Brewery resource and energy recovery system

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In this paper, a bio-gas and spent grain utilization system for a brewery is presented. The bio-gas component of the system consists of a generator to produce electricity for sale through the Feed-In Tariff program offered by the Ontario Power Authority. The spent grain component consists of a gasification system to produce syngas, which will reduce the natural gas requirements of the facility. A membrane bioreactor will be used downstream of the current anaerobic digester in order to eliminate the municipal surcharges on the effluent water and allow for water recycling. The design was analyzed using a net present value (NPV) analysis. The results showed a capital cost of \$8.9 million for the overall system, a payback period of 8 years, and a 20-year NPV of \$24 million. Recommendations are made as to how the economic and environmental benefits to the brewery could be improved.

The Guelph Sleeman Brewery is a mid-sized facility with an on-site wastewater treatment plant (WWTP). An opportunity was identified to capture the bio-gas from the WWTP to generate useful energy. The brewery also generates spent grain (SG) as a waste product from the brewing process. This represents another potential energy resource. A system has been designed for this brewery to utilize both the bio-gas and the SG stream.

This system had to be able to accommodate daily fluctuations in wastewater (WW) flows, as well as an expected 10% increase in the amount of WW and SG generated for the next five years. The system was optimized for energy generation. This both maximizes the economic benefits and reduces the usage of non-renewable energy resources.

Research was initially conducted to investigate possible solutions for the system. Aerobic and anaerobic techniques can be used to increase water quality and enhance methane production from the water treatment process [1,2]. The bio-gas generated from the WWTP must have the moisture removed in order to generate usable fuel. Water vapour can be removed from the bio-gas by cooling, compression or sorption methods [3]. The fuel can then be utilized in many ways, including electricity production with a generator or turbine, steam production in boilers, or space heating. SG can be utilized via anaerobic digestion to produce bio-gas, or by thermal treatments for energy production [4]. The system presented in this paper is unique in the combination of the components used and in their application for a brewery. The

components were optimized individually and then combined to form an efficient system.

CONCEPTUAL DESIGN

The brewery resource and energy recovery system consists of three independent components or subsystems: a bio-gas utilization system, a wastewater treatment enhancement system and a SG utilization system. Figure 1 shows the conceptual process flow diagram for the overall system.

Moisture in the bio-gas will be removed using passive underground cooling. This gas will then be used in a generator to produce electricity for sale through the Ontario Power Authority's Feed-In Tariff (FIT) program. A membrane bioreactor (MBR) will be used as a wastewater polishing step to eliminate the municipal surcharges for WWTP effluent disposal. The MBR effluent will be suitable for reuse within the facility. The SG will be used in a gasification process to generate synthetic gas (syngas). This syngas will be used in the brewery boilers resulting in natural gas savings.

DETAILED DESIGN

Bio-gas Utilization

The passive underground cooling system consists of a pipe and a gravel drainage bed. The pipe will travel underground for two meters to allow for adequate condensation of the water vapour. This length is based on an

Figure 1 System Process Flow Diagram

average summer soil temperature of 15°C and an incoming gas temperature of 35°C. The condensate will drain into the gravel bed and infiltrate into the soil, while the gas continues up the pipe. The cooling system is shown in Figure 2.

The maximum water content allowable in bio-gas for use in a generator is 80% saturated [3]. A factor of safety of two was applied to account for fluctuations in the initial bio-gas temperature and gas flow. As a result, the target moisture content for this design was set to 60% saturated. The gravel bed is designed to hold 24 hours worth of condensate assuming a porosity of 0.4. The capacity is based on the predicted bio-gas flow rate 20 years from now. A factor of safety of 1.5 was applied to the design of the gravel bed to account for any fluctuations in drainage conditions.

The brewery claims their bio-gas has a methane content of approximately 79% by volume. Methane content at the brewery is calculated estimating 2% water content, while saturated gas at 35°C has a 6% water content. To account for this difference, a reduced methane content of 75% was used for the design of the system.

To produce electricity from the bio-gas, a G3406NA Caterpillar Generator will be used [5]. The generator will be connected to the power distribution system for the sale of electricity. Electricity generated will be sold at a rate of 16¢ per kilowatt-hour [6]. The generator will be placed adjacent to the flare currently at the facility. After approximately 10 years, the bio-gas produced will exceed the capacity of this generator. The economical solution at this time will be to burn the excess gas with the current flare. A valve will be installed upstream to allow the gas to be diverted to the flare when maintenance is required. With the current bio-gas production of 1,140 m³ per day, approximately 75 kW of power will be produced [5]. The overall bio-gas utilization system has a capital cost of \$337,400 and generates a 20-year net present value (NPV) of \$1,725,000 [5].

Figure 2 Underground Passive Cooling System

Membrane Bioreactor (MBR)

The MBR will be placed downstream of the existing anaerobic digester. It will consist of a suspended growth biological reactor with a submerged ultrafiltration hollow fiber membrane component. A ZeeWeed MBR from GE Water & Process Technologies has been selected for this application.

The degradable material is aerobically digested in the bioreactor and a vacuum is applied to draw the clean water through the membranes. Airflow is intermittently introduced at the base of the membranes to prevent fouling [7]. The MBR has been sized for the current average inflow of 600 m³ per day. It is an expandable modular design which will accommodate the projected 10% growth in the WW flow. A high quality effluent will be discharged from the MBR with a total phosphorus content less than 0.05 mg/L and a total suspended solids content less than 2 mg/L [8]. The effluent water quality exceeds the municipal discharge standards which will result in savings for the brewery. This water will be reused within the facility in the coolers and boilers.

Spent Grain Gasification

To be suitable for gasification, a mechanical dewatering stage is required to lower the moisture content of the SG from approximately 80 to 58-60 wt%. A Flottweg Belt Press (Model BP 2500 TR) was chosen based on the current 300 tonnes of SG generated per week and the expected growth in production. Dewatering will be followed by a gasification stage using a Nexterra Updraft Gasifier. The resulting syngas will be burned in one of the brewery's existing boilers with a dual fuel burner nozzle.

The gasifier is a fixed-bed updraft gasifier from Nexterra and includes a system for connecting to the boilers. Nexterra's gasifiers have not yet been operated with SG as a fuel source, but other types of biomass have been used. The critical parameter that will determine if SG is suitable for this type of gasifier is the ash melting point. This value needs to be determined before a system for SG can be designed [9].

Table 1 Sensitivity analysis of bio-gas production growth

Growth for 5 Years	Growth after 5 Years	Generator Size	Payback (Years)	5-year NPV	10-year NPV	20-year NPV
10%	5%	3406 & 3412	5	\$-43,000	\$978,000	\$3,757,000
7.5%	3.8%	3406 & 3406	5	\$3000	\$776,000	\$2,514,000
5%	2.5%	3406	3.1	\$218,300	\$807,700	\$1,725,600
2.5%	1.3%	3406	3.4	\$160,000	\$620,000	\$1,398,000
0%	0%	3406	3.6	\$110,000	\$470,000	\$989,000

Note: 10% and 7.5% growth require reinvestment in a larger generator, resulting in a longer payback period

DISCUSSION

Sensitivity Analysis

Sensitivity analyses were conducted on the bio-gas moisture content, methane content, bio-gas yield, water reuse, and SG moisture.

A sensitivity analysis was completed to determine the effects of soil temperature on the moisture removal capacity of the bio-gas utilization system. The targeted 40% moisture removal will be achieved for the 20 year flow rate with soil temperatures up to 17°C. This allows for some system flexibility if unexpected soil temperatures occur. For lower flow rates, there is a greater margin for unexpectedly high soil temperatures. With a decrease in soil temperature to below 0°C in the winter months, it is expected that approximately 20% more moisture will be removed as compared to during the summer months.

The effect of bio-gas methane content on the economic performance of the system was analyzed since there is the possibility that the brewery's current methane content is overestimated. The sensitivity analysis investigated the effect of varying the methane content from 60 to 80%. This resulted in a 20-year NPV varying from \$1,430,800 to \$1,840,500.

The hydraulic retention time within the anaerobic digester will decrease as the wastewater flow to the WWTP increases. It is thus anticipated that the bio-gas yield will not increase proportionally with the increase in WW flows in

future years. A sensitivity analysis was conducted varying the growth in bio-gas production per year from 0 to 10% for the next 5 years. The results showed that the 20-year NPV will vary from \$989,000 to \$3,757,000. More detailed results of this analysis are presented in Table 1.

The cost savings associated with the MBR system depend on the quantity of effluent water reused in the facility. The effect of the water recycle rate on the payback period for the MBR was assessed. A cost-benefit analysis was performed, taking into account the financial benefit from surcharge avoidance and the supplementary benefit of reducing water consumption through water reuse. Implementing the MBR will eliminate all municipal surcharges. On a per volume basis, this amounts to \$0.86 per m³ of discharge. This surcharge rate exceeds the MBR operational costs of \$0.55 per m³. Cost savings will thus be realized right from the time of implementation, and will be proportional to the quantity of water recycled. It was found that as the rate of water reuse is increased from 0-100%, the annual profit will increase from \$68,600 to \$550,400. A summary of the economic analysis performed can be found in Table 2. As the rate of water reuse increases, the payback period decreases significantly. The brewery will realize maximum economic benefit by maximizing the quantity of water reused.

Since the moisture content of SG can vary, the effect of moisture on the economic benefits from the gasification system were investigated. Annual natural gas savings are

Table 2 Summary of the economic analysis performed for various recycle rates

Recycle Rate (m ³ /day)	Payback Period	5-year NPV	10-year NPV	20-year NPV
0	11.1	-\$1,487,000	-\$429,000	\$2,903,900
200	7.1	-\$493,000	\$2,228,700	\$11,598,000
400	5.3	\$500,900	\$4,886,400	\$20,292,000
600	4.3	\$1,494,400	\$7,544,000	\$28,986,200

Table 3 Sensitivity analysis on spent grain initial moisture content

Moisture Content (w/w)	Initial Revenue	Payback (Years)	5-year NPV	10-year NPV	20-year NPV
75%	\$537,400	9.6	-\$3,529,600	\$336,300	\$9,648,500
80%	\$405,700	11.9	-\$4,248,600	-\$1,250,400	\$6,045,900
85%	\$274,000	15.7	-\$4,967,600	-\$2,837,200	\$2,443,300

affected by moisture content. A lower moisture content implies there will be more SG solids available to produce energy. It was found that as the moisture content of SG varies from 75-85 wt%, the annual natural gas savings decrease from \$658,300 to \$395,000. At a lower moisture content, the NPV increases at a much faster rate, resulting in a greater 20 year NPV and smaller payback period. A summary of the results based on a capital cost of \$6.58 million [10] are given in Table 3. There is a 6 year difference in payback period and a \$7 million difference in the 20 year NPV when the moisture content varies from 75-85% w/w. This shows that moisture content greatly affects the economic potential of the SG system.

Design Evaluation

The overall system proposed consists of a bio-gas utilization system, an aerobic MBR, and a SG gasification system. These three subsystems were analyzed separately and as a unified system. Table 4 gives the capital cost, annual profit, payback period, and 20-year NPV. The following values were used for these calculations: 75% methane content; 5% bio-gas, 10% wastewater and 10% SG growth for 5 years; a water reuse rate of 50%; 300 tonnes of SG produced per week; an electricity price of \$0.16 per kWh; a

Figure 3 NPV for overall system and components

natural gas price of \$9.58/GJ; and interest and inflation rates of 5% and 2%, respectively. Costing information was obtained from Caterpillar [5], GE Water & Process Technologies [8], Flotwegg Separation Technology [11] and Nexterra Systems Corporation [10].

There are clear economic differences between the subsystems, as shown in Table 4. The bio-gas utilization system represents the lowest capital investment and shortest payback period. This may be viewed as advantageous to the Sleeman Brewery. The MBR and gasification systems require larger investments; however, they result in greater NPVs in the long term. Figure 3 graphically shows the value of each system projected over time, as well as the combined NPV generated for the entire system.

The overall system is modular as the subsystems are not dependent on one another. Each of the subsystems has its own economic and environmental advantages. This allows the Sleeman Brewery to select which subsystems to implement based on their needs. The greatest overall benefit will be achieved by implementing all three subsystems.

Environmental Assessment

Generating electricity from the bio-gas results in 628,000 kWh of renewable energy per year. It also results in reduced carbon dioxide (CO₂) emissions since the electricity is carbon neutral and can displace other carbon emitting electricity sources.

Reusing the MBR effluent at a rate of 50% would result in a yearly water use reduction of just over 110,000 m³. Without reuse, the effluent would be discharged to the municipality where it would undergo additional wastewater treatment. By recycling the water, the energy required to treat the water both before and after use is eliminated. This results in a decrease in the CO₂ emitted.

The gasification system will replace 55,000 GJ of natural gas per year. The use of syngas instead of natural gas replaces the use of a non-renewable resource with a renewable one. This results in a reduction in CO₂ emissions, as syngas is carbon neutral.

The combined system results in an overall total reduction in CO₂ emissions of 3,662 tonnes per year [12]. An additional motivation for reusing the WW is the aspect of creating a competitive advantage. A company's image can be enhanced through environmentally progressive projects which have positive economic and ecologic effects.

CONCLUSIONS

This report conveys a detailed design of the resource and energy recovery system proposed for the Guelph Sleeman Brewery. The design is composed of bio-gas utilization in a generator, a MBR wastewater treatment system, and a SG gasification system. The overall system is unique in the modularity it presents, and the wide range of benefits offered by each individual subsystem. The

Table 4 Summary of subsystem and overall system economic results

	Capital Cost	Annual Profit	Payback Period	20-year NPV
Generator	\$337,400	\$107,400	3 years	\$1,725,000
MBR	\$2,000,000	\$309,500	5 years	\$15,950,000
Gasification	\$6,580,000	\$380,000	12 years	\$6,100,000
Overall	\$8,917,400	\$796,900	8 years	\$23,775,000

utilization of bio-gas and SG at the Guelph Sleeman Brewery can generate clean, renewable energy. Projects of this type are important for the future, as dwindling non-renewable energy sources generate pollution and greenhouse gases.

There are a number of recommendations for the brewery to consider for the continuation of this project. It is recommended that the brewery investigate opportunities within the facility to reuse 100% of the MBR effluent to maximize economic benefits. The operational costs of gasification could be reduced by selling fertilizer made from the ash remaining after the gasification process. It is also possible to use the press water from the dewatering stage to replace some of the brew water used for production. A number of incentive programs in addition to FIT have been identified, but further input is required by the brewery. The brewery would be eligible for financial support from the City of Guelph through the ICI Capacity Buyback program for water use reduction. SG gasification funding opportunities include the ecoENERGY for Biofuels program, the Sustainable Development Technology Canada Fund, and the Scientific Research and Experimental Development program.

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