Biogas Production From A Covered Lagoon Digester And Utilization In A Microturbine

Williams, Douglas W., Professor
BioResource and Agricultural Engineering Department
California Polytechnic State University
San Luis Obispo, CA 93402, USA, e-mail: dwwillia@calpoly.edu
Gould-Wells, Diana, Instructor
Civil and Environmental Engineering Department
California Polytechnic State University
San Luis Obispo, CA 93402

ABSTRACT

This paper will summarize results of data collection from the lagoon-type methane recovery system at the Cal Poly dairy, which has approximately 300 cows, calves and heifers. The project at present consists of a 14,000 cubic meter (4 million gallons) earthen lagoon, with pump and piping to transfer the dilute dairy manure wastewater from the solids separator to the new lagoon. Also included is a 45-mil thickness, reinforced polypropylene lagoon cover of approximately 4600 square meters including Styrofoam floats, weights, tie-down and gas manifold system. This covers approximately 90% of the total lagoon surface area. The existing biogas handing system includes piping to condensate trap, gas meter, gas blower and continuous-ignition flare. A 30 KW microturbine with associated compressor and heat exchanger has also been obtained for converting the biogas into electricity. Grants from the California State University Research Initiative (CSU-ARI) and the Western Regional Biomass Energy Program (WRBEP) have paid for purchase, installation and initial operation of the equipment. The lagoon-microturbine system has been operating for 9 months in order to obtain the following operating parameters – wastewater flows, biogas production, and estimated electrical production. The microturbine produces from 15 to 25 KW at an efficiency of 20 to 25 %, and with reduced NOX emissions of 3 ppm. This project will provide the following environmental and economic benefits: odor control by capturing the manure gases including ammonia; preventing methane, a significant greenhouse gas, from escaping into the atmosphere; and providing the economic benefit of electricity and process heat worth $10,000 annually.

1.0 INTRODUCTION

The total manure produced by dairy cows in the state of California is 33,000,000 tons/year. As presently handled, dairy manure produces undesirable odors, biogas, and nutrient overloads resulting in air and water pollution. California Polytechnic State University (Cal Poly) has devised a system at its dairy to capture methane, a naturally emitted manure biogas, and convert it into a usable energy source to create electric power. By incorporating a Covered Lagoon Digester System with a Microturbine Electric Generation System, manure's undesirable byproducts can be transformed into valuable assets for a dairy farmer. If the total manure produced by dairy cows in the state of California could be converted to methane, the theoretical energy production would be 20 trillion BTU which would be enough to power a 200-megawatt power plant. At the Cal Poly dairy, about 90 percent of the manure is deposited on concrete, flushed through a solids separator, and pumped into a 14,400 cubic meter covered lagoon. As the manure is anaerobically digested by bacteria located at the bottom of the lagoon, methane is produced and is trapped underneath a floating cover, collected, and piped over to be used to fuel a 30 kW microturbine electric generator. Figure 1 shows the system that is installed at the Cal Poly dairy, and the specific information on the design and construction of the covered lagoon digester and methane collection system was discussed in detail by Williams and Frederick (2001) and Williams and Hunn (2002).

2.0 OBJECTIVES

2.1 The first objective of this paper will be to report on the baseline operating parameters of the CLDS in treating flushed dairy manure.

2.2 The second objective is to determine the operating characteristics of the 30 KW Microturbine Electric Generation System when fueled with biogas from the Covered Lagoon Digester System.

2.3 The third objective is to estimate the energy and environmental benefits of the combined systems.

3.0 PROCEDURES

3.1 BASELINE OPERATING PARAMETERS OF THE COVERED LAGOON DIGESTER

3.1.1 LAGOON DIGESTER VOLUME – Based on the length, width, and depth of the lagoon as measured in meters.

3.1.2 INFLUENT FLOW RATE – Rate of the flushed manure entering the lagoon as measured in liters.

3.1.3 HYDRAULIC RETENTION TIME – Volume of the lagoon divided by the daily influent flow as measured in days.

Figure 1. Microturbine Electric Generator System and Covered Lagoon Digester System

3.1.4 AVERAGE BIOGAS PRODUCTION – Average production of biogas as measured in cubic meters per day.

3.1.5 METHANE CONCENTRATION IN BIOGAS – Biogas concentration as measured as measured in percent by volume.

3.1.6 LAGOON DIGESTER TEMPERATURE – Average temperature of the lagoon contents as measured in degrees C.

3.1.7 INFLUENT COD CONCENTRATION – Chemical Oxygen Demand as measured in milligrams per liter.

3.1.8 EFFLUENT COD CONCENTRATION – Chemical Oxygen Demand as measured in milligrams per liter.

3.1.9 COD REDUCTION – Reduction in COD from influent to effluent as measured in percent.

3.1.10 OTAL AND VOLATILE SOLIDS PERCENTAGE – Percent of dry solids in the influent and percent of organic solids in the dry solids.

3.1.11 INFLUENT AND EFFLUENT LAGOON PH

These baseline parameters were continuously measured during a period of time from January 1, 2002 through May 31, 2002. A more complete explanation behind the measurement of these parameters can be found in Hunn (2002) and Williams and Hunn (2002). The average daily values for these parameters are listed in Table 1.

Table 1. Covered Lagoon Digester Baseline Operating Parameters

Parameter	Average Value	Units
Lagoon Volume	14400	m^3
Influent Flow Rate	365,000	l./day
Hydraulic Retention Time	40	days
Average Biogas Production	127	m^3/day
Methane Concentration	55	%
Lagoon Temperature	15	^oC
Influent COD Concentration	4300	mg/L
Effluent COD Concentration	1800	mg/L
COD Reduction	59	%
Total Solids	0.5	%
Volatile Solids	0.4	%
Influent pH	7.64	
Effluent pH	7.04	

3.2 OPERATING CHARACTERISTICS AND FIELD TESTING

The following section describes the microturbine performance from July 1, 2002 through March 2003. Table 2 summarizes the results of this testing, showing biogas utilized, microturbine kilowatt setting, and kilowatt-hours generated. The data can be divided into roughly 1-month periods, during which times the microturbine power setting was maintained at specific KW levels.

During the first part of July 2002, when the power was set at 15 KW, the average daily running time was 3.6 hours, the biogas consumption was 44 cubic meters per day, and the net electrical output was just over 28 kwhrs. When the power setting was increased to 20 KW later in July, the daily running time dropped slightly to 3.4 hours, the biogas consumption increased to almost 54 cubic meters per day, and the net kwhrs increased dramatically to 47 kwhrs per day. When the setting was raised to 25 KW, the average daily running time dropped dramatically to 2.4 hours, accompanied by a drop in biogas consumption to 38 cubic meters per day and a net electrical production of only 31 kwhrs per day. The microturbine was then reset to 15 KW, and the resulting daily hours, biogas, and net electricity were only 1.6 hours, 22 cubic feet and 14 kwhrs respectively. In comparison with the baseline parameters in Table 1, where over 100 cubic meters per day were reported, the biogas production after July 2002 was markedly lower. Reasons for this change are addressed later in this section of the paper.

Table 2. Microturbine Performance Summary

Time Period	Hours/Day of Operation	Ave. KW Microturbine setting	m^3/day Biogas	Kwhrs/day Net Energy
July 1-9, 2002	3.6	15	44	28.
July 25-Aug 8, 2002	3.4	20	54	47.
Aug 9-18, 2002	2.4	25	38	31
Aug19-Sept 19, 2002	1.6	15	22	14.
October 2002	1.4	15	13	12
November 2002	1.6	15	20	14
December 2002	2.7	15	29	25
January 2003	4.0	15	32	36
February 2003	3.7	20	34	47
March 2003	15	15	127	143

During the initial 2-1/2 month testing phase, the microturbine was set to run as many hours per day as there was biogas available. In almost all instances, the reason for the microturbine shutting down was a “fuel fault” reading shown on the control panel. The situation that would trigger this readout was a drop in the Btu value of the biogas, due to possible air intrusion as the biogas was depleted from under the lagoon cover. This air intrusion would occur when the microturbine compressor was pulling biogas from under the cover at a slight negative pressure.

It was also suspected that biogas was being lost from the same leak points that air intrusion occurred. Biogas leaking would occur when the microturbine was off, and a slight positive pressure under the cover would be forcing some of biogas out through the leak points. One of the suspected leak points was the soil under the area where the cover was attached to the lagoon bank. In order to correct this situation, a second plastic sheet was placed on the ground under the lagoon cover at the attachment area on the bank of the lagoon.

Low microturbine production was experienced during the months of September and October 2002 because the covered lagoon liquid level was lowered by two feet during those months in anticipation of heavy rainfall in November and December that could exceed the runoff capacity of the overflow lagoon. When the level of the covered lagoon was lowered to this extent, it resulted in the outlet pipe’s being above the level of the lagoon. Therefore, since the lagoon level was below the outlet to the overflow lagoon, the only way to remove liquid from the covered lagoon was via the recycle pump which had its inlet in the exit area of the covered lagoon. Later in November, when the lagoon level was restored to its full capacity, the biogas production, and thus microturbine performance, increased, as shown in Table 2. Yet, even this increase was not as high as the production achieved during the initial testing in the summer months, and this was due in part to the lower lagoon temperatures in November and December (~15^{o}C) compared with July and August (~21^{o}C).

One very interesting result of the microturbine testing was observed in December 2002. On December 17 biogas utilization peaked at 100 cubic meters, as did net electrical output at almost 100 kwhrs. Because a very heavy rainfall occurred on the 17th, and this resulted in significant water accumulation on the lagoon cover, it is speculated that this water pushed the lagoon cover down onto the water surface such that the biogas was forced to migrate to the Styrofoam cells and thus to the gas manifold at the lagoon bank.

From the maximum observed in mid-December, biogas utilization and resulting electrical production began to fall, and in January 2003 the average hourly use was 4.0 hours per day, at a setting of15kW. This resulted in an average biogas production of 32 cubic meters per day, with a net energy production of 36 kwhr/day. In February 2003, hourly usage averaged 3.7 hours at a setting of 20 kW. The resultant biogas production averaged 34 cubic meters, and produced a net energy production of 47.0 kwhr/day. The change from 15 kW to 20 kW between January and February 2003, and the resultant increase in net kwhr/day, shows a more efficient utilization of the biogas.

During the first week of March 2003, it was discovered that the biogas pipeline was partially blocked by a dirty flame check. This blockage was subsequently removed, and as a result, the hourly usage, the biogas consumption, and kwhrs production increased dramatically to over 15 hours/day, over 127 cubic meters/day, and 143 kwhrs/day, respectively. These performance figures compare favorably with the baseline gas production reported in Table 1. To measure exhaust emissions from the microturbine, tests were run on August 16, 2002 when the microturbine was set at 25kW power output. Table 3 summarizes these test results along with performance data at 15 kW and 20 kW power settings.

Table 3. Microturbine Performance at 3 Different Power Settings and Emissions at 25 KW

Microturbine Power Setting	15 kW	20 kW	25 kW
Hours of Operation	4.15 hrs	4.5	4.34
Biogas @57% Methane	59 m^3	73 m^3	82 m^3
Microturbine Efficiency	20%	23%	25%
Exhaust Emissions			
NOx			3 ppm
CO			200 ppm

3.3 ENERGY AND ENVIRONMENTAL BENEFITS

The overall goal of this project is to recover as much energy as possible from the waste of the dairy cows and re-incorporate that energy back into the Cal Poly electrical grid for the benefit of the dairy. Cal Poly's dairy produces a monthly electric bill of almost $3,000, which results in a yearly expenditure of nearly $35,000. When the Microturbine Electric Generation System is operating at its optimal performance rate, the predicted energy production of the microturbine system is just over 52,000 kWh per year. This energy, at a rate of $0.12 per kWh, is worth about $6,240 which is about 18% of the dairy's yearly energy costs.

In addition to the above electrical output, when operating at the optimal run time of 15 hours per day, the exhaust heat energy produced by the microturbine can be recovered at a rate of 100,000 Btu/hr and is worth about $3,300 annually when compared to the average $6 per 1 million Btu cost of natural gas. The total economic benefits of the Microturbine Electric Generation System, including electricity and process heat, can then be estimated to be worth ~$10,000, or about 28% of the Cal Poly dairy's $35,000 annual electrical usage.

The actual energy production of the Microturbine Electric Generation System, as explained above, falls well below the anticipated production which was expected to be between 40% to 50% of the energy needed for the Cal Poly dairy. Primarily because of design flaws in the lagoon cover, less methane was able to be collected than originally calculated, and a properly designed operations system should be able to maximize the energy and heat production of the microturbine system.

The environmental benefits of a Covered Lagoon Digester System, although not quantified in a measurable economic value, are considerable. By virtue of the cover capturing the gas emissions from the dairy manure, both odor and the release of greenhouse gases are considerably reduced. Methane is a very potent greenhouse gas and is twenty-one times stronger than carbon dioxide. The methane emissions from the dairy at Cal Poly can be calculated as being almost 100 pounds per day or 18 tons per year and is therefore equivalent to over 380 tons of carbon dioxide per year. It is anticipated that in the future greenhouse gas credits will be available to the dairy farmer, and the farmer will be paid for capturing methane from a dairy lagoon.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations that can be reached from the results of this study are the following:

4.1 The greatest restriction on energy production of the microturbine system is the amount of methane available as fuel. In order to maximize methane production, a consistent flow of influent liquid entering the digester lagoon is necessary.

4.2 Inconsistencies in the influent flow rate can potentially cause large fluctuations in the digester lagoon level, and therefore affect the hydraulic retention time of the liquid. Consistent influent flow will increase the hydraulic retention time and allow for increased production of methane.

4.3 Increasing the amount of livestock in the dairy would also increase the amount of animal waste. This, in turn, would increase the volatile solids concentrations since the amount of flush water would not increase. An increase in volatile solids would increase methane production considerably.

4.4 Increased conversion rates of the volatile solids into methane would improve overall methane production rates. Improved conversion rates can be accomplished by introducing heat into the liquid or by mixing the liquid in the lagoon. While mixing would be nearly impossible in a lagoon of this size, heating the lagoon contents would not be as difficult. In fact, the exhaust heat produced by the microturbine would be the perfect heating source, and it could be sent directly back into the digester lagoon via the heat exchanger installed next to the microturbine. The next phase of this project will be to set up the system to test this heating concept.

4.5 Several methods might be used to minimize air intrusion into the lagoon digester system, thus improving the quality of the biogas. An anticipated improvement for this project will be to incorporate a bank-to-bank cover on the lagoon digester. In the current configuration, about 90% of the lagoon is covered, leaving small areas where the valuable methane can escape.

5.0 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the California State University Research Initiative (CSU-ARI) and the Western Regional Biomass Energy Program (WRBEP) for providing funding for purchase, installation and initial operation of the equipment utilized at the Cal Poly Covered Lagoon Digester.

6.0 REFERENCES

Hunn, David. 2002. Operations Design and Evaluation of Cal Poly Dairy methane collection system. Unpublished Senior Project, Bio Resource and Agricultural Engineering Dept., Cal Poly, San Luis Obispo, CA.

Johnson, E. 2002. Personal communication about Cal Poly Dairy annual electrical usage. Cal Poly Energy & Utilities Manager, San Luis Obispo, CA. February 12, 2002.

Williams, D.W., Frederick, J. J. 2001. Microturbine Operation with Biogas from a Covered Dairy Manure Lagoon. Presented at the 2001 ASAE Annual International Meeting, held in Sacramento, California on July 30-August 1. Pp. 1-8.

Williams, D. W. and Hunn, D. 2003. Western Regional Biomass Energy Program, DOE, Final Report: Biogas Production from a Covered Dairy Lagoon Digester and Utilization in a Microturbine