MID-TERM REPORT

Evaluation of technical and economic feasibilities for energy and compost production from dairy manure waste in Coahuila, México

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Executive Summary

The primary objective of this analysis is to determine the technical and economic feasibilities to produce energy and soil amendment from dairy manure. This mid-term report includes the literature review of existing technologies for manure conversion and also, a brief description of activities performed during the first meeting in Torreón, Coahuila, México, for exchange of information between institutions.

The literature review provides an examination of some of the current technologies applied to the recovery of energy (biogas) from the anaerobic digestion of dairy manure and evaluates them in the context of dairy practices in dry climates, such as the ones prevailing in New Mexico and Torreón, Coah., México. Anaerobic Digestion (AD) consists of the breakdown of complex organic molecules by microorganisms in the absence of atmospheric oxygen, generating methane, carbon dioxide, and other trace gases. For a long time, traditional manure disposal has been to simply spread the green manure on agricultural land. This has become unacceptable in the United States over time and has caused a shift in management practices. An increasing number of dairy operations are considering composting and AD as appropriate manure management strategies. Both, composting and anaerobic digestion, control odor and yield biosolids that can be used as a beneficial soil amendment. Anaerobic digestion also produces energy and retains nitrogen in the solids. AD significantly reduces the pathogens present.

Because of the regulatory environment in Europe, most of the existing technologies are from Germany and Denmark. The European regulations have made the complex systems flourish, but the systems currently in use in the US are much simpler and less expensive in capital requirements and operation and maintenance (O&M) requirements. In general, the European technologies are too complex to be practical on New Mexico dairies. In NM, there is no regulatory driver requiring the degree of treatment commonly required in Europe. In the US, there are three common systems in use on dairies: anaerobic lagoons, complete mix AD, and plug flow AD. By far the most common and apparently the most practical are the mesophilic (95 °F) plug flow AD.

Because of the open corral system used in NM, a higher percentage of the manure is deposited in corrals and therefore, it has significant exposure to the environment before collection, making it less desirable for energy production. One of the major operational concerns with dairy digesters is sand that settles out in the digesters. This is usually a problem where sand is being used as bedding. In NM, it is very likely this would be a concern because of the open corral system. Another concern regarding AD for New Mexico dairies is the lack of heating and cooling load compared to other dairies in the country. NM dairies do not have the large heating and cooling costs because, in general, they are not enclosed animal operations.

Most technologies require that the manure be slurry. Because more than fifty-percent of the manure in NM dairies is dropped in the corrals, the flush water would have to be used to re-slurry the manure. This is not a simple task once the manure is dry. This will probably require an industrial blending step, and would have to be pilot proven on site. If all of these issues can be overcome and the economics are attractive, it is critical that the dairy management be fully committed to operating, maintaining, and managing the AD system. Very few AD digester systems at dairies fail due to technical shortcomings. The two main reasons for failure are low return on investment, and unacceptable management burden. AD systems require maintenance and management. The dairies in NM are large by industry standards and dairy operators are in the business of milking cows not producing energy. Conversely the large size of our dairies and their relatively close proximity to one another allow for the possibility of hiring dedicated personnel – or sharing consultant assistance across several farms.

In the future, nutrient management in manure, odor management, and energy from waste will all play an important role in the dairy industry. It is suggested that as these issues gain importance the dairy industry will increasingly view anaerobic digestion as the environmentally friendly option. However, anaerobic digestion is not a panacea or a magic box that will solve all manure and/or energy problems. The success of AD as a strategy for manure disposal and treatment depends not only on the correct selection of the technology, but also on the role of the farmer and dairymen and management aspects that are crucial elements.

Introduction

Document Overview

This document contains the following topics that are important in accessing the potential to use bio-energy technology to utilize dairy biomass resources:

- Description of the three steps in the microbiology driving anaerobic digestion and factors affecting it provide a framework for understanding traditional manure systems.
- A description of traditional digester systems used in dairy manure management, including the experimental system currently being operated on the NMSU campus.
- Advantages derived from digester use including odor control and pathogen reduction.
- A summary of the activities performed during the first meeting between project collaborators in Torreón, Coah., México.

Odor and pathogen control, soil amendment enhancement, and treatment facility space-savings are non-monetary benefits that may make digester technology more attractive. Although the additional burden of system management must be considered, ultimately it will probably be regulatory changes that drive adoption, as has been witnessed in Europe.

Current Regulatory Situation in the United States

In the United States, in light of the recent USDA-EPA- Unified National Strategy for Confined Animal Feeding Operations (CAFO), animal waste now represents a significant financial liability. Regulatory agencies are scrutinizing animal waste management practices and revising regulations to reduce environmental impact. Consequently, dairy farms and other confined animal feedlots have been under increasing public and regulatory pressure to manage their animal waste. Manure is the primary source of pollution from CAFOs. Such sources include direct discharges, open feedlots, pastures, treatment and storage lagoons, manure stockpiles, and land application fields. According to EPA's 1996 *National Water Quality Inventory*, twenty-two states reported on the impacts of specific types of agriculture on rivers and streams, attributing 20 percent of the agricultural impairment to intensive animal operations (Nelson and Lamb, 2002; EPA, 1998). These findings, as well as incidents of waste spills, excessive runoff, leaking storage lagoons, and odor problems in the swine industry have heightened public awareness of environmental impacts from CAFOs. Much of the consuming public has lost track of the fact that the CAFO operations produce the food that is on their tables, and would like all waste and odor associated with CAFOs to simply go away. As a result, CAFO operators are evaluating waste management practices that convert wastes into higher value products. This led to early interest in composting and anaerobic digestion of animal manures.

One the other hand, the global depletion of fossil fuels, raise in fuel costs, and higher demand for energy has increased the attractiveness of using anaerobic digestion to generate energy from the manures. Wise use of appropriate technology can accomplish the conversion of agricultural waste into energy, reduce the reliance on fossil fuel, minimize environmental pollution, and add value to agricultural byproducts (Engler, et al.) However, one has to be careful because this alternative is not without increased cost and management demands on the producer.

Description of the Project

The New Mexico Dairy Industry comprises of about 320,000 milk cows. The dairy industry is the number one cash producing industry in the State of New Mexico, but it is also a source of environmental concern due to the large amount of animal manure waste that is being generated. The faculty at New Mexico State University (Las Cruces, New Mexico) has been working on technologies to convert the manure waste into energy (methane) and compost or soil amendment. The technology is developed for dry climates with limited water supplies and solid manure waste. This technology has proven to be feasible and cost effective for NM.

The climate of New Mexico is similar to the one on the State of Coahuila in México. The state of Coahuila, particularly the area known as "La Laguna" is the major dairy producer in the country. Due to the high number of milking cows, the dairy industry in this area is also generating a significant amount of cattle manure which has been estimated to be more than one million tons per year (El Siglo de Torreón, February 2004). This waste has potential adverse environmental impact due to uncontrolled methane emissions and contamination of air, water, and soil. Traditionally, manure is applied to agricultural lands as soil amendment, but due to the high cost of transportation and limited water supplies in New Mexico and Coahuila, the land application of manure is not economical. An alternative manure management approach would be to convert the waste into energy (methane) and a compost like byproduct which can be used in agriculture as well as green house industry. An anaerobic digestion (AD) system has been constructed at New Mexico State University and is being utilized to produce energy and a valuable residual from agricultural and domestic waste, including food wastes, cotton gin waste, and paper. Currently, some research is being conducted to generate energy and compost using cattle manure only. Preliminary results show that the residual has a significant higher nitrogen content, while the process requires a lower amount of water and processing time is less when compared to traditional aerobic composting processes.

Objectives of the project

The objective of this project is to evaluate the technical and economical feasibilities of converting manure waste in Coahuila into energy (methane) and compost (soil amendment).

Description of activities

The tasks to be performed in order to achieve the objectives and goals of this project are:

- Literature review: search for technologies for manure treatment. ***(Progress)***
- Collection of information about dairies location in New Mexico and Coahuila. ***(Progress)***
- Arrange joint visits to selected local dairies in New Mexico and Coahuila. ***(Progress)***
- Meetings in Torreón, Coahuila and Las Cruces, New Mexico for exchange of information between institutions. Presentations directed to students and the community will also be made. ***(Progress)***
- Visit selected dairies to collect information including: herd size; manure generation, handling, collection and disposal systems; current treatment or disposal alternatives. ***(To be conducted)***
- Laboratory analysis: moisture, total solids and, total volatile solids content in the samples of manure. ***(To be conducted)***

Progress of the Project

This mid-term report includes a literature review about AD process and technologies for manure treatment and, a summary of the activities performed from August to November, 2004.

Literature Review

Anaerobic Digestion Process

Anaerobic digestion is a natural process performed by microbes in the absence of atmospheric oxygen to break down organic matter into simpler molecules. A symbiotic relationship with anaerobic bacteria is what allows cattle to survive on a cellulose based diet. Converting organic matter to methane requires two different microbial processes to break down organic materials and ultimately produce the biogas composed of methane, carbon dioxide, and other trace gases. The organic feedstock used to produce the energy is stabilized and odor free at the end of the process.

Microbiology of the Process

Generally, three biochemical processes occur during anaerobic digestion: hydrolysis, acetogenesis and, methanogenesis. Figure 1 shows a simplified schematic that summarizes the four main theoretical stages of the anaerobic digestion process.

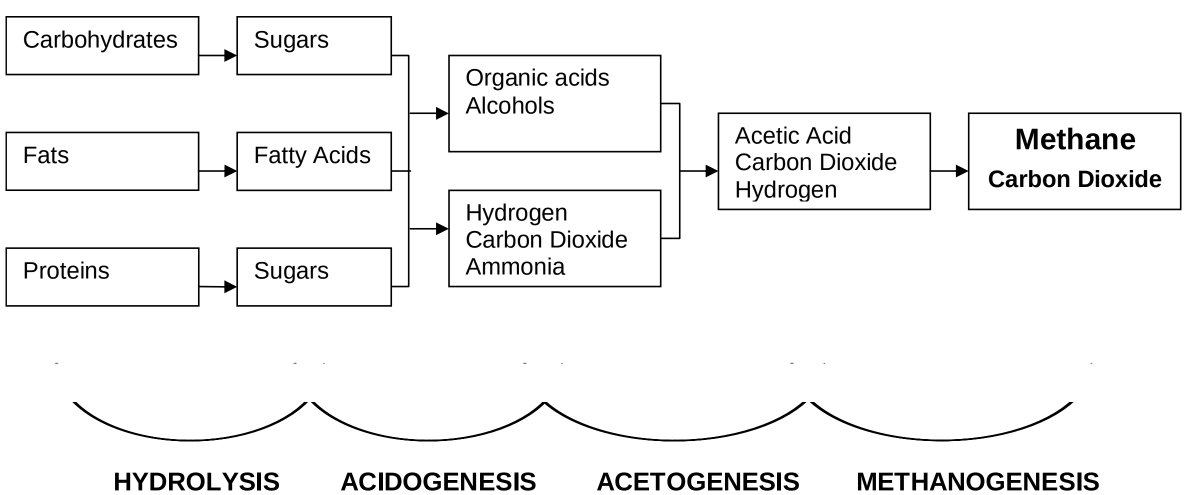

Figure 1 Diagram of the Anaerobic Digestion Process. Source: Al Seadi, (2001)

1) *Hydrolysis/Liquefaction*

In hydrolysis, fermentative bacteria convert the insoluble complex organic matter, such as carbohydrates (cellulose), proteins, and fats, into simple, soluble molecules such as sugars, amino acids, and fatty acids. The hydrolysis occurs with the aid of hydrolytic enzymes such as cellulases, proteases, and lipases that are secreted by the microbes.

2) *Acetogenesis*

In the second step, the acid formers, or acetogenic bacteria, transform the simple molecules formed by the hydrolysis of the complex organics to various volatile acids, carbon dioxide, and hydrogen. The principal acids generated in this process are acetic acid, propionic acid, and butyric acid. Hydrogen, carbon dioxide, and various nutrients are also produced as by-products of the reactions.

2) *Methanogenesis*

The last step of the anaerobic digestion process is called methanogenesis. In this stage, the volatile fatty acids produced during the acetogenesis phase are broken down by the methanogenic bacteria in two ways: either by means of cleavage of acetic acid molecules to generate carbon dioxide and methane, or by reduction of carbon dioxide with hydrogen. Even though the formation of methane can occur by either of these two ways, the dominant pathway is by cleavage of the acetic acid. The rate of production is higher from the reduction of carbon dioxide but the reaction is limited by hydrogen concentration. The biogas produced during methanogenesis is a mixture of gasses consisting of methane (55 to 70%), carbon dioxide, nitrogen, hydrogen, oxygen, and hydrogen sulfide.

Factors Affecting Methane Production

Anaerobic digestion can occur over a wide range of environmental conditions, although narrower ranges are needed for optimum operation. The rate and efficiency of the process is controlled by several factors including both environmental conditions and system parameters. Factors affecting the anaerobic digestion process include: Organic substrate, Nutrients, Solids and Moisture Content, Temperature, pH, Presence of Toxic

Materials (ammonia, hydrogen sulfide, antibiotics), Loading Rate and, Volatile Acids Concentration (Lusk, 1998; Burke, 2001; Verma, 2002; BioCycle, 2002).

Substrate Characteristics and Nutrients

Anaerobic bacteria degrade organic material at different rates. Even though bacteria require a sufficient concentration of nutrients to achieve optimum growth, substrates containing high nitrogen and sulfur concentrations can be toxic to bacteria due to the generation of high concentrations of ammonia and hydrogen sulfide. The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio. The C/N ratio in the waste should be less than 43 and for an optimum performance between 20 and 25. Typically, “as excreted” manure has a C/N ratio of 10. As mentioned before, if the C/N ratio is very low, nitrogen will accumulate in the form of ammonia. This will cause a rise in reactor pH as the material is digested. If the pH is higher than 8.5 it will start to cause a toxic effect on the methanogenic bacteria. On the other hand, if the C/N ratio is very high, the nitrogen will be consumed rapidly by the microbes to meet their protein requirement and will no longer react with the left over carbon content in the material. This will cause gas production to decrease.

Solids and Moisture Content

The moisture content of “as excreted” dairy manure has been reported to be approximately 12% total solids. The waste characteristics can be altered by the addition of water, in other words, by simple dilution. High solids digestion creates high concentrations of end products that inhibit anaerobic decomposition. Therefore, some dilution can have positive effects. Actually, most treatment systems operate at solids concentrations lower than 12%. The optimum waste concentration is also based on temperature and the quantity of straw or other constituents that may separate in the anaerobic digester.

Temperature

As in all biological processes, temperature has a significant effect on digestion rate. Seasonal and diurnal temperature fluctuations significantly affect the anaerobic digestion process and the quantity of biogas produced. Two temperature ranges provide optimum digestion conditions for the production of methane: the mesophilic and the thermophilic range. Mesophilic digestion occurs between 70ºF and 105ºF while thermophilic digestion occurs between 110ºF and 160ºF. Although thermophilic digestion is more efficient in terms of methane rate production, it is operationally more complicated and the digesters, piping, and energy for heating are all more expensive. Temperature also affects the quantity of moisture, ammonia, and hydrogen sulfide in the biogas, the quantity of gas, and the volatile organic substances dissolved.

pH

Another very important variable of the anaerobic digestion process is pH. Optimum biogas production is achieved when the pH value of the substrate is between 6 and 7. Acid forming bacteria have a faster growth rate than methanogenic bacteria. If acid-forming bacteria grow too fast, they may produce more acid than the methanogenic bacteria can consume and an excess of acid will build up in the system. This accumulation of acid will drop the pH, and the system may become unbalanced, having an inhibitory effect on the activity of methanogenic bacteria. The final effect will be a drop in methane production. The pH value will also be affected by the detention time of the substrate in the digester. In the initial period of fermentation, large amounts of organic acids are produced. Therefore, the pH can drop to a level below 5, causing inhibition, stopping of the methanogenic bacteria activity, and, in extreme cases, killing the reactor culture.

Toxicity

As any other living organism, bacteria require minimum amounts of minerals (sodium, potassium, calcium, magnesium, ammonium and sulfur) and metals (copper, nickel, chromium and zinc) for optimum growth. However, if salts are present in concentration beyond bacterial requirements, they can become toxic and inhibit the system, in this case, anaerobic digestion. Heavy metals, antibiotics, detergents, and ammonia are other frequently found materials that inhibit bacterial growth. Recovery of digesters after an inhibition problem due to the presence of toxic substances can only be achieved by cessation of feeding and diluting the contents to below the toxic level or inhibitory concentration.

Loading Rate

Loading rate is another important process control parameter. The loading rate determines the amount and rate of substrate introduced to the digester, affecting the availability of nutrients to the microorganisms. If the loading rate to the system is insufficient, it may result in a shortage of nutrients, and therefore a drop in the gas production. On the other hand, if overloading occurs, an imbalance in the system results, which may lead to a drop in pH, and cause serious inhibition problems. Another potential problem associated with overloading is the accumulation of toxic materials.

Volatile Acids Concentration

The volatile organic acid concentration is a practical parameter of digester performance since they are the primary substrate for methanogenic bacteria. There is equilibrium between the acid formers and the utilization of the acids by the methanogenic bacteria. Even though a high concentration may not be toxic to bacteria, the drop of pH originated by such increase in concentration may inhibit the system. Volatile acid concentration may also serve as an indicator of malfunction of the system. If the concentration is persistently high, an inhibition of the methanogenic bacterial could be occurring.

Types of Anaerobic Digester for Manure Management

Anaerobic digestion of animal manure (cattle, swine, and poultry) is the most common utilization of AD technologies in the agricultural community. The objective is to produce energy, minimize odor, manage nutrients, and improve the quality of animal manure when use as compost or soil amendment. The main component of the anaerobic digestion system is a reactor or tank where the manure is digested or treated. The system also includes equipment necessary for biogas collection, biogas pretreatment, energy production, waste heat recovery, and digested manure handling.

Anaerobic Digestion is not a new technology; historical evidence indicates that biogas was used for heating bath water in Assyria during the 10^{th} century B.C. and in Persia during the 16^{th} century. The industrialization of AD began in 1859 in India and in 1895 in England. In the 20^{th} century, AD had a wide use, mainly during the WWII due to shortage of fuels in Europe, but after this period AD was forgotten. However, the 1973 and 1979 energy crisis renewed interested in AD systems worldwide. Several countries, including India, China, Southeast Asia, and European countries, installed AD systems for village electrification and other common uses. The United States established renewable energy programs, including energy production from biomass using anaerobic digesters. Unfortunately, this on farm increase in AD focused on energy production with a technology that was still in a fledgling state and numerous failures occurred. Examples of this challenge can be observed worldwide; China and India reported 50% failure rates and the United States 80% failures of farm digesters.

Although a high percentage of on farm digesters in the United States are designated as failed, it is more accurate to say they have discontinued use. The majority of these have discontinued use due to unacceptable management burden, and unacceptable financial return on investment. Dairymen were being told that the systems were minimal maintenance and would produce 1 KW for every 4-6 cows being milked. What in fact has been observed is that the systems are not high maintenance, but they do distract from traditional milk production activities. The power production was more on the order of 8-13 cows per KW. This in turn significantly increased the payback period. Experience has shown that this is a good reliable technology, but it is critical that it not be oversold if it is to be sustainable. Typically, unmet expectations can result in discontinued use.

Regarding animal manure management systems, three types of AD systems for biogas recovery are common in the US agricultural community. The preferred technology for a particular farm depends upon the type of livestock, how the manure is collected, and on the total solids content of the manure. The three common AD technologies are Covered Lagoons, Completely Mixed Reactors and Plug Flow Digesters.

Covered Lagoons

The oldest, simplest, least efficient, but also, the least expensive form of AD technology is the covered lagoon (Figure 2). A covered lagoon digester is an earthen lagoon fitted with a cover that collects biogas as it is produced from the manure. Development of covered lagoons as an AD system was, in a sense, making lemonade out of lemons.

The industry had existing lagoons, and needed to control odor. The lagoon was covered and an effort was made to maximize the benefit from the covered lagoon by capturing biogas. The cover is constructed of an industrial fabric that floats on the surface of the lagoon. This cover not only collects the gas, but it also reduces odors and controls air emissions. A lagoon may have a retention time measured in weeks or months. In order to make practical use of the lagoon technology and shorten the retention time, mixing devices have been added to many lagoons to improve the contact between the organic matter and the microorganisms. These digesters are best suited for flush or pit recharge manure collection systems with a total solids content of 0.5 to 3 percent. The main disadvantage of the system is that since it is driven by atmospheric heat, it needs a warm climate to be operated under optimal conditions. Covered Lagoons in the North of the United States produce economic quantities of gas only during the summer. Therefore, this technology tends to be used in the Southern United States.

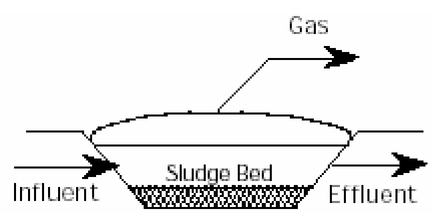

Figure 2 Covered Lagoon. Source: Burke, (2001)

Completely Mixed Reactors

The Completely Mixed (CM) process was developed for use in municipal wastewater treatment, and was applied to on-farm digesters during the 1970's. A complete mix digester is a heated tank, constructed of either reinforced concrete or steel, with a gas-tight cover (Figure 3). The CM reactor uses a mixer, either a motor-driven impeller or a pump, to maintain constant contact between the organic matter and the microorganisms. In order to increase organic load and reduce detention time, biomass can be separated from the effluent and recycled back to the digester. This improved version of the CM digester is called a "contact" reactor. Both approaches usually have detention times of 30 days or less, so they typically offer greater space efficiency than covered lagoons systems. However, compared to retention time of the remaining technologies, they are usually considered “low” rate systems that work best with slurry manure having a total solids content of 3 to 10 percent. An example is farms that use rinse or flush systems for manure removal. This system is more expensive to build and operate then the lagoon or the plug-flow digester systems.

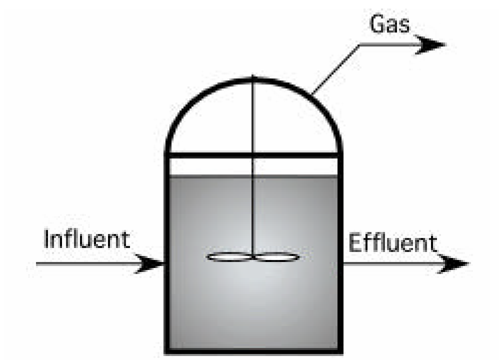

Figure 3 Complete Mixed Reactor. Source: Burke, (2001)

Plug Flow Digesters

Because of the expense and complexity of the CM digester, agricultural engineers at Cornell University proposed a simplified technology, which became the plug-flow (PF) digester. A plug-flow digester is a long, relatively narrow, heated tank (usually 95 to 105ºF), often built below ground level, with a gas-tight cover (Figure 4). These digesters are only used for dairy manure. In general, they are most appropriate for dairies that mechanically remove manure from barns, rather than by flushing. Manure fed into one end of the digester pushes processed manure out the other end. Hot water pipes running through the reactor keep it heated. This type of digester requires thick manure with total solids content between 11 to 13 percent. Plug flow digesters can tolerate some bedding, but the amount should be minimized, and sand bedding must be avoided. As this digester operates at a constant temperature year-round, the gas flow is stable and can support gas-to-energy applications in all climates.

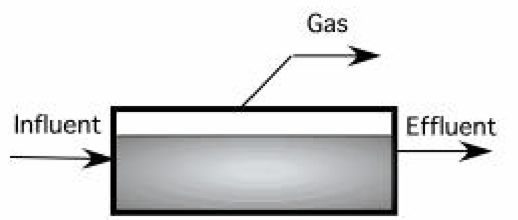

Figure 4 Plug Flow Reactor. Source: Burke, (2001)

Alternative and Emerging Manure Waste Management Systems

An alternative strategy for managing feedlot waste is conversion of the available carbon in the manure to methane and reuse of the resulting solids as soil amendment. As mentioned earlier, the existing technologies have been designed to handle a maximum solids content of 12-14%. However, all of those technologies raise some concerns regarding suitability for manure digestion in dry climates such as in New Mexico and Coahuila. This is due to the nature of dairy operations and waste handling that results in generation of manure mixed with sand in a dry or semi-dry state. With the existing practices on NM dairies, batch digestion appears to have some practical advantages in biomass-energy conversion of manure waste.

Two-Phase Bio-Fermentation

During the past nine years, New Mexico State University investigators (Zohrab Samani and Adrian Hanson) have been working on a two-stage system. This system physically isolates the two major microbial phases in two separate reactors. The novel aspect of this two-phase system is the solid phase reactor followed by a liquid phase methane production reactor, shown in Figure 5. In the solid phase reactor, water is applied from the top of the waste pile using a drip or sprinkler system, and is collected at the bottom through a drain line and sump. The water is then re-circulated through the solid waste until a desired pH level is achieved. At this point, the leachate is transferred to the methane reactor where the VFAs are converted to biogas. The water is then returned to the solid phase, adding alkalinity to the acid producing solid phase. The system works with a much lower volume of water than traditional systems. Sufficient water is added to reach initial saturation, and then 25% more water is added, which is the re-circulated water.

Results obtained by the investigators, using MSW and manure waste, have shown that this simple system converts the volatile solids in the waste to methane within a period of two weeks to three months depending on the feedstock. The methane concentration from the two-phase system is 70-85%. Other results have shown that the manure waste can be converted into methane gas and compost within 20 to 25 days. The process is quick, and water requirements are low compared to traditional composting systems (aerobic processes).

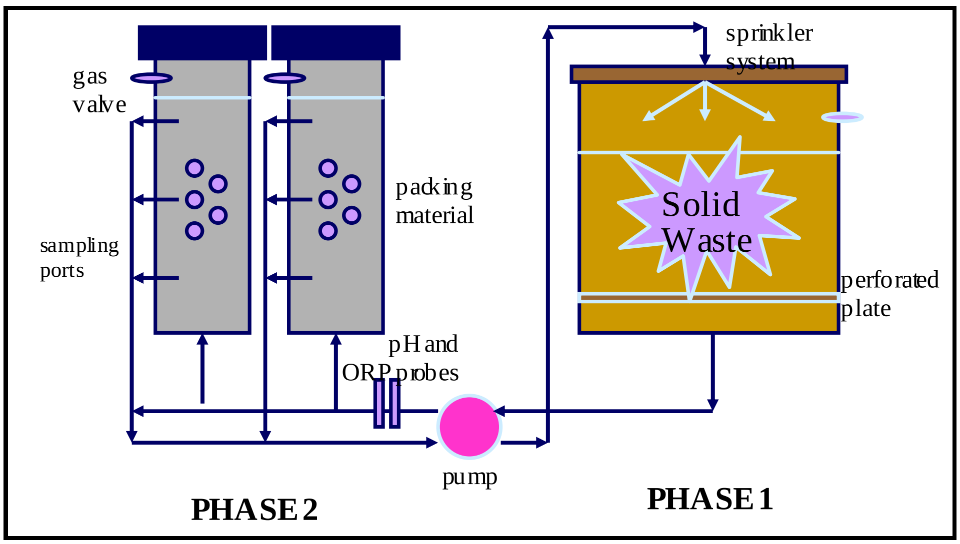

Figure 5 Two-Phase Anaerobic Digestion System at NMSU.

This two-phase anaerobic digestion system has several advantages over traditional single-phase process: it is easy to construct; low water use; high quality gas production (70-85% methane) and; a short process period (20-25 days). Considering these advantages, the process is suitable for dry climates such as New Mexico and possibly, Coahuila, where manure is in solid form and necessitates batch digestion. It is not fully proven in full-scale application.

Potential Benefits of Anaerobic Digestion of Dairy Manure

At present market prices, energy production alone cannot fully justify constructing a digester on a New Mexico dairy. However, there are some other benefits associated with anaerobic waste treatment, which some quite often are not quantitative.

Odor

In areas where urban areas are encroaching on dairy farms odor may be the number one pollution issue, especially where herd sizes are large. In the Magic Valley of Idaho, several dairies were sued over perceived odor problems. Most odors are caused by the byproducts of early anaerobic digestion: ammonia, VFAs, and sulfides. Experiments have reported that flushed dairy manure odor is significantly diminished after digestion. Digestion reduces odor by 97%, while short-term storage of flushed dairy manure in facilities such as lagoons increases odor by 77%. Reduction of odor, more than dealing with manure nutrients is the reason that the swine industry has adopted digestion technology. In urbanizing areas where economics still allows for the profitable operation of dairy facilities, this may be a compelling enough reason to install AD technology.

Pathogens

There is a wide range of infectious agents found in dairy manure however, only a few of them pose a substantial threat to infect humans. The primary agents of concern include *Escherichia coli* 0157:H7, *Salmonella ssp., Listeria monocytogenes,* and *Cryptosporidum;* organisms such as *Campylobacter spp.,* which are a problem for the swine and poultry industries, are of less concern to the dairy industry. Table 1 shows typical bacteria present in farm manures generally, though not dairy manure specifically. When used properly, manure poses little threat to human health. However, with the size of U.S. operations growing there will be more manure available for off-site use. Because manure represents a low cost, ecologically friendly source of important plant nutrients, manure is an attractive solution to farmer’s fertilizer needs.

Grossly improper handling of manure can lead to runoff into streams, contamination of waterways, and pathogens on human foodstuffs or drinking water. Not all manure contains potentially harmful human pathogens. However, if manure does house pathogens, conventional storage may not eliminate them. *Salmonella, E. coli* O157:H7, and *Cryptosporidium parvum* can live for up to two months after experimental introduction to manure piles.

Table 1 Common Pathogens found in Farm manure

Primary Pathogens	Secondary Pathogens
Salmonella typhimurium	*Yersinia*
Salmonella newport	
Salmonella enteritidis	
Escherichia coli 0157	
Pfisteria piscicida	
Fecal coliforms	
Fecal streptococci	
Campylobacter jejuni	
Campylobacter coli	
Mycobacterium paratuberculosis	
Listeria	

Far more important in the consideration of pathogen reduction is the life cycle of disease on a dairy farm. Because spreading of dairy manure on cattle feed crops is common, diseases can become endemic or epidemic on a dairy if the pathogen cycle is not broken. Diseases which pose a threat to cattle such as Johne's or *Salmonella* and those that pose a threat to humans post-slaughter such as *E. coli* 0157:H7, *Salmonella*, *Listeria*, and *Campylobacter* can be propagated in a herd by manure and feed.

Current practices in New Mexico consist of dry stacking of pen manure and solid separated manure from lagoon effluent. Dry stacks with enough moisture to undergo aerobic heating have low risk of pathogens remaining. However, manure spread directly from pens or stacked at low moisture content may never undergo sufficient heating. There is little data available as to the extent to which pathogens are inactivated during manure drying processes or during dry storage because there have been few studies. However, desiccation or drying of municipal biosolids and soils (<1% moisture) results in extensive (>4 log10) inactivation of pathogens.

Digesters can help mitigate the risk of pathogens escaping the dairy when nutrients are exported and reduce the risk of pathogen cycling from manure to feed. Digesters designed to operate at temperatures higher than 120°F are optimal for the reduction of pathogens. Digesters engineered to operate entirely at high temperature are ideal for aerobic digesters. Anaerobic digesters operate most efficiently at temperatures between 95-105^{o} F. However, high temperature post-treatment is an option where economics is not an issue. Treatment of manure at 158°F for one hour achieves a 4-log reduction in pathogens (99.99%). However, a mesophilic digester (95-105^{o}F) can achieve a 95% pathogen reduction and will kill nearly all common pathogens except for some viruses and helminths. Anaerobic digestion can significantly reduce the risk of microbial contamination from manure compared to untreated manure, but it can never eliminate it. In the next few paragraphs, we will examine known effects of anaerobic digestion on common pathogens found in dairy manure.

First Meeting in Torreón, Coahuila, México

In compliance with the objectives and activities previously described in this report, two meetings took place in Torreón, Coah. in November, 2004. The first one was a presentation directed to Faculty and Representatives from the Universidad Autónoma de Coahuila, government representatives (SAGARPA**,** Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación) and, industry representatives from local dairies. The purpose of this meeting was to give some background information about the current status of manure management regulations and practices in the United States and also, the application and potential use of the emerging technology developed by NMSU researches for manure treatment in arid regions.

Figure 6 Dr. Zohrab Samani during his speech at Universidad Autónoma de Coahuila (UAdeC), in Torreón, Coah., México.

The objective of the second meeting was not only to exchange technical information related to the project, but also, to present the project to senior students which will be graduating next June from Universidad Autónoma de Coahuila. The main reason to invite these students to attend the presentation was to encourage them to go to Graduate School. Other people attending the presentation were community leaders from one of the local chapter of Rotary Club. Faculty from other institutions such as Universidad La Salle, campus Laguna and Instituto Tecnólogico Agropecuario No. 10 (ITA No. 10) were also present (Figures 6 to 9). It is important to mention that at the end of the presentation, several students stayed in the auditorium to ask for more information about opportunities and requirements to attend Graduate School in New Mexico State University.

Figure 7 Senior students, Faculty and Community representatives attending Dr. Samani's presentation at UAdeC, in Torreón, Coah., México.

Figure 8 Dr. Zohrab Samani (NMSU) and Project Collaborator, Maritza Macias-Corral (NMSU), at the end of his presentation at UAdeC, in Torreón, Coah., México.

Figure 9 Dr. Zohrab Samani and Project Partner, Salvador Luevano Martinez (UAdeC), at the end of his presentation at UAdeC, in Torreón, Coah., México.

Conclusions

Dairy management practices in arid regions are markedly different from those of areas where climate is not so drastic. Waste treatment technology suited to regions where water is not a restricted use resource cannot be transferred to this one without major modification. Anaerobic digesters make use of several microbiological processes including cellulose breakdown, conversion to VFA and conversion to methane gas. Benefits that can justify AD systems are not limited to the economics. It has also to be taken into account the non-quantitative impacts such as environmental (odor control and water pollution prevention), and bio-security (pathogens reduction). As waste treatment becomes increasingly important from a regulatory compliance standpoint, anaerobic digestion of dairy waste may become increasingly attractive.

Future Activities

Activities to be conducted in the next months are:

- Conclude literature review and ollection of information about dairies location in New Mexico and Coahuila.
- Visit selected local dairies in New Mexico and Coahuila to collect information about manure management practices.
- Exchange of information between institutions.
- Presentation of final results and conclusions.

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