conventional digester. Since the tank is now 40% of a digester system cost, this approach has the potential to greatly reduce digester system cost.

There may be some efficiencies to be gained by using a heat exchanger to transfer heat from the effluent to the incoming manure (Gebremedhin). Systems that reduce the solid content of the manure first like fixed film digesters may particularly be able to use this technique. Steam may be a possible way to heat digesters. This could especially be used if thermophillic digesters are desired for pathogen control. High temperatures in conventional heating coils in digesters can get manure baked on them. Sending steam into the digester would be one way to get high temperatures without baked on manure.

The possibility of using other digestible products from on and off the farms should be considered. Adding specific organic matter to optimize the digestion process is one way of increasing the energy output without increasing the capital costs (Bush, Dugba, and Wright and Ma).

Digester performance can be enhanced with the use of micronutrients and enzymes. Both startup and operation can be improved with some bacterial products and some mixes of nutrients. Systems that recycle a concentrated effluent to increase microbe populations may also be a method to increase the output from a digester.

Conclusions

- There are a number of different anaerobic digestion configurations that might be appropriate for different farms depending on the farm goals, resources, and situation. Each farm needs to determine the type that works best for them.

- There are significant differences in the performance of the digesters. Volatile acids and pathogen reduction varied from digester to digester. Nutrient values seemed to vary less on each farm, as well as between farms.
- There are significant differences from farm to farm in the cost of manure systems components.
- The addition of food waste increased the amount of methane produced by the anaerobic digester, and dramatically increased the amount of biogas produced.
- Anaerobic digesters have a high capital cost and potentially higher annual costs than traditional manure treatment systems. Farms with fewer cows may not be able to afford a digester system because they have fewer animals to spread the costs over. Grants can offset capital costs for some farms.
- Food waste provides the farm with an opportunity to turn manure treatment into a profit center.
- Anaerobic digestion has the potential to significantly reduce the number of potential pathogens in the effluent. When more emphasis is placed on reducing the potential for pathogen contamination from spreading manure, anaerobic digestion should be one of the techniques considered.
- Farms should consider anaerobic digestion if:
    - Odor control is needed,
    - Much of the manure on the farm can be easily collected in a liquid handling system,
    - The technical skills and interest in running the system are available and,
    - Financial resources are available to provide the high construction costs.

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