Economics and Environmental Impact of Biogas Production as a Manure Management Strategy

Cady R. Engler[1], Ellen R. Jordan[2], Marshall J. McFarland[3], and Ronald D. Lacewell[4]
[1]Associate Professor, Department of Agricultural Engineering, Texas A&M University
[2]Professor and Extension Specialist, Texas A&M Research & Extension Center-Dallas
[3]Resident Director of Research, Texas A&M Research & Extension Center-Stephenville
[4]Associate Director, Texas Agricultural Experiment Station, College Station

ABSTRACT

Conversion of animal waste to biogas through anaerobic digestion processes can provide added value to manure as an energy resource and reduce environmental problems associated with animal wastes. An anaerobic digester located at the Kirk Carrell Dairy in Johnson County near Godley, Texas, has been renovated as a demonstration of current anaerobic digestion technology for treatment of animal waste and recovery of energy. Economic analysis indicates that energy credits alone are not enough to offset the cost of investing in a biogas production facility. Annual operating costs were estimated to be $21,400 with energy credits of $14,300 for electricity produced and used on-site. Credits for reduction of odors, insect pests and other environmental problems have not been included in the analysis.

INTRODUCTION

With the increasing size and regional concentrations of confined animal feeding operations (**CAFO**s), there is growing public concern over potential impact on environmental quality caused by CAFO-generated wastes. In response to this, regulatory agencies are scrutinizing animal waste management practices and revising regulations to reduce environmental impact. CAFOs in Texas produce over 5 million tons (dry) of animal waste annually (Sweeten, 1994). Handling these wastes in compliance with stricter environmental regulations can have a significant economic impact on CAFOs. As a result, CAFO operators are evaluating waste management practices that convert wastes into higher value products. One approach to increasing the value of waste is to use it as an energy resource.

The amount of waste produced varies with the type of animal, but generally ranges from 60 to 85 kg (wet basis) per 1,000 kg live animal mass per day in intensive production systems. The energy potential of these wastes is given by the volatile solids (organic matter) content, which ranges from 10 to 18% of the total wet waste or 75 to 85% of the dry weight (ASAE, 1997). The energy potential of the manure produced in Texas ranges from 12×10^{12} to 25×10^{12} Btu annually depending on the method used for conversion (Parker et al., 1997). This equates to 12 to 25 billion cubic feet of natural gas annually.

Either biological or thermochemical conversion methods can be used to obtain energy from animal wastes. Anaerobic digestion, a biological conversion process, has a number of advantages for waste conversion. Fresh wastes have high moisture content (about 80%), making them unsuitable for most thermochemical processes, and their varied composition and high content of lignocellulosic material makes them unattractive for fermentation to ethanol or other products. Another advantage is that operators of CAFOs frequently are familiar with this type of process since anaerobic lagoons are an essential component of most current liquid waste treatment systems. Anaerobic digestion also has some advantages from a waste treatment standpoint. Microbial action in the lagoon substantially reduces chemical and biological oxygen demands (**COD** and **BOD**, respectively), total solids (**TS**), volatile solids (**VS**), nitrate nitrogen, and organic nitrogen in the waste stream. Although total nitrogen and phosphorus contents are not changed substantially by anaerobic digestion, the effluent is amenable to further treatment for their removal. Coliform bacteria, other pathogens, insect eggs and internal parasites also are destroyed or reduced to acceptable levels by anaerobic treatment.

In 1995, the Texas Agricultural Experiment Station began a project to renovate an anaerobic digester located at the Kirk Carrell Dairy in Johnson County near Godley, Texas, as a demonstration of current anaerobic digestion technology for treatment of animal waste and recovery of energy. The digester originally was installed in 1984 to generate enough electricity to operate the dairy and have surplus to sell to the local utility. Unfortunately, biogas production from the digester did not meet expectations and operation was abandoned after about a year. The challenge for the renovation project has been to identify shortcomings in the original design and develop modifications to overcome these. In addition to providing power for the dairy, the renovated system will reduce the potential for water pollution.

BACKGROUND

Anaerobic digestion is a microbial process that occurs in the absence of oxygen. In the process, a community of microbial species breaks down both complex and simple organic materials, ultimately producing methane and carbon dioxide. Anaerobic digestion can occur over a wide range of environmental conditions, although narrower ranges are needed for optimum operation (Table 1). Temperature has a significant effect on digestion rate with most processes occurring at temperatures in the mesophilic temperature range of 75-100°F, but anaerobic digestion also can be carried out at thermophilic temperatures (125-140°F). Although methane production has been observed at temperatures as low as 50°F, the rate is quite slow, which is why anaerobic lagoons generally do not function efficiently in the winter.

Anaerobic digestion is slower than aerobic waste treatment processes, typically requiring retention times of 10-30 days for mesophilic digestion. Thermophilic digestion is more rapid, but requires more energy to heat the digester. Loading rates (rates at which organic material is fed to the digester) are based on VS content of the feed and generally are in the range of 0.15-0.35 lb VS/ft^3·d for mesophilic processes. Biogas yields are in the range of 3-8 SCF/lb VS, and methane content of the biogas usually is 60-70%, with the balance mostly CO_2. Trace amounts of hydrogen sulfide (H_2S), which is both toxic and corrosive, are produced also.

Table 1. Operating conditions for anaerobic digestion processes.

Operating Parameter	Typical Value
Temperature	
Mesophilic	95°F
Thermophilic	130°F
pH	7 - 8
Alkalinity	2500 mg/L minimum
Retention time	10 - 30 days
Loading rate	0.15 - 0.35 lb VS/ft^3/d
Biogas yield	3 - 8 ft^3/lb VS
Methane content	60 - 70%

ENERGY PRODUCTION

The Carrell Dairy currently milks about 400 cows, and the amount of biogas produced is expected to supply the winter energy needs of the dairy. Several factors may have contributed to poor performance of the original installation, the most significant being a low feed rate to the digester. We do not have original design calculations, but it appears the amount of manure available to feed the digester was substantially overestimated. To exacerbate this problem, the number of cows being milked was reduced after the system was designed.

The dairy originally housed all cows on a dry lot, and feed to the digester consisted of manure scraped from the lot and waste flushed from the milking parlor area. The scraped manure was diluted with water and pumped into the digester. As part of the renovation, a free stall barn housing 180 cows was added, which allows collection of all the manure from the animals housed there. About 220 more cows are housed on the dry lot, and we estimate 25% of their manure will be collected to feed the digester. Total manure collected should be about 3300 lb VS daily. However, larger solids will be separated prior to feeding the digester, thus the amount of volatile solids going to the digester is expected to be about 67% of the total or 2200 lb VS daily. Laboratory studies of digestion of dairy waste have given biogas yields of about 6.4 SCF/lb VS, so the digester should produce about 14,000 SCF/d of biogas. The energy content of biogas is about 600 Btu/ft^3. Assuming a conversion efficiency in the engine/generator system of 25%, we should be able to generate an average of 25 kW. Records of electrical usage at the Carrell Dairy over a one-year period indicate an average demand of about 25 kW in winter and 35 kW in summer with spikes up to 50 kW when motors are started. Therefore, it is estimated the system would be able to produce enough biogas to provide all the power required for the dairy during the winter and a substantial portion the rest of the year.

SYSTEM DESCRIPTION

The original digester system consisted of a plug flow digester tank, a rubber/fabric gas bag covering the tank, a 100 hp engine driving a 65 kW generator, and a hot water circulating system to maintain the digester at an operating temperature of about 95°F using waste heat from the engine. A metal building was constructed over the tank to protect the gas bag, and a smaller metal building housed the engine/generator system and electrical equipment. When the renovation project started, we found the gas bag was rotted, and the building housing the tank was severely corroded. We decided to replace the building and gas bag with a lightweight reinforced concrete plank cover over a hypalon membrane to contain the gas, eliminating the need for a building. Although replacing the gas bag would have been less expensive, the bag would have had a shorter life span and would not have allowed placement of access ports along the length of the digester to monitor instrumentation, to facilitate sampling, or to install additional equipment.

The digester tank, which has not been modified, is a rectangular concrete tank 18 ft wide by 104 ft long with a V-shaped bottom. The tank is 8 ft deep at the sides and 12 ft 10 in. deep at the centerline. The outlet overflow is 30 in. below the top of the tank giving a liquid volume of 110,000 gal. A 4 ft opening was left at each end of the tank when the new cover was installed to provide access. The hypalon liner is a continuous sheet extending below the liquid level on each side and folded over the edge of the tank and held by the concrete planks. The liner also extends below the liquid level at each end and is held in place by 3/4 in. thick fiberglass panels. Although a safety relief valve is installed on the gas line, the end curtains provide additional protection from excess pressure in the tank.

The original heat exchanger, which maintained the digester temperature at 95°F, consisted of 4 pipe loops supported in a vertical plane down the center of the tank. The pipes were found to be severely corroded when the digester was cleaned out at the beginning of the project, so were removed. Since the primary heat load is to raise the feed temperature to 95°F, the new heat exchanger was installed in the inlet end of the tank. New plumbing has been installed for the temperature control loop, but the general design is similar to the original. An antifreeze solution circulating through the heat exchange pipes in the digester is heated by waste heat from the engine to a temperature of 140-150°F. If the water circulating to the digester is hotter than 150°F, some of the microbes may die, causing a decline in gas production.

The original digester was of the plug flow type with some mixing caused by gas production and convection currents from the heat exchanger. However, the mixing was inadequate to keep solid particles in the feed from settling or forming a crust on the top of the liquid. To increase mixing in the inlet end of the digester, biogas is recirculated through gas spargers placed under the heat exchange units. The recirculated gas, along with natural convection currents generated by the heat exchanger, should keep solids suspended, allowing them to move toward the outlet as feed is added. Mixing has not been provided downstream of the inlet section, but gas spargers can be added through access ports at other locations if needed.

The original mechanical system included a 100 hp oil-field engine coupled to a 65 kW generator. The estimated cost for overhauling the engine was about $20,000, whereas a new engine/generator set based on an automotive engine cost less than $10,000. While the service life for an automotive engine is not as long as for the oil-field engine and it is somewhat less energy efficient, parts are easier to obtain and routine maintenance easier to perform. The system which was selected is similar to systems designed for powering irrigation pumps in remote locations. The new system consists of a 454 cubic inch displacement automotive engine, which can develop 150 hp at 1800 rpm, coupled to a synchronous generator rated for 60 kW in continuous duty. This generator is larger than needed for the demand created by the dairy; however, a smaller generator that would more closely match the demand would have required the same size engine. While the larger generator may not be quite as efficient, it provides additional capacity that could be used for expansion of the dairy or to provide power for an adjacent dairy if enough biogas is produced.

The generator originally was connected in parallel with the utility grid so that excess electricity could be sold; however, most of the equipment for controlling the connection was not salvageable and there was no incentive to sell electricity back to the utility. Therefore, it was decided to connect the generator as a stand-alone system and flare any excess biogas produced. The utility grid is available as a back-up for periods when the generator is down.

Hydrogen sulfide is a contaminant present in biogas at a concentration of around 1000 ppm. The original system did not have any provisions to remove H_2S from the biogas, which is not a problem provided a rigorous engine maintenance schedule is followed. To reduce potential problems from H_2S, a scrubber designed to remove H_2S and other contaminants from natural gas has been installed in the fuel line to the engine.

Manure is scraped and flushed from the freestall barn and other paved areas into a collection pit. The freestall barn initially had rubber mats for bedding, but the cows tended to not use the stalls, resulting in numerous foot and leg problems. Recently, sand bedding has been added to the stalls, which increased cow comfort. Because sand now is present in the material flushed into the collection pit, the manure slurry passes through a settling basin and solids separator. Only the liquid is pumped to the digester. A new manure slurry pump has been installed and placed on level control to remove liquid as it accumulates in the sump. In addition, mechanical mixers are available to assist in keeping the manure handling system functioning smoothly.

One goal of the project is to obtain operating characteristics of the digester over a period of several years. To accomplish this we have included more monitoring instrumentation than normally would be used for a biogas process. We will record temperatures, pressures and flow rates of the gas going to both the engine and flare, temperatures at several locations in the digester, temperatures of the water going to and returning from the digester heat exchanger, the flow rate of manure slurry to the digester, and the power output of the generator. In addition, we will collect liquid and gas samples from the digester on a regular basis to determine compositions of these streams. Data collection has been automated as much as possible, with all electronic data being monitored by a data logger and downloaded through a modem.

ECONOMIC ANALYSIS

The investment cost for the renovated system is \$149,700 (Table 2). This is based on actual installation cost for everything except the tank. Since the existing tank was utilized, its construction cost was estimated using data from Saylor (1997). A 15-yr life was assumed for all equipment except the engine, for which a 5-yr life was assumed. The annual cost of the investment was determined by amortizing the investment at 7.5% over the life of the investment, assuming a zero salvage value. Repair and maintenance costs were estimated as 5% of investment cost and the risk variable was included as 3% of investment cost. Annual costs related to the investment are summarized in Table 2.

Although this anaerobic digestion system probably could be operated with no additional labor required, we have included an increment of 10 hr/wk of labor at a cost of \$10/hr for operating the system. Supplies needed for the operation have been estimated at \$1,000 annually. The total expected annual costs are estimated to be \$23,911 (Table 3).

Table 2. Investment costs for Carrell Dairy anaerobic digester.

Item	Life (yr)	Investment	Annual Cost[1]	Repairs & Maintenance[2]	Risk[3]
Tank	15	$ 40,000	$ 4,215	$ 211	$ 126
Cover	15	47,800	5,037	252	151
Solids Separator	15	22,000	2,318	116	70
Engine	5	5,000	1,150	57	34
Generator	15	5,600	590	30	18
Other Equipment	15	18,000	1,897	95	57
Materials/Supplies	15	5,600	590	30	18
Contractor	15	5,700	601	30	18
TOTAL		$ 149,700	$ 16,398	$ 821	$ 492

[1] Investment amortized at 7.5% for life of investment with no salvage value.
[2] Estimated at 5% of annual investment cost.
[3] Estimated at 3% of annual investment cost.

Table 3. Expected annual costs.

Item	Annual Cost
Investment	$ 16,398
Repair & Maintenance	821
Risk	492
Variable (labor[1], supplies[2])	6,200
TOTAL	$ 23,911

[1] Labor estimated at 10 hr/wk at $10/hr.
[2] Supplies estimated at $1,000.

The electricity generated using the digester biogas as fuel should be enough to make the dairy self-sufficient during the winter months. Average electrical usage monitored at the dairy is 25 kW during the winter and 35 kW during the summer, with each rate occurring over about a six-month period. This gives a total annual electrical usage replaced of 214,000 kWh. The cost of electricity for the dairy is 6.7¢/kWh, so the annual savings on electricity charges would be $14,300.

The expected annual costs are about $23,900 compared to an economic benefit of $14,300, giving a net annual loss of about $9,600. These are first estimates and will be revised as we gain operating experience with the digester. Also, this analysis does not include any credits for reduction in odor, insect pests, weed seeds or other environmental concerns.

ENVIRONMENTAL BENEFITS

Typically, animal waste management systems utilize anaerobic or facultative lagoons for treatment of liquid waste streams, such as flush water and runoff, and land application to dispose of solids. The solids may be stockpiled for a period of time before application can be made. Manure stockpiles and improperly operating lagoons can be sources of odors and insect pests which are nuisances for neighbors. Effluents from lagoons contain substantial nitrogen and phosphorus nutrient loads and must be applied to land for disposal. Effluents from well-designed and properly operated systems constitute a very low potential for nonpoint source pollution of water resources; however, unfavorable weather may significantly increase the pollution potential from these systems.

Enclosed anaerobic digestion systems for biogas production are not subject to pronounced influences of the weather, making effluents from digesters more stable and uniform than effluents from anaerobic lagoons. Additionally, odors are controlled since all the gas is burned prior to release into the atmosphere. Anaerobic digestion processes result in source strength reduction by converting incoming organic matter to methane, carbon dioxide and small amounts of microbial biomass; pathogens and weed seeds are destroyed; and odors are reduced. Total nitrogen, phosphorus and other minerals remain largely unchanged; therefore, effluent from a digester must be retained in a holding pond and used either as recycled flush water or for irrigation. The potential for nonpoint source pollution resulting from heavy rainfall is lessened since the influent to the holding pond will have undergone complete digestion.

Another environmental benefit from using biogas as an energy resource is that there is no net production of greenhouse gases. The carbon dioxide released during biogas combustion originally was organic plant material and so is just completing a cycle from atmosphere to plant to animal and back to the atmosphere. Methane is a more severe greenhouse gas than carbon dioxide and capture of biogas as a fuel prevents the release of methane into the atmosphere. Land application of solids and anaerobic lagoon treatment of liquid wastes releases a substantial amount of methane to the atmosphere. Capture of the methane for use as a fuel would significantly reduce the net greenhouse gas production from CAFOs.

LITERATURE CITED

ASAE. 1997. Manure production and characteristics, ASAE D384.1 DEC93, *In: ASAE Standards 1996*, 44th Ed., ASAE The Society for Engineering in Agricultural, Food, and Biological Systems, St. Joseph, MI.

Saylor, Lee. 1997. *Current Construction Costs*, 34th Ed., Saylor Publications, Inc., Walnut Creek, CA.

Parker, D.B., B.W. Auvermann, B.A. Stewart, and C.A. Robinson. 1997. Agricultural energy consumption, biomass generation, and livestock manure value in the southern high plains, Livestock Waste Streams: Energy and Environment, Texas Biomass Energy Opportunities Workshop Series, Amarillo, TX, August 4.

Sweeten, J.M., J.R. Clark, W.L. Harman, B.L. Harris, B.J. Johnson, W.R. Jordan, M.J. McFarland, C.B. Parnell, S.C. Ricke, and R.B. Schwart. 1994. Animal Waste Management Task Force Report, Agriculture Program, Texas A&M University System, College Station, September 27.