Paper No. 984104
An ASAE Meeting Presentation

COVERED LAGOON METHANE RECOVERY SYSTEM FOR A FLUSH DAIRY

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Written for Presentation at the
1998 ASAE Annual International Meeting
Sponsored by ASAE

Disney's Coronado Springs Resort
Orlando, Florida
July 12-16, 1998

Summary:

This paper describes the design, construction and anticipated operation of a lagoon-type methane recovery system for the Cal Poly Dairy housing approximately 350 cows, heifers and calves. The lagoon was designed and constructed according to USDA-NRCS standards and will be covered with a flexible membrane for collecting biogas to fuel a micro-turbine electric generator, and produce up to 25 kW in parallel with the utility system. Odor control is the most important non-economic benefit; in addition, electrical and hot water benefits from the biogas combustion will total $16,000 annually.

Keywords: anaerobic digestion, manure, biogas, methane and renewable energy.

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ABSTRACT

This paper describes the design, construction and anticipated operation of a lagoon-type methane recovery system for the Cal Poly Dairy. The initial design was based upon the present and anticipated herd size, from 300 to 600 cows, heifers and calves. The lagoon design was performed according to USDA-NRCS standards, and the limitations of the site, primarily depth-limited due to sandstone. The new lagoon with a volume of 16,000 cubic meters was constructed next to the existing lagoon. The new lagoon will be covered with a flexible membrane incorporating buoyant material so that the covert floats on the surface, and a gas collection system. The predicted output of the lagoon for the present population of approximately 350 cows, heifers and calves is estimated to average 370 cubic meters of biogas per day. The biogas will fuel a micro-turbine electric generator, and produce up to 25 kW in parallel with the utility system. Odor control is the most important non-economic benefit. Conversion of volatile solids to biogas and recovery and use of the biogas limits odor to surrounding areas. The methane recovery system will produce electrical benefits of approximately 170,000 kWh annually, as well as 77,000 KJ of hot water, together worth $16,000.

Keywords: anaerobic digestion, manure, biogas, and methane.

FARM DESCRIPTION AND BACKGROUND

The Cal Poly Dairy is located adjacent to the Cal Poly campus in San Luis Obispo, California. The dairy presently milks 180 cows with a total population of over 350 animals. Most of the herd is housed in freestall barns. About 90 percent of the manure is deposited on concrete and flushed with fresh or recycled water to the lagoon. The remaining 10 percent of the manure is deposited in the corrals and is only collected seasonally. Solids are separated from the flushed wastewater prior to storage in a single cell lagoon. This lagoon has a volume of 19,000 cubic meters, which translates to 50 to 90 days of storage, depending upon the water used by the dairy.

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The electric and natural gas usage was determined from Cal Poly and utility records. These are the energy forms that could be displaced by farm-produced methane. The main electrical service is a 480-Volt, 600 Amp, 3 phase; Y connected 4-wire system. Most electric motors are 3 phase while minor uses such as outlets and lights are single phase. The dairy electric service load includes a variety of equipment associated with the University that would not be found on a normal dairy such as an elevator and classroom.

The dairy purchases electricity through one meter. The milking parlor is the largest electricity use area with the separator system and lagoon recycle pumps are the next largest uses. The milking parlor electric power use is variable during the day. During the 2 daily milkings of 4 hours each, the electricity use is relatively high. However, it is relatively low during the rest of the day. The monthly consumption is also variable, increasing during months when the irrigation pump is used to empty the lagoon. Table 1 shows the annual power purchases at the milking parlor in 1995. As of 1998, the average electrical rate was $.09 per kWh, so the cost would rise to approximately $21,000 annually. The natural gas consumption is only that used for water heating, and amounts to approximately 77,000 KJ per year, which at $.58/100,000 KJ($.60/therm) would annually cost $450.

Table 1. Cal Poly Dairy Electricity Purchases January 1995 - December1995

	Electricity	Cost	Total Cost
January	23,616	$0.0663	$1,565.74
February	19,008	$0.0664	$1,262.13
March	16,128	$0.0679	$1,095.09
April	26,208	$0.0669	$1,716.42
May	19,008	$0.0903	$1,716.42
June	10,368	$0.0993	$1,029.54
July	21,024	$0.0895	$1,822.00
August	23,040	$0.0942	$2,170.00
September	15,552	$0.0948	$1,474.00
October	24,192	$0.0905	$2,189.00
November	12,672	$0.0676	$ 857.00
December	23,616	$0.0699	$1,651.00
TOTALS	**234,432**		**$18,548.34**

METHANE PRODUCTION TECHNOLOGIES

A number of methane producing technologies that have been developed and could be considered for dairy manure. The choice of the most appropriate technology is dependent upon specific waste characteristics. Complete mix systems and plug flow digesters are used for concentrated dairy waste and were not considered because of the dilute nature of the Cal Poly dairy waste. Packed bed and upflow anaerobic sludge blanket digesters have been used for soluble organic wastes and are just now being tested for use with dairy flushwater (Wilke, 1998). Anaerobic sequencing batch reactors are still in pilot scale development and would not be suitable for use at individual farms at this time. Covered lagoons have been successful at dairies and are the most appropriate technology for consideration at this site.

Moser (1996) and Williams, et al (1996) described the initial design assumptions for this lagoon digester project. This paper describes both this original design and the actual lagoon design and its construction details. It was proposed to construct a new, primary lagoon adjacent to the existing lagoon. The reason for this is that the existing lagoon is needed for the storage function, whereas the primary lagoon must be held at a constant volume in order to function as a methane recovery digester. The Cal Poly Dairy uses flushwater manure removal producing a wastewater with less than 1% total solids. This along with the location of Cal Poly being in a warm climate, it was determined that the ambient temperature covered lagoon would be the most appropriate technology. Full scale covered lagoon systems have been built to stabilize manure and recover methane. The importance of this work is the continuing operation at reduced temperatures. Safley (1989), Chandler (1983) and Moser (1993) have reported on lagoons treating flushed dairy or flushed hog waste operating year- round at temperature between 10 and 28°C at loading rates of 0.1 to 0.25 $kg/m^3/d$. These systems have operating volumes between 40 and 70 days of flush liquid volume. Sixty to eighty percent of the volatile solids are destroyed.

CAL POLY COVERED LAGOON DESIGN

Influent Manure and Flush Water

The barn and parlor flush water containing very dilute manure is a feasible digester feed for an unheated covered lagoon. Design of a constant volume methane-producing lagoon must consider all of the volume flowing into the lagoon to avoid hydraulic washout of bacteria. Table 2 summarizes the expected daily volume flowing to the separator including the manure solids from 180 milk cows, 169 heifers and 8 calves. The inclined screen will capture 15% of the manure volatile solids from the liquids flowing to the lagoon.

Table 2. Estimated Characteristics of Cal Poly Dairy Wastewater

Volume	**Liters/day**		**Gallons/day**
Fresh Parlor Washwater	45,400		12,000
Manure @ 10.4% TS	10,600		2,800
Recycled Flushwater	302,000		79,800
TOTAL	358,000		94,600
After Inclined Screen @ 15% Removal of Solids:	**kg/day**	**%**	**pounds/day**
Total Solids, TS	1,100		2,400
Volatile Solids, VS	900		2,000
Screened Water and Manure	357,000		785,000
%TS		0.29%	
%VS		0.25%	

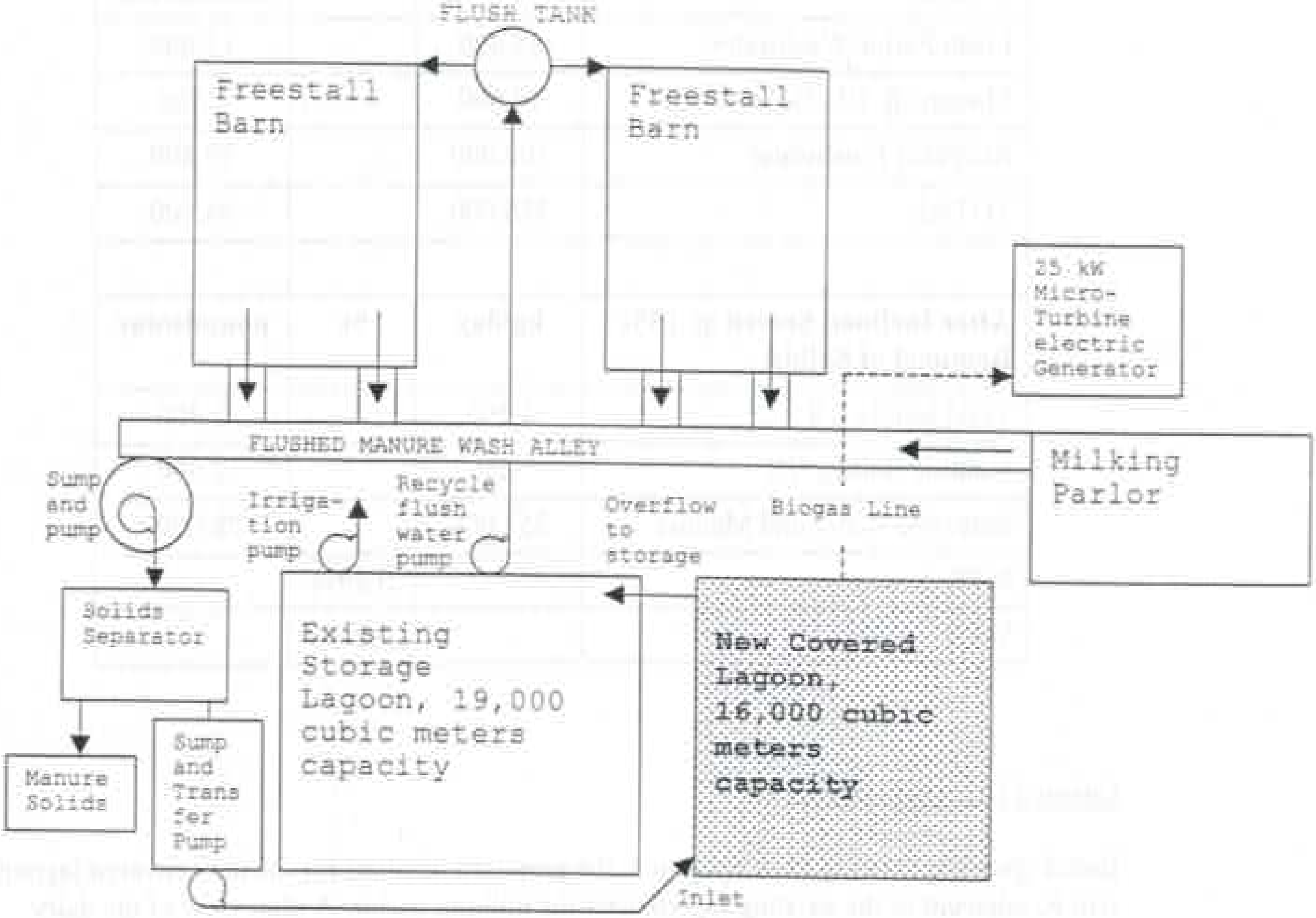
Covered Lagoon Location.

Based upon the existing farm operation, the proposed location for the new covered lagoon will be adjacent to the existing lagoon near the milking parlor. A plan view of the dairy and lagoons is shown in Figure 1. This area was originally designated for a lagoon and is partially excavated, thereby minimizing the construction costs. The proposed location will avoid adding all the corral runoff into the covered lagoon.

Manure Collection

Flush and parlor washwater will continue to flow from the parlor to the existing sand trap and concrete collection tank, be agitated and pumped over the inclined screen solids separator. The screened wastewater will then flow into a new sump tank and pumped from this tank through a new underground pipe bypassing the existing lagoon and discharging into the new lagoon. From here it will then discharge through an overflow pipe into the storage lagoon, for further recycling or as irrigation water.

Figure 1. Cal Poly Dairy and Lagoon System Schematic.



Sizing of Covered Lagoon

Two design variables were analyzed to size the methanogenic covered lagoon: the organic loading rate (OLR) with units-kilograms of volatile solids per cubic meter per day (lb-VS/1,000 ft^3/d); and the hydraulic retention time (HRT), with units - days. The limitation on OLR for the climatic condition in San Luis Obispo County, California, is no more than 0.16 kg VS/m^3/day (10 lb-VS/1,000 ft^3/d). Using this parameter for the 900 kg of VS per day from the dairy (See Table 2), the calculated lagoon size would be 5,700 cubic meters (200,000 ft^3). The recommended HRT for this region is 39 days. Based upon this parameter and the 357,000 liters of flushwater per day, and allowing for two feet of freeboard, the lagoon should be almost 17,000 m^3 (600,000 ft^3), with 14,000 cubic meters of effective liquid storage. Since this is the larger of the two lagoon sizes, HRT is the controlling factor for this lagoon. The OLR of this lagoon would be only 0.06 kg VS/m^3/day (4 lb-VS/1,000 ft^3/d). This indicates the lagoon will be able to accommodate manure from additional cows and/or cheese whey from the nearby dairy processing facility, as along as the flush volumes do not significantly increase.

Components and Construction

As shown in Figure 1, the new primary lagoon will be located next to the existing lagoon, and have approximate surface dimensions of 74 meters x 74meters(240 feet x 240 feet). The depth will vary from 4.6 meters to 3.3 meters (15 feet to 11 feet), with 2:1 side slopes. The reason for the relatively shallow depth is the existence of sandstone at the design depths. A new influent line will be installed from existing lagoon inlet, via a sump and transfer pump to the corner of the new lagoon. An overflow outlet pipe will be located at the corner of the lagoon opposite the inlet pipe, and set to maintain 0.6 m (2 feet) of freeboard. Floating cover bids are presently being solicited from interested companies, and may be either modular or bank-to-bank designs. According to Farmware, EPA (1997)–developed computer program for farm digester design, the predicted output of the lagoon will average 365 cu. m (12,900 cubic feet) of biogas per day over the year. As the gas bubbles form in the lagoon, they will be channeled along flotation blocks under the cover to a gas takeoff hose. This hose will be connected to a 10-cm (4-inch) diameter PVC buried pipe. The pipe will run along the edge of the lagoon and under the cow lane to the gas handling/utilization building. A small gas blower will pull the gas from under the cover for delivery to the gas utilization area. The biogas, containing 60 percent methane, will then be metered and filtered with a particulate filter prior to entering the electric generation system. The methane production from the covered lagoon is adequate to produce between 20 and 25 kW on a continuous basis from the present cow population. Table 3 lists the design parameters of the new covered lagoon digester.

Table 3. New Covered Lagoon Design Parameters

Total cow numbers	180	milk cows
	177	heifers and calves
Influent volume	358,000	liters/day
Digester		
Liquid Volume	14,000	cubic meters
Length	74	meters
Width	74	meters
Depth	3.3 to	meters
Approximate cover area	4,500	sq. meters
Gas Use		
Average Gas Flow	365	cu.m/day
Electric Generator Size	25	kW
Continuous Generator Output	20 to 25	kWh/hr

After considering the purchase of an internal combustion-type engine generator, and after consultation with a company who is seeking to test a new concept in electric generation from biogas, it was decided to select a biogas-fired micro-turbine with 25 kW maximum electrical output. The micro-turbine electric generator will operate in parallel with the utility system at a constant level of output controlled by the biogas supply. The micro-turbine will be supplied at no cost by Reflective Technologies. The actual and estimated cost to date of this methane recovery system including the lagoon construction, flexible cover, influent piping, gas handling, and associated labor and engineering is approximately $150,000. Table 4 shows the details of this cost estimate.

BENEFITS OF METHANE PRODUCTION

Non-economic Benefits

Installation of a covered lagoon and demonstration of its operation to the students and visitors at Cal Poly will serve the California Dairy Community. Odor control is the most important non-economic benefit. Conversion of volatile solids to biogas and recovery and use of the biogas limits odor to surrounding areas. Another important benefit will be additional storage volume made available in the existing lagoon by adding a new covered lagoon. This extra storage will allow the existing lagoon to be properly emptied and allow over-winter storage of a larger volume of flushwater.

Table 4. Estimated Cost of Construction of Covered Lagoon Digester

	Cost
EQUIPMENT	
Flushed Manure Transfer Pipe and Pump	$10,000
Excavation	$60,000
Digester Cover	$40,000
Subtotal	**$110,000**
Gas Handling	$5,000
Micro-Turbine Electric-Generator	$0
Electric Generator Building and Utility Tie-in	$10,000
Subtotal	**$15,000**
Equipment Subtotal	**$125,000**
CONSTRUCTION	
Engineering	$25,000
Engineering Subtotal	**$25,000**
TOTAL	**$150,000**

Electricity Benefits

The annual dairy electrical use by the dairy operation is approximately 234,000 kWh with a value of $21,000, averaging almost $0.09/kWh. Benefits from using biogas to produce electricity to replace purchased electricity are based upon an average of 23 kW. A Farmware analysis was performed using the Cal Poly dairy parameters and continuous operation of the electric generation system with an 85% operating factor. The University purchases electricity in bulk and it is assumed that any electricity not used on the dairy will mix back into the university electric grid and offset other use. The methane recovery system will produce approximately 170,000 kWh of electricity and 77,000 KJ of hot water annually, worth approximately $16,000. When subjected to the Farmware economic analysis with a project life of 15 years and operation and maintenance costs of $0.015/kWh, the $150,000 capital cost has a simple is payback of just over 11 years. Although there is no capital cost of electric generation for this project, the cost of the state-bid lagoon construction was very high, $60,000 compared with typical farm construction of under $25,000 as calculated by Farmware. Since the estimated cost of a 25 kW engine-generator is over $30,000, the higher lagoon cost offsets the absence of an electric generation capital cost for the Cal Poly system. Table 5 lists the assumptions and results of this analysis and the data suggest that a covered lagoon is marginally economically feasible at the current cow population. If the herd is increased or if cheese whey from the nearby dairy processing facility is introduced, the wastewater generation would not increase significantly because no greater amount of flush water would be required to clean the barns or parlor. Therefore, construction costs would not increase but biogas and thus electricity production would increase and the financial evaluation would improve.

Table 5. Financial Analysis Cal Poly Covered Lagoon Project

Item	Value
Project Life:	15 years
System Cost:	$150,000
Amount Financed:	$0
First Year Revenue:	$16,000
First Year O&M:	$2,700
Simple Payback:	11.4 years

PROJECT STATUS

As of the first week of July 1998, the new lagoon is almost complete and bids have been solicited for the lagoon cover. Upon completion of the lagoon, the contents of the existing lagoon will be transferred into the new lagoon, so that the methane bacteria will have a head start. In July and August the transfer pump, sump and piping will be installed, and the screened manure flushwater will be pumped directly into the new lagoon in order to bring it to capacity. The lagoon cover installation will then occur in late summer, 1998, and the biogas piping will then be installed. The biogas quantity and quality will be monitored, and the micro-turbine generator will be installed in the fall, 1998, and testing of the system will occur over the following six months. Electricity should be flowing into the utility lines by the end of 1998.

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