Anaerobic Digestion in the United States

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Overview

Farms in the United States, as well in other countries, are increasingly being required by their comprehensive nutrient management plans (NMPs) to store manure, time land application so it coincides with crop growing seasons, and utilize more fields so agronomically appropriate application rates can be met. These practices each increase the potential for manure-borne odor conflicts with farm neighbors. While storing manure reduces a farm's risk for water pollution, farms are facing increased opposition from those who object to the odor associated with stored manure.

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. While it is very difficult to quantify farm odors and the success of odor control technology, farmer anecdotal experience consistently indicates that there is less on-farm odor with the presence of the anaerobic digester than without.

Historically, U.S. anaerobic digester systems have met varying degrees of on-farm operational success. In general, farmers are not well positioned to operate anaerobic digesters. The workload, even without operating and maintaining a digester, is extensive and very time demanding. The time needed to operate and properly maintain a digester can exceed the available time budget a farmer has. This, combined with the traditionally poor rate of return on investment of these systems has been some of the major factors precluding wider span adoption of anaerobic digester technology in the U.S.

However, in the recent past, many factors have changed that will result in more anaerobic digesters in the U.S. Energy prices continue to rise, the country desires to be less depend on the Middle East for energy, more digester technology is being develop and implemented in several U.S. states, federal and state governments are financing anaerobic digestion capital construction projects, and lastly the trading of carbon sequestration credits is of interest.

Background

Different types of anaerobic digesters have been researched and proposed as appropriate technology for on-farm use and many have been implemented.

Basic digester types include plug-flow, horizontal and vertical mixed, fixed-film, and covered lagoon; each is discussed in brief detail below.

All but the covered lagoon digesters utilize a heating source to raise influent to proper digestion temperature and maintain it. The majority of the digesters in the U.S. are operated in the mesophilic temperature range (38C) while a few operate in the thermophilic range (54C). Of the animal wastes largely available in the U.S., dairy manure is most suited for anaerobic digestion in today's systems. The following information is provided in a context for application to dairy manure.

<u>Plug-flow</u>

To my knowledge, the first anaerobic digesters constructed on farms were plug flow digesters. Plug flow digesters are comparatively low in equipment and operating costs (not necessarily overall costs) to mixed digesters. The theory of plug-flow digesters is just as the name suggests; influent material is introduced at one end of the digester and flows linearly, like a plug, through the digester and exits at a point of time in the future that equals the digester's hydraulic retention time (HRT). The designed HRT in most plug-flow digesters is about 21 days; HRT is calculated by dividing the digester treatment volume by the average daily volume of influent digested. The aspect ration for plug-flow digesters normally ranges from 4 – 6 to 1.

A key to the success of this system is correct moisture content, about 12 percent total solids, of the influent material. Influent that is too dry will not flow properly through the digester and material that is too wet will result in solids partitioning – some will settle and some will float.

Plug-flow digesters are generally constructed below-grade using poured-in-place concrete to construct the digester material containment structure. The tops are either concrete (either pre-cast or poured-in-place) or flexible membrane. A plug-flow anaerobic digester with a flexible membrane top cover located on a New York State dairy farm is shown in Figure 1. Further information on this digester is available by reading Wright and Graf (2003a).

<u>Horizontal mixed</u>

Horizontal mixed digesters incorporate agitation systems in plug-flow digester vessels. The mixing system is mainly installed in systems that have total solid concentrations greater than 12 percent or less than 10 percent. In the U.S., some farmers are interested in mixing food waste with manure due to the increased biogas production potential the mixture produces. Food waste generally has a very low (less than about 3 percent) solid content so when combined with manure, the resulting mixture needs to be mixed in the digester to help keep the solids in suspension. The electrical demand of the mixing units should be given due consideration when designing a mixed plug-flow system. The electrical energy the agitators consume increases the system's overall parasitic load thus reducing the energy available for sale to the electrical grid.

Figure 1. A plug-flow anaerobic digester processing manure from a 800-cow dairy in New York State.

The HRT of mixed digesters varies at the micro level from manure particle to manure particle. Some particles of manure will remain in the digester for greater than the theoretical HRT while some will short-circuit due to the agitation process and exit sooner. In Denmark, mixing of food waste with manure is common practice and the Danish government requires that the food waste/manure mixture be pasteurized (70C for one hour) prior to being land applied in order for the farm to be in compliance with standard manure application laws.

In New York State and others as well, farms are limited in the amount of food waste that can be brought on-farm and digested. Food waste contains nutrients (Nitrogen, Phosphorous, and Potassium) that must be considered when assessing the impact importing food waste has on the farm's ability to comply with their CNMP. Technologies originally developed for treating municipal wastewater are readily available for removing excessive Phosphorous from manure (and a manure-food waste blend) but the economics of the implementation of such systems on-farm is not well established. More work is required in the area of evaluating the overall sustainability of on-farm digestion of food wastes.

A horizontal mixed hairpin turn plug-flow anaerobic digester with a flexible membrane top cover located on a New York State dairy farm is shown in Figure 2. The digester produces significantly more biogas per unit influent volume due to the blending of food wastes with manure. Additionally, the biogas contains more methane (about 65 percent) than biogas generated from digesting manure alone (about 58 percent). Further information on this digester is available by reading Gooch and Mathews (2005) and Wright and Ma (2003b).

Figure 2. An on-farm horizontal mixed anaerobic digester processes manure from a 600-cow dairy mixed with food wastes in New York State.

<u>Vertical mixed</u>

Vertical mixed digester tanks can be either below grade (atypical) or above grade (typical) as shown in Figure 3. Tanks constructed above grade have less lateral load applied to the sidewall than those constructed below grade. Cast-in-place concrete, welded steel, and glass-lined steel panels are all used to construct vertical tanks. Vertical tank digesters in the U.S. are predominately used when dilute digester influent (TS<10 percent) is involved.

The mixing process is achieved by various methods, depending on the preference of the system designer. In one method, external electrical motors (about 20 kW) turn a vertical shaft, concentric with the digester tank that has several large paddles attached. The shaft speed is about 20 RPM's. This system is common for solid top tanks. Another method uses submersed impeller agitators each driven by either an electrical motor or a centrally located hydraulic motor. These systems have a much higher blade speed, perhaps 1,750 RPM's and can be used with both flexible top and solid top applications. One clear advantage of the first method is the electrical motor is easy to service and replace. Also, there is some thought that the higher speed impeller agitators negatively effect the operative microbes but this does not appear to have been proven at this time.

Tanks are insulated during the construction process to minimize the maintenance heating requirement (heat to maintain digester operating temperature). Significant heat can be lost from vertical tank digesters if they are not properly insulated. Applicable insulation options are to spray the tank with foam insulation or to use rigid board insulation attached to the tank and then covered with metal cladding. In either case, it seems that the typical insulation thickness used is 12 cm.

Figure 3. A vertical mixed anaerobic digester processing manure from a 800-cow dairy in Wisconsin mixed with food wastes.

<u>Fixed-film</u>

A fixed-film anaerobic digester is a digester that contains media within the treatment volume of the digestion vessel. The purpose of the media is to provide surface area for operative microbes to grow and propagate with the overall goal of reducing the HRT yet maintaining a reasonable level of biogas production.

The media can be constructed of plastic, polypropylene, or probably other materials as well.

Digesters using fixed-film technology are targeted to treat dilute slurries such as the liquid effluent from a solid-liquid separator (about 5 percent TS) or from an alley flush or flush flume conveyance system (1 percent TS or less). The HRT is usually three to five days.

A fixed-film anaerobic digester in New York State operated successfully for two years without incidence; a picture of this digester is shown in Figure 4. During the operational period, it was found that sufficient biogas production existed to maintain the digester at target operating temperature (38C) during the winter months (Ludington et al. 2006). The generated biogas was used to fire a boiler that in turn provided heat to a shell and tube heat exchanger for digester heating.

In another example, a larger fixed-film digester has been in operation for several years at the University of Florida dairy research farm near Gainesville, Florida. This farm has 600 cows and uses a flush system to convey sand-laden dairy manure from the barns to a passive sand-manure separation system where sand is settled and subsequently removed. Effluent from the sand separation system is processed in a fixed-film digester. This digester operates at near ambient temperature; no supplemental heat is provided.

Figure 4. A vertical fixed-film anaerobic digester processing the liquid effluent from a solid-liquid separator on a 100-cow dairy in New York State.

Covered lagoon

Many farms in the southern part of the U.S. have utilized anaerobic lagoon technology as a manure treatment process for several decades. The effluent from anaerobic lagoons can easily be spray irrigated on crop land. And between application periods, treated wastewater is used as source water for alley flush systems. Both the flush system and the spray irrigation systems are popular due to their comparatively low operating costs compared to other manure removal and field application systems.

Anaerobic lagoons are very large in comparison to anaerobic manure storage ponds. Lagoons are designed based on the geographic location (the further south they are, the smaller they need to be to perform their task) and the daily volatile solids loading rate they will receive. Properly designed anaerobic lagoons will have less offensive odor than anaerobic manure storage ponds but they still emit offensive odors, especially in the spring and fall when temperatures within the lagoon profile change quickly.

Some producers with lagoon systems are interested in, and a few have installed, gas impervious covers over the anaerobic lagoon. The biogas trapped under the cover is collected in a series of drain tile pipes that are connected together in a manifold system and piped to a boiler, engine-generator set, or flare. No supplemental heat is normally added to a covered lagoon anaerobic digester system. An existing anaerobic lagoon on a California dairy farm has been partially covered (see Figure 5) and biogas is being collected and used to fire an engine-generator set.

Figure 5. A partially covered anaerobic lagoon on a large California dairy that flush cleans their cow barns.

Impact on Nutrient Management

Any affect the anaerobic digestion process has on Nitrogen, Phosphorous, and Potassium is important to understand and account for as part of a farm's CNMP. Cornell data shows that there is a transformation of organic-nitrogen to ammonia-nitrogen and organic phosphorus to ortho phosphorus during the anaerobic digestion of dairy manure. The percent change in concentration in total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), organic-nitrogen (ON), total phosphorus (TP), ortho phosphorus (OP), and potassium (K) for five anaerobic digesters is shown in Figure 6 (Gooch et al., 2006). Percent changes greater than zero, equal to zero, and less than zero represent a decrease, no change, and an increase in effluent concentration value compared to influent concentration value, respectively. The chart shows that there is a clear increase in NH_3-N and ortho phosphorus during the anaerobic digestion process. Both ammonia-nitrogen and ortho phosphorus are readily available for both plant utilization and mobilization in the silo profile. Therefore, it is best to apply digester effluent on a growing crop otherwise significant loss to the environment is possible.

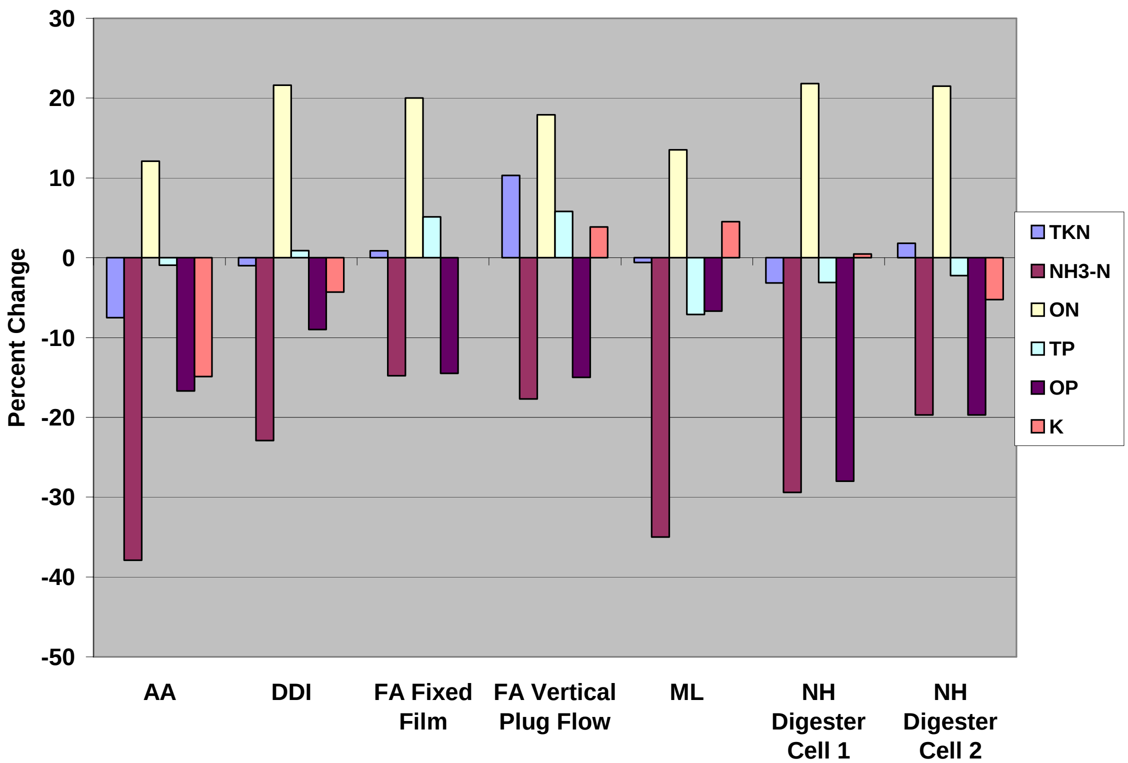

Figure 6. Anaerobic digester influent-effluent percent change in nutrient concentrations for five digesters on commercial dairy farms in New York State (Source: Gooch et al., 2006).

Discussion

The process of evaluating an anaerobic digester for a dairy farm is best initiated by having a feasibility study performed by a qualified engineer(s). The goal of a feasibility study is to provide factual-based information that can be used to determine if the goals and objectives of the farm can be met or not.

Experience has shown that many farmers also need assistance in determining and prioritizing the goals and objectives for their farms in relation to manure treatment, nutrient management, and energy use and generation potential. In this case, a qualified team of professionals consisting of engineers, nutrient management planners, and economists is needed.

The results of an energy audit are always beneficial to the engineer performing the feasibility study. An energy audit will provide monthly electrical energy usage along with energy used for heating purposes. This information is used to determine if sufficient heat and power is available from the proposed anaerobic digestion system to operate the farm continuously or only partially.

Farms must carefully consider the economic implications of investing in an anaerobic digester system before they begin construction. Anaerobic digesters in the U.S. vary in capital cost depending on factors such as the size, design, materials used, equipment, and complexity of the system but in general the current range seems to be 900 to $1,200 per cow. This is in the same price range as a new freestall housing barn. A qualified economist can use information provided by the feasibility study results to make cash flow projections and calculate the projected return on investment prior to making a final decision on building a digester or not.

Further information regarding anaerobic digestion feasibility studies can be obtained from Gooch and Ludington (2005) and Ludington and Gooch (2005).

Closing comments

It is important to mention that each dairy farm is different in layout, infrastructure, management ability, and interest in manure treatment systems like anaerobic digestion. Likewise, anaerobic digestion systems vary in function and capacity and thus also vary in capital cost and total annual cost. More on farm data is needed so various anaerobic digester systems can more accurately be compared and contrasted. The economics of anaerobic digestion need to be improved for those systems that involve comparatively high capital costs in order for wide span adoption to take place. While it is potential that capital costs can be lowered somewhat, many believe the key is increased payment for the sale of the "green power" generated by biogas-fired engine-generator sets. The Cornell Manure Management Program web site (www.manuremanagement.cornell.edu) has extensive information available on dairy manure treatment and management.

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