Overview of Anaerobic Digestion Systems for Dairy Farms

Peter Wright
Senior Extension Associate
PRO-DAIRY Program
Biological and Environmental Engineering Department
Cornell University

Introduction

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 (NMP) 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 (see Table 1). 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 with the material in the digester. This agitation is used to keep the material in consistent slurry. Material leaving the digester will contain a fraction of the just added manure. Their retention time is also about 20 days.

Anaerobic digestion can occur in lagoons. Anaerobic lagoons are popular in warmer climates. Because lagoons operate at ambient temperature rather than at an elevated temperature, lagoons break down 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, the bacteria won't function properly at low temperatures, and 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 small shift of about 5% 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 (see Figure 3). 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 several 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.

Anaerobic Digestion Process

Anaerobic digestion is the breakdown of complex organic material by microorganisms in the absence of oxygen. The end products are methane CH_4, carbon dioxide CO_2, some trace gases, and stabilized organic matter. This process does occur naturally in many existing manure storages. Unfortunately in most natural situations it doesn't go to completion and many of the intermediate products of the anaerobic digestion are quite odiferous.

The process involves three groups of microbes, and is illustrated in Figure 1. Liquifying bacteria start the process called hydrolysis by using extra cellular enzymes to convert insoluble fibrous material into soluble material. Not all the material can be converted. Inorganic solids, and hard to digest organic material will come through the digestion process intact. Next acid forming bacteria convert the soluble carbohydrates, fats, and proteins to short chained organic acids. These acids are the food for the methane producing bacteria or methanogens. They are the ones that live by obtaining small amounts of energy converting acids into methane and carbon dioxide.

The methanogens are much more sensitive to pH and temperature changes, cannot tolerate oxygen, and need the simple organic acids for food. The range of pH methanogens prefer is from 6 to 8 with optimum pH of 7. The acid formers are much more robust. They grow faster than the methanogens, are less sensitive to temperature fluctuations and pH changes, can tolerate oxygen and can feed on a wide variety of organic material. Digesters need to be able to retain enough methanogens to complete the breakdown of the acids and produce the methane. It is very important that an anaerobic digester designer consider the environment in the digester to be sure the pH, temperature, and retention time are appropriate for the population of methanogens to survive and thrive.

There are three temperature regimes that methanogens grow in. The lowest temperature range, less than 68 degrees F, is called the psychrophilic range. Methanogens in this range grow slowest and produce the least biogas per unit of time. Covered lagoon systems, especially those in northern climates, will be in this range much of the year. The mesophillic range that centers at an optimum of about 100 degrees F is the most common temperature for methane digesters. Thermophillic operation at about 130 degrees F may be able to produce more biogas per unit of time, provide better pathogen control, and shorter retention times, but the difficulty of getting and holding the high temperatures steady has so far prevented livestock operations from adopting this temperature range.

It typically takes 20-25 days to allow time for the methanogens to grow and reproduce in sufficient quantities to replace the ones that are removed on a daily basis. Shorter retention times are possible under conditions of high growth. Thermophillic conditions have often been thought to foster faster growth. Providing a media that the bacteria cling to can also retain more bacteria. Systems that take a portion of the effluent, concentrate the bacteria and then recycle it back into the influent end of the digester can increase the solid retention time allowing for more growth of the slower growing organisms.

The anaerobic digester digests the solids in the manure. The solids can be divided into total solids (TS), which include the volatile solids (VS), typically 70% of the TS, and the remaining inorganic fraction. The volatile solids can be divided between biodegradable volatile solids, typically 50%, and non-biodegradable solids. Typical dairy manure entering the digester at 12% total solids will leave with about 8% solids. That is, one half of the volatile solids, the biologically degradable ones, are converted to methane and carbon dioxide. Typical solid separation of the effluent will remove 4% of the solids from the effluent. About one third of the solids are converted to gas, one third can be separated out mechanically, and one third remain in the separated liquid effluent (Mattocks).

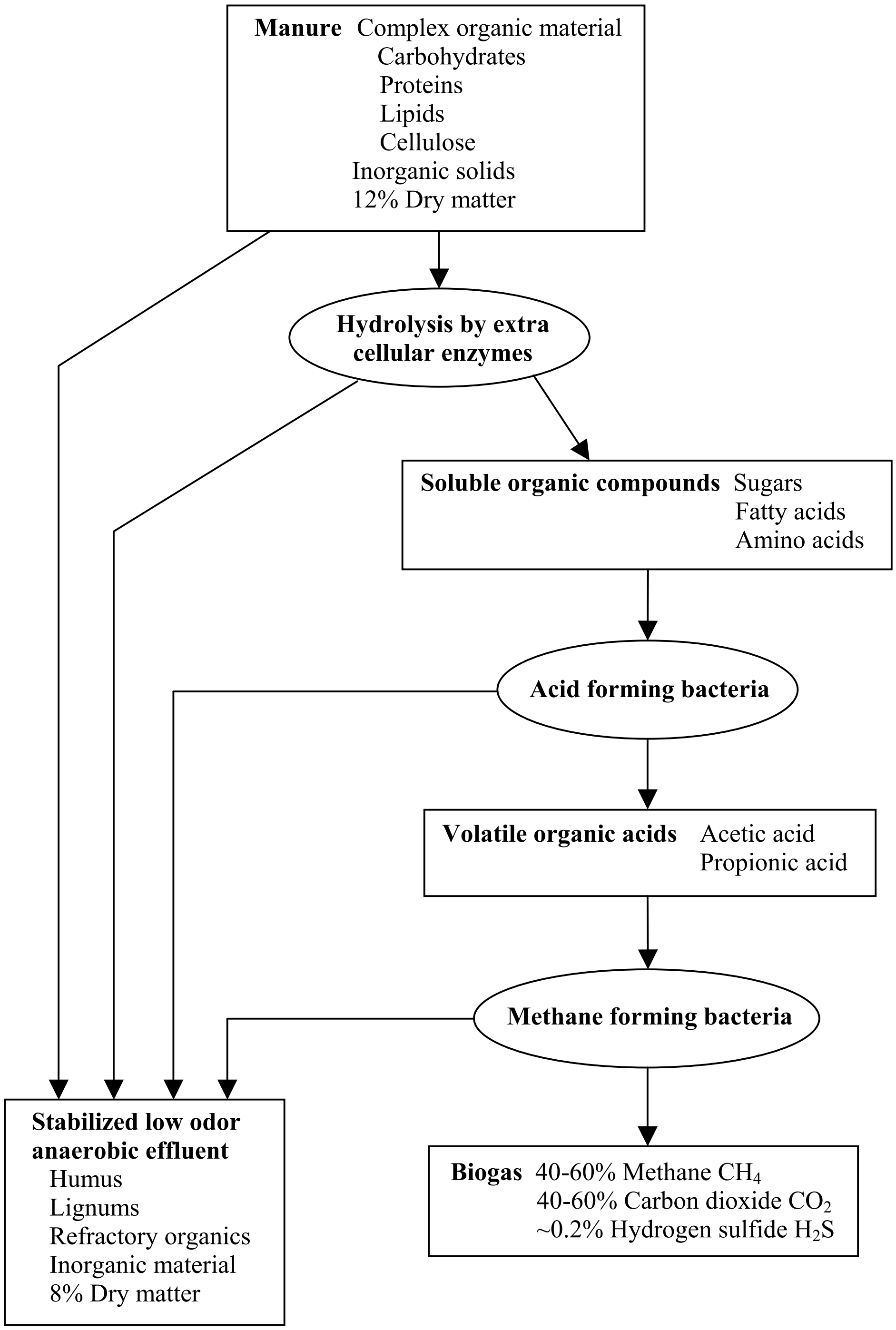

Figure 1. Anaerobic digestion of dairy manure.

Peter Wright, "Overview of Anaerobic Digestion Systems for Dairy Farms," Natural Resource, Agriculture and Engineering Service (NRAES-143), March 2001.

Biogas

The biogas produced is expected to be about 60% methane and 40% carbon dioxide. 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 sq.in. 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).

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. Choose a naturally aspirated engine since turbochargers are susceptible to corrosion from the impure biogas.

Table 1 compares typical fuel-to-power efficiencies of various types of prime movers. These efficiency figures do not account for increases due to the use of cogenerated heat.

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).

Table 1. Typical Fuel-to-Power Efficiency Values

Prime Mover Type	Efficiency
Spark ignition engine	18-25%
Compression ignition engine (Diesel)	30-35% above 1 MW 25-30% below 1 MW
Gas turbine	18-40% above 10 MW
Microturbine	25-35% below 1 MW
Steam boiler and turbine	6-35% above 20 MW
Fuel cell	40-60%

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 only a small 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.

Big gun or even center pivot irrigation systems could be used without the odor causing problems of irrigating raw manure. This would allow these efficient systems to be used to cut the costs of application. Environmental problems from accidental spills, runoff from over application, and flow into tile lines would not be as severe since the biological oxygen demand (BOD) of the anaerobically digested effluent is lower than the raw manure.

Drag hose systems would benefit from the increased moisture content of the effluent. Tanker spreaders operating later in the spring, because odor was no longer a concern, would compact the soil less since the ground would be drier. These two systems may have less applicability on growing crops, but they could be used on recently cut hay land.

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. 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.

Other benefits

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.

Preliminary data suggests some Johnes survive the mesophilic anaerobic digestion process. There is a reduction in the numbers of organisms reaching the compost and the storage pond. This does impact biosecurity issues on the use of effluent on growing crops. Other studies have shown a two to three log reduction of E. coli in mesophillic anaerobic digesters (Wastewater Residuals Stabilization)

Anaerobic digestion increases the amount of solids separated and decreases the maintenance costs of separation (Wright and Perschke). A Fan screw press separator produced 1.2 cubic feet of separated solids per minute. The solids produced were approximately 0.6 cubic feet per cow per day.

The separated effluent appears to exhibit settling characteristics that can be managed to concentrate the nutrients. Samples obtained from the storage of this liquid, shown in Figure 2, increased in nutrient concentration dramatically as the depth increases. While most of the storage pond contained 1% of the content at the 12-foot bottom depth was about 4%. This would require agitation of the effluent prior to land application to achieve a homogeneous mix, or management of the application as emptying progresses to apply the higher concentrations at a lighter rate.

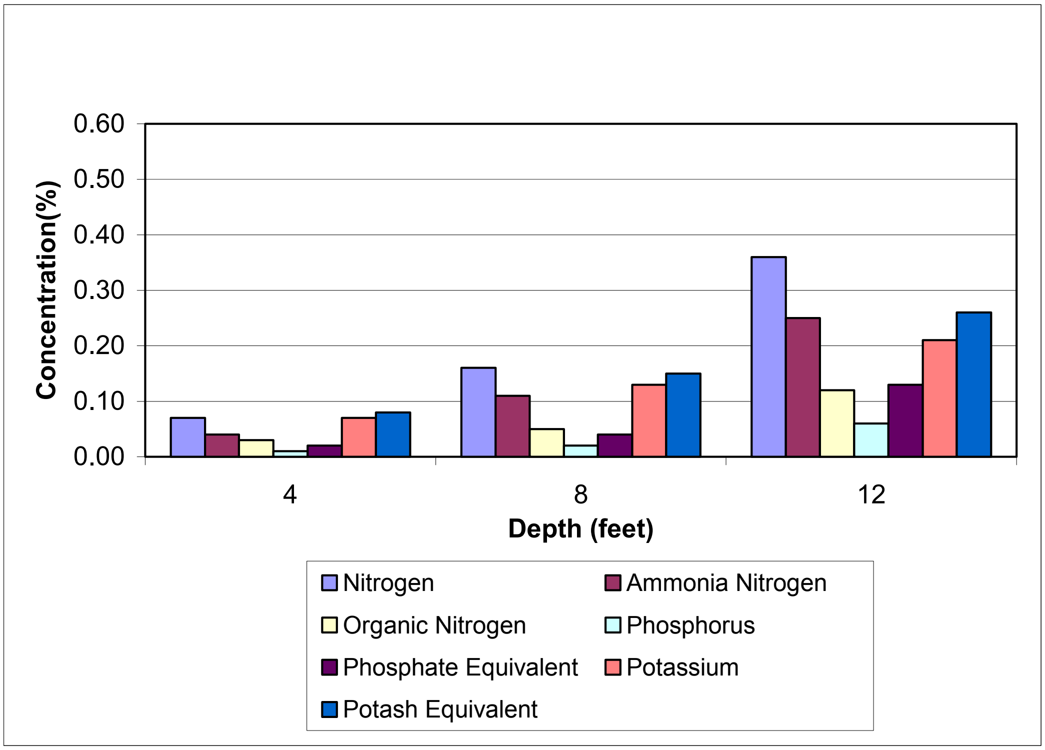

Figure 2. Nutrient concentration at different depths in an anaerobic effluent storage pond.

Although the nitrogen is retained as it is anaerobically digested, about 5% is converted from an organic form to ammonia. There can be ammonia detected, as a separator processes the effluent. Ammonia can also be volatilized during storage. Table 2 shows the nutrient concentrations at various points in the anaerobic system. The loss of N in the stored effluent may be related to settlement, dilution with precipitation or volatilization. If the effluent was used immediately and incorporated into the soil the inorganic ammonia would be more immediately available to crops.

In Table 2, the mass for the digester effluent was estimated based on the change in moisture content in the samples. The mass of solids was estimated using previously measured densities of the separated solids of 30 lbs/ft^3. The mass of the separated liquid was determined by subtracting the mass of the separated solids. The mass of the stored liquid was estimated by adding in the average precipitation for 180 days.

Table 2. Manure characteristics and estimated amounts per cow from Anaerobic Digestion System (Wright and Pershke).

	% M	% N	% P	% K	Lbs.
As produced per day	90	0.44	0.09	0.29	152
After digestion per day	93	0.45	0.07	0.26	146
Separated liquid per day	95	0.43	0.06	0.28	126
Separated solids per day	77	0.51	0.11	0.26	21
From storage per day	98	0.27	0.02	0.16	165
Nutrients available (lbs/ yr)		163	12	97	

Disadvantages

The $365,000 first year expense for a typical system is high, but there is more opportunity for potential returns than other treatment systems. After converting to a present value over a 20-year life with 8% interest, the net per cow benefit is $698.22. Sales of electricity are assumed to be $24,000 per year. The sales of solids are assumed to be $32,445 per year, and assuming the value of the nutrients at $0.25 per pound; the nutrients remaining are worth $34,060 per year. There are of course many factors not taken into account in this analysis. The nutrients were assumed to be needed when it may be that only nitrogen is needed on the farm. The electric value will depend on a number of pricing and production interactions. The sales of the solids hopefully will continue without competition from another farm that might be closer to the market providing the organic material at a lower cost.

Yearly expenses include $15,000 per year for the maintenance of the digester, engine, and generator. This will include occasionally replacing the cover and removing the grit in the bottom of the digester. The engines and generator repairs and scheduled overhauls are also included in this yearly cost as is the one half hour of daily maintenance to check the system. The spreading costs of the manure were ignored as well as the offsite storage. The cost of the alley scrapers is also not included in the system. The pumps were estimated to have a 10-year useful life. Their replacement was included in the present value calculation. These costs are shown in Table 3.

Table 3. Costs for anaerobic digestion manure handling system (Wright and Pershke).

	Present Value	Yearly Amount
First Year Expense	($365,000)	
Ten Year Expense	($22,696)	
Operation and Maintenance	($151,786)	($15,460)
Nutrient Value Remaining	$334,406	$34,060
Solids Sold	$318,550	$32,445
Electricity Sold	$235,636	$24,000
Net Income	$349,109	
Net Income per Cow	$698	$35

Peter Wright, “Overview of Anaerobic Digestion Systems for Dairy Farms,” Natural Resource, Agriculture and Engineering Service (NRAES-143), March 2001.

Without including the nutrient value the system has a present value of $1 per cow over the 20-year life of the system. Some farms may not be able to obtain a benefit from the manure. Farms with fields that have high to excessive levels of phosphorus and potassium may even see these nutrients as a detriment. Appropriate nutrient management will be needed to utilize the nutrients to maximize crop uptake. The ability to irrigate the effluent on growing crops without excessive odors will increase the likelihood that the nutrients can be used.

There may be ways that an earth reinforced plastic lined digester could be used to reduce the initial cost. If a farm could find a use for more of the electricity to change the value of the excess produced from $0.02 per kW sold to the utility to $0.09 per kW of avoided cost on the farm, the digester system would have even more value. There is some potential value in using some of the waste heat to heat water in the milking center.

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 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.

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.

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.

Bedding that won't settle can add to the gas production of the digester. Sand will settle and rapidly fill the digester reducing the retention time.

Peter Wright, “Overview of Anaerobic Digestion Systems for Dairy Farms,” Natural Resource, Agriculture and Engineering Service (NRAES-143), March 2001.

Farms that can collect all the manure produced in one location will be easily adopted to a methane digester. If a large portion of the manure is deposited where it can't be easily collected, or the different barns have many different places where manure is collected it may be more difficult to supply the digester with a regular amount of manure daily.

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.

Normal maintenance and monitoring of the digester may take about one half hour per day.

Settling has occurred with phosphorous concentrations in the bottom of the effluent storage pond 5 to 8 times the levels in the top of the pond, as shown in Figure 2. This could help farms meet P spreading criteria.

Discussion

Methane digestion as a technology has not been adopted by significant numbers of dairy farms in the past. Some of those that did adopt it are no longer using it. Some are still using it successfully. Trends in the dairy industry may make it more popular in the future.

During the 1970s energy prices went up and were expected to go up higher. Incentives for non-utility generators were set up that guaranteed a price for the electricity produced. The technology was demonstrated successfully on several different farms. Other farms installed anaerobic digesters at this time but didn't continue them.

Some of the problems that farms with digesters encountered in the 1970s were that they didn't have a good grasp of the biological system that they were working with. The digester was treated more as a physical process. That could be started and stopped by turning on or shutting off the flow. The farms looked at it as a way to meet their energy needs. Since their energy needs had peaks they tried to have the digester meet the peak energy demands on farm. Figure 3 shows the energy needs of a 100-cow dairy, the energy delivered by a digester on the 100-cow dairy, the energy needs of a 600-cow dairy and the energy an anaerobic digester could deliver to the 600-cow dairy.

The high maintenance costs on engines that were turned on and then shut off to meet peak energy demand discouraged operators. As the engines were shut off, hydrogen sulfide condensed and formed sulfuric acid that rapidly corroded engine parts.

There were few large farms during the 1970s. Recent studies have shown that around 800 cows is the lower limit for economically viable digesters (Jewell et. al.). The large capital costs of the digester could not be justified on the smaller farms. The time for regular maintenance was also at a premium on small farms. There was little opportunity to specialize and the skills in running a digester had to compete with skills and time for all the other operations on the farm. Many farms in those times kept the herd outside on pasture for significant amounts of time in the growing season. The manure deposited on the pasture was not available to run the digester.

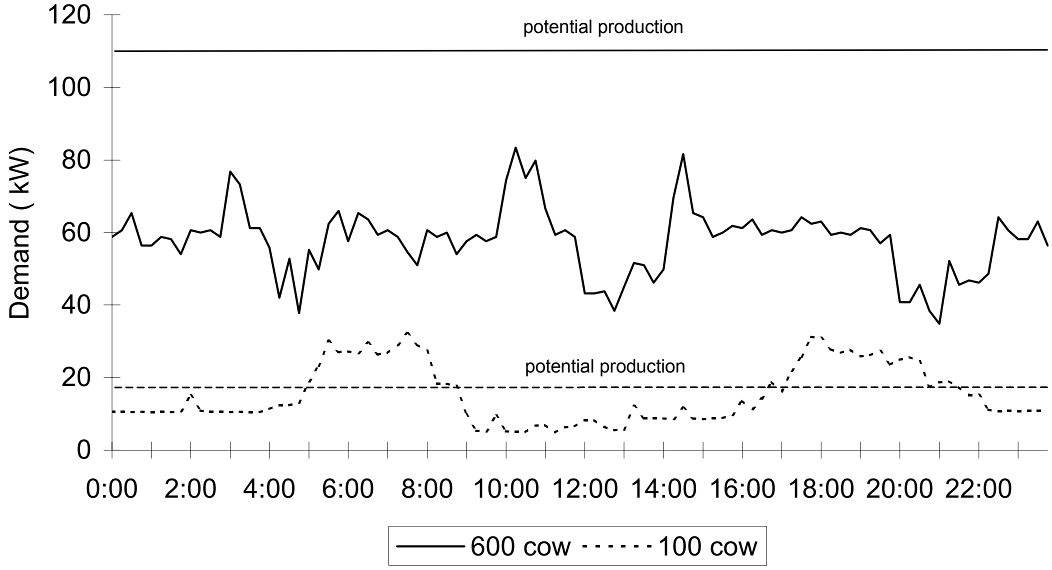

Figure 3. Electricity use profile for 100 and 600 cow dairies (Jewell).

Things have changed in the last 30 years. Odor control is now a real need on many large farms. Farms are looking for a way to achieve odor control without a large annual cost. There are many more 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, as shown in Figure 3. 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.

There are still obstacles to over come in the 21st century. The high capital costs for the anaerobic digestion system will still keep many farms from implementing this technology. A support industry is not developed to provide design and maintenance on a timely or cost efficient basis. The wholesale electric price is low preventing these systems from recovering the fixed costs rapidly.

Digesters that failed in the past have failed for three main reasons:

1) Some digesters had a poor design that was not compatible with the manure handling system on the farm.
2) Some owners that installed the digesters to make a profit did not generate the anticipated revenues over time.
3) Owners lost interest in digestion and/or farming.

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.

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 efficiency to be gained by using a heat exchanger to transfer heat from the effluent to the incoming manure. 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).

Digester performance can be enhanced with the use of micro-nutrients 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

Anaerobic digestion can be used on farms to treat dairy manure.

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.

References

Bush, Randy, Clifford B. Fedler, Nick C. Parker. "Effectiveness of Additives to Increase Organic Conversion in Anaerobic Digestion." 1998. ASAE Meeting Presentation. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659. Paper No. 984102.

Campbell, Joseph K., Richard K. Koelsch, Richard W. Guest, Eileen Fabian. "On-Farm Systems Information Dissemination Project." 1997. Department of Agricultural and Biological Engineering, Cornell University, Ithaca, NY 14853.

Dugba, P.N., D.R. Schneider. "Stabilizing the Performance of Anaerobic Digesters with Biological Additives." 2000. Animal, Agricultural and Food Processing Wastes Proceedings. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659. pp 372-378.

EPA. "A Manual for Developing Biogas Systems at Commercial Farms in the United States." 1997. U.S. Environmental Protection Agency. EPA-430-B-97-015.

Jewell, W.J., P.E. Wright, N.P. Fleszar, G. Green, A. Safinski, and A. Zucker. "Evaluation of Anaerobic Digestion Options for Groups of Dairy Farms in Upstate New York." 1997. Department of Agricultural and Biological Engineering, Cornell University, Ithaca, NY 14853.
Koelsch, R.K., E.E. Fabian, R.W. Guest, J.K. Campbell. "Anaerobic Digesters for Dairy Farms." Agricultural and Biological Engineering Extension Bulletin 458. Cornell University, Ithaca, NY 14853.

Koelsch, R.K., E.E. Fabian, R.W. Guest, J.K. Campbell. "Experience with Three Anaerobic Digestion Systems on Commercial Dairies." 1989. ASAE Meeting Presentation. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659. Paper No. 896550.

Leggett, Jeannie, Robert E. Graves, Les E. Lanyon. "Anaerobic Digestion: Biogas Production and Odor Reduction from Manure." Department of Agricultural and Biological Engineering, Pennsylvania State University, University Park, PA 16802.

Mattocks, R.P., Mark A. Moser. "Fate of Incoming Solids to Measure Manure Digester Performance." 2000. Animal, Agricultural and Food Processing Wastes Proceedings. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659. pp 187-193.

Moser, Mark A., Richard P. Mattocks. "Benefits, Costs and Operating Experience at Ten Agricultural Anaerobic Digesters." 2000. Animal, Agricultural and Food Processing Wastes Proceedings. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659. pp346-352.

Moser, Mark A., Leo Langerwerf. "Plug Flow Dairy Digester Condition After 16 Years of Operation." 2000. Animal, Agricultural and Food Processing Wastes Proceedings. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659. pp 379-384.

Poe, Gregory, Nelson Bills, Barbara Bellows, Patricia Crosscombe, Rick Koelsch, Michael Kreher, and Peter Wright, "Documenting the Status of Dairy Manure Management in New York: Current Practices and Willingness to Participate in Voluntary Programs" Staff Paper SP 99-03 September 1999, Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, New York 14853-7801 USA

Ross, Charles C., Thomas Jefferson Drake, James L. Walsh. "The Handbook of Biogas Utilization." 1996. 2nd ed. Environmental Treatment Systems, Inc., P.O. Box 94005, Atlanta, GA 30377-1005.

Wastewater Residuals Stabilization. 1995. Water Environment Federation, 601 Wythe St., Alexandria, VA 22314. Manual of Practice FD-9.

White, John G., Catherine Van Horn. "Anaerobic Digester at Craven Farms: A Case Study." 1998. Oregon Office of Energy, 625 Marion St. NE, Suite 1, Salem, OR 97301.

Wright, Peter E. and Perschke, Stephen P. "Anaerobic Digestion and Wetland Treatment Case Study: Comparing two Manure Odor Control Systems for Dairy Farms." 1998. ASAE Meeting Presentation. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659. Paper No. 964014.

Wright, Peter and A. Edward Staehr, "Environmental Factors to Consider When Expanding Dairies" 1999, Northeast Regional Agricultural Engineering Service. NRAES-95 Cooperative Extension, 152 Riley-Robb Hall, Ithaca, New York 14853-5701