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Microturbine Operation with Biogas from a Covered Dairy Manure Lagoon

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Abstract. This paper describes the design, construction and preliminary operation of a covered lagoon-type methane recovery system for the California Polytechnic State University (Cal Poly) Dairy. The dairy houses 300 cows, heifers and calves. A new lagoon was constructed with a liquid volume of 14,000 cubic meters. This lagoon was covered with a flexible membrane incorporating buoyant material so that the cover floats on the surface, and a gas collection system. The output of the lagoon for the present population of animals ranged from 200 to 300 cubic meters of biogas per day. The biogas will fuel 30 KW micro-turbine electric generator, which will be grid-connected with the utility system. Odor control is the most important non-economic benefit. This project will provide environmental benefits - odor control by capturing the odorous gases that result from dairy manure storage; methane, a significant greenhouse gas is kept out of the atmosphere, and water pollution is reduced through the reduction in organic matter in the lagoon. Economic benefits including electricity and process heat are estimated to be worth $16,000 per year.

Keywords. Dairy Manure, Lagoons, Anaerobic, Methane, Digester, Biogas, Microturbine

Introduction

The Cal Poly Dairy is located adjacent to the Cal Poly campus in San Luis Obispo, California. The dairy presently milks 200 cows with a total population of over 300 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. The average annual power consumption is approximately 234,000 Kwhrs at an average electrical rate $.09 per kWh, for a total annual cost of $21,000 annually. The natural gas consumption is only that used for water heating, and amounts to approximately 77,000 MJ per year, which at $.58/100 MJ would annually cost $450.

Methane Production Technologies

A number of methane-producing technologies have been developed and could be considered for dairy manure. The choice of the most appropriate technology is dependent upon specific waste characteristics. 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, 2000). Covered lagoons have been previously successful at dairies (Safley and Lusk, 1990) are the most appropriate and reliable technology for consideration at this site. Lusk (1998) reported in a recent study of animal manure digesters in the US, that covered lagoons had a much higher success rate, 78%, as compared with either plug flow, 37%, or complete mix digesters, 30%. Williams and Moser (1998, 1999) described the initial design assumptions for this lagoon digester project. The project equipment 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 1.0-ml thickness, reinforced polypropylene floating lagoon cover of approximately 4600 square meters including Styrofoam floats, weights, tie-down and gas manifold system. The biogas handing system includes piping to condensate traps, gas meter, gas blower and continuous-ignition flare. The piping used was 7.5 cm dia. Schedule 80 polyethylene for below ground, and 5-cm dia stainless steel for above ground. A Capstone® microturbine electric generating system will be connected to the biogas line, and the electrical connection will be a 4-wire, 440 volt grid-connection for direct input of power to the Cal Poly campus-wide electrical system. This microturbine system includes a scroll-type 55 psi compressor, gas drier with desiccant tank, Capstone Model 330, 30-KW, 440 volt, grid-connected microturbine and Unifin® heat recovery system from the turbine exhaust. Figure 1 shows a schematic of the dairy and covered lagoon layout, and Figures 2 and 3 show photographs of the methane recovery system.

RESULTS AND DISCUSSION

Influent Manure and Flush Water

The barn and parlor flush water were measured using an electronic pulse flowmeter. The daily volume flowing to the solids separator ranged from 240 to 400 cubic meters per day. An inclined screen separates approximately 15% of the manure volatile solids from the liquids flowing to the lagoon. These liquids were estimated to average 300,000 liters per day at a COD of 3000 mg/liter or 3200 mg/l volatile solids (VS).

Covered Lagoon Operational Parameters

Two operational variables were determined for the covered lagoon digester: the organic loading rate (OLR) and the hydraulic retention time (HRT). For the 14,000-cubic meter lagoon, the average HRT was 45 days and the average ORL was 0.07 kg VS. These are well within the climatic limitations in central California of an OLR of no more than 0.16-kg VS/m^3/day and an HRT of no less than 39 days. The effluent has a COD of approximately 100 to 1500 mg/l and an ammonia content of 90 mg/liter.

Biogas Production

Preliminary gas measurements have shown a range of 200 to 300 cubic meters of biogas-produced daily from the cover over 90% of the total lagoon surface area. The biogas has been flared and is maintaining a self-supporting flame. Preliminary measurements with a Fyrite@ combustion test kit indicate approximately 12% carbon dioxide and 88% methane by volume.Tests were conducted with a 10 KW engine-generator that was salvaged and restored from the old Poultry Unit at Cal Poly. This engine-generator set was connected to a light board to provide a load and is pictured in Figure 4 along with a Cal Poly Ag. Engineering Lab class conducting an efficiency test using biogas as fuel. The tests indicated that the gas could be successfully used in a natural gas carburetor with minor modifications. At the maximum power output of 10 KW, the biogas consumption was 11 cubic meters per hour, for and overall efficiency of 10 %. By contrast, the Microturbine specifications indicate that at a fuel consumption of 13 cubic meters of methane per hour, the output would be 28 KW, or an efficiency of 27%. The biogas quantity and quality will continue to be monitored, and the micro-turbine generator is being installed in the summer of 2001, and testing of the system will occur over the following six months.

Capital Cost and Electricity Benefits

The costs of this methane recovery system including the lagoon construction, flexible cover, influent piping, gas handling, microturbine system and associated labor and engineering was approximately $225,000. Based on the measured biogas production and the rated efficiency of the microturbine, the completed methane recovery system will produce 170,000 kWh of electricity and 77,000 kJ of hot water annually, worth approximately $16,000.

CONCLUSIONS

- Tests with a 10 KW Engine-Generator fueled by methane showed the following performance
  - Biogas Input: 11 cubic meters/hour
  - Electrical Output: 10 KW
  - Efficiency: 10%
- The specifications of the 30 KW Microturbine indicate the following potential performance:
  - Biogas Input: 13 cubic meters/hour
  - Electrical Output: 28 KW
  - Efficiency: 27%
- The covered lagoon effluent showed the following characteristics:
  - 1000 to 1500 mg/l COD
  - 90 mg/l ammonia

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Figure 1. Cal Poly Dairy and Lagoon System Schematic.

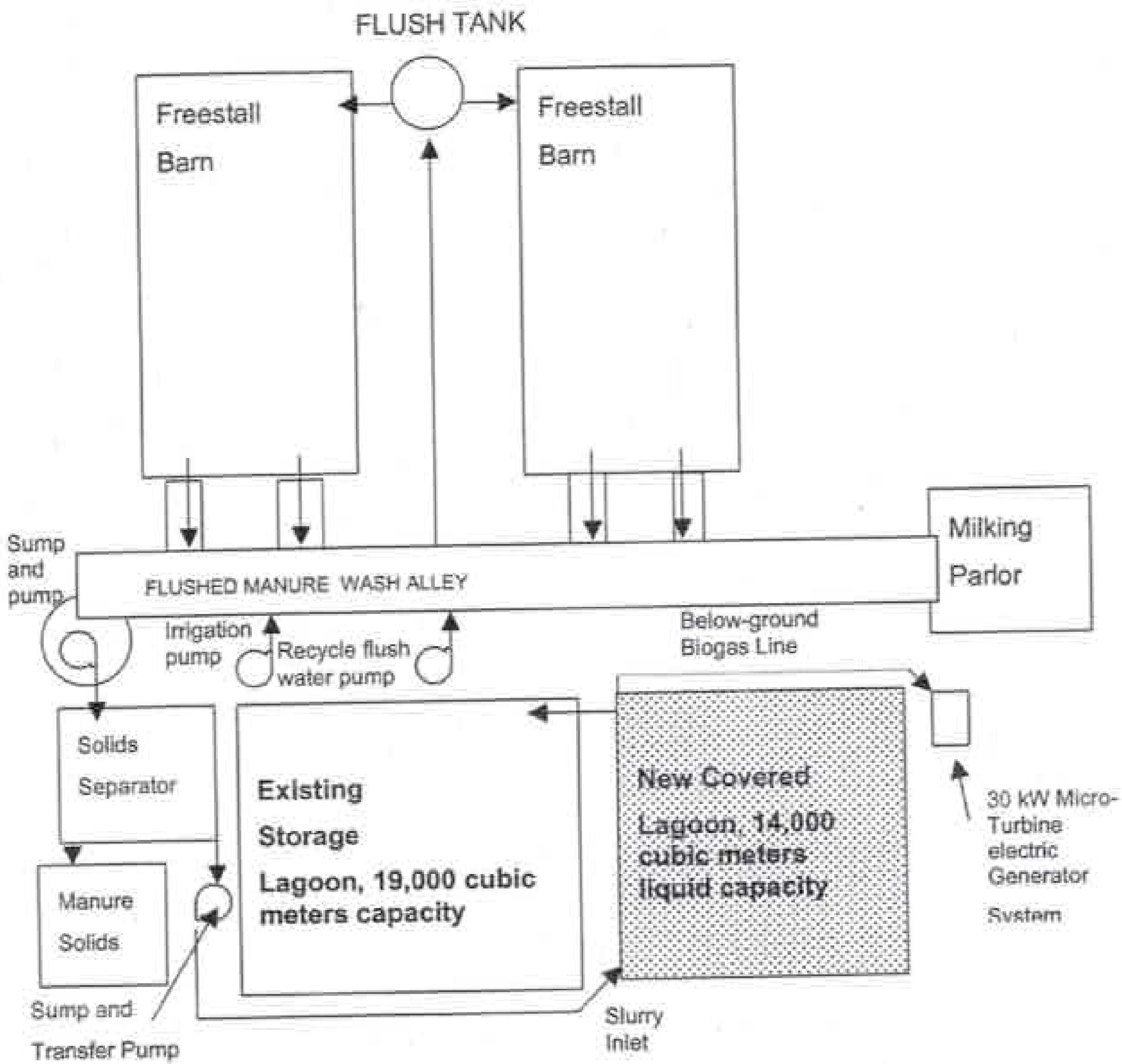

Figure 2. Floating Lagoon Cover at the Cal Poly Dairy

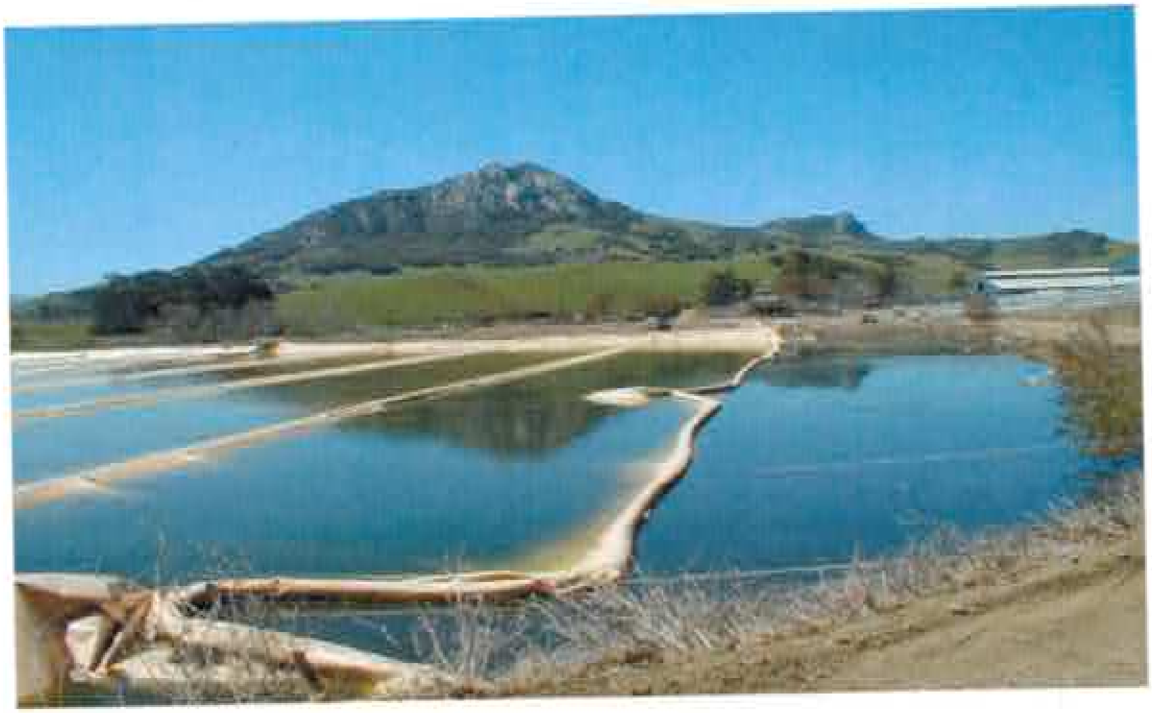

Figure 3: Biogas Handling System and 25 KW Microturbine Electric Generator

Figure 4: 10 KW Engine-Generator Test