Anaerobic Digester Produced Biogas and Solid Oxide Fuel Cells: An Alternative Energy Source for Ontario Wastewater Treatment Facilities

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Abstract

In Ontario, 45 of the 56 wastewater treatment plants (WWTP) in large urban areas incorporate an anaerobic digestion (AD) process to reduce the volume of disposable sludge. A byproduct of the AD process is biogas, a primary constituent of which is methane. The energy content of the biogas represents a significant resource for power production that has remained largely underexploited. In Ontario, a majority of the AD-generated biogas is simply flared off to the atmosphere. In some cases, a portion of the biogas is used to supply the heating requirements of the AD process.

This research focused on the feasibility of exploiting the biogas produced in Ontario WWTP for producing electrical and thermal energy using solid oxide fuel cells (SOFC). Biogas production rates and composition data from major urban area WWTP in Ontario have been compiled and analyzed to quantify the energy potential of this fuel source. Key contaminants in biogas and methods for their clean-up were also determined.

Based on these analyses, the most suitable Ontario sites for the installation of biogas-fueled SOFC in the near-term have been identified. An environmental assessment was also undertaken in order to determine the reduction in greenhouse gas emissions if such systems are installed in Ontario.

Wastewater Treatment

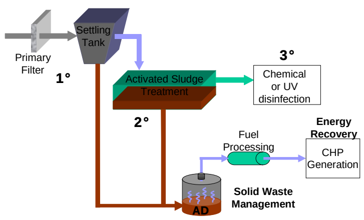

Fig. 1. A schematic diagram of a typical wastewater treatment plant (WWTP). A plant is normally comprised of four sections.

1° Treatment – A primary filter and settling tank remove large particular matter.

2° Treatment – Wastewater (WW) is mixed with solid waste material containing micro-organisms that consume organic material. The micro-organisms are aerobic and therefore the addition of air or oxygen is required.

3° Treatment – Effluent from the secondary treatment process is disinfected prior to discharge. Disinfection is done either chemically or with UV light.

Solid Waste Treatment – The solid waste from 1° and 2° treatment processes are mixed and digested in an anaerobic digester (AD).

Energy Recovery – Biogas produced from the digestion process, a low to medium heating value gas, can be used in a combined heat and power system, such as a solid oxide fuel cell (SOFC), to generate electricity and heat for the WWTP.

Solid Oxide Fuel Cells

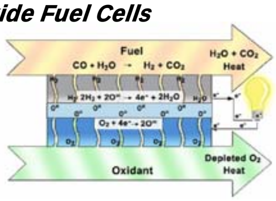

Fig. 2. A schematic diagram of a solid oxide fuel cell system [1].

Solid oxide fuel cells are solid-state energy conversion devices that produce electricity and heat by electrochemically oxidizing fuel. Compared with other types of fuel cells, SOFC operate at temperatures greater than 800°C, resulting in a number of advantages:

- Rapid reaction kinetics allow for the use of low-cost Ni catalysts.
- The high-quality byproduct heat of the electrochemical reaction is available for localized heating - combined heat and power (CHP).
- Compared with polymer electrolyte fuel cells (PEMFC) , SOFCs are very fuel flexible, and can more readily utilize fuels such as methane, biogas and CO.
- SOFC can also use CO as fuel which is a poison for low-temperature PEMFC.

Biogas Generation from WWTP in Ontario

Biogas produced from the anaerobic digestion of WW is typically a medium heating value gas composed of 58-62% CH_4, 30-35% CO_2, N_2, O_2 and H_2S. Other contaminants such as siloxanes and halides may also be present. The location of biogas producing WWTP in Ontario that we have identified are shown in Fig. 2. The composition data of selected sites is shown in Table 1.

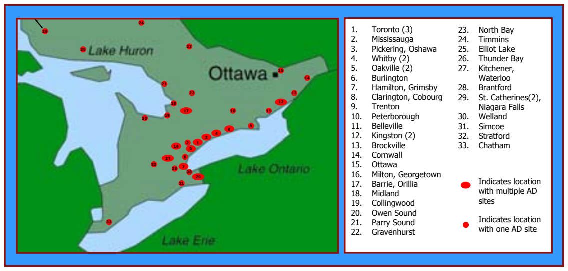

Fig. 3. Location of WWTP with AD in Ontario

Biogas Clean-up and Processing

Prior to entering SOFC the contaminants in the biogas must be removed or reduced to low levels to avoid damaging the system. In cases of low H_2S content, such as those shown in Table 1, an activated carbon bed is sufficient to reduce contamination to acceptable levels. A similar absorption bed can also be used to remove siloxanes. It is these sites, with low contamination levels, that are best suited for the near-term application of biogas-fuelled SOFC systems.

	Ravensview WWTP *Kingston, ON*	Humber WWTP *Toronto, ON*	Pickard Environmental Centre *Ottawa, ON*
Biogas (m^3/day)	1 900	25 000	27 000
HHV (MJ/m^3)	23.8	23.1	24.2
CH4 (vol%)	59.9	58.2	61.0
CO2 (vol%)	30	31.9	37.4
N2 (vol%)	7.3	7.1	1.2
O2 (vol%)	2.1	2.0	N/M
CO (ppm)	< 0.005	<100	19.5
H2S (ppm)	2.5	164	6.5
other	< 6.0 ppm	~0.01%	< 3.0 %

Table 1. Composition data from biogas producing WWTP in Ontario.

Once cleaned, the biogas must be processed or 'reformed' to generate a hydrogen-rich fuel stream, which is more easily consumed by the SOFC. This reforming can take place in several ways, and is discussed elsewhere [2].

Biogas Energy

There is a lack of data on the topic of WWTP biogas produced in Ontario. In general, biogas volumetric flowrate data is not collected and, in most cases, biogas composition data is unavailable, while all plants keep records of wastewater input to the plant. It was therefore necessary to derive a correlation between the wastewater input and the biogas output from the collected data to estimate the amount of biogas produced in Ontario.

The correlation is shown in Fig. 4. An extrapolation of the data to 1000 m³/day of WW influent shows that on average 56 m³ of biogas is produced per 1000 m³ of WW influent.

If the energy content, or HHV, of the biogas is taken as 24.4 MJ/m³, an average of 8 sites surveyed with composition data, then per 1000 m³ of influent WW, 1080 MJ or 0.3 MWh of energy is available. In the case of the Humber WWTP one of the largest sites, 138 MWh per day of biogas is generated.

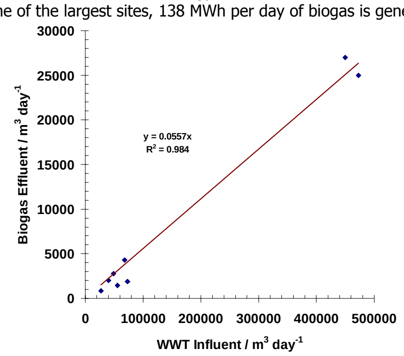

Figure 4. Correlation between biogas generation and wastewater input.

Biogas Energy

In Fig. 5 the amount of biogas energy available in selected regions in Ontario is shown. These values were calculated using the correlation developed in Fig. 4, and the average biogas composition from the collected data.

When considering an efficiency of 70% for a combined heat and power SOFC system, a total of 1.22 GWh per day is available from the existing AD sites in Southern Ontario, nearly 30% of which comes from Metropolitan Toronto and over 60% from the greater Toronto region. If the WWTP sites in Ontario which do not currently employ AD are considered the total amount of biogas energy available increases to 1.51 GWh/ day.

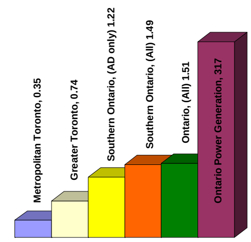

Figure 5. Potential electrical energy generation from WWTP biogas in Ontario in GWh per day.

When compared to the average amount of 317 GWh consumed each day in Ontario, the available biogas energy is relatively small, but the generation of power from biogas does represent an important reduction in CO_2 emissions. On average, 0.3 kg of CO_2 are produced per kWh of energy produced from OPG [3]. The total amount of biogas energy available from current AD sites in Southern Ontario represents a savings of 432 tonnes of CO_2 per day.

Biogas as an electrical energy source would also allow for the distribution of the electrical generation infrastructure.

Future Work

A significant amount of difficulty was encountered when collecting data from the various WWTP in Ontario, as there is no centralized data collection or listing of the WWT facilities in Ontario. The collection of this data is still underway and as we identify more WWTPs that employ AD the amount of biogas energy available in Ontario will be more accurate. Further information regarding the electricity usage of WWT, the composition of the biogas, and methods for treating the biogas is also being collected.

Several municipalities are currently evaluating the possibility of utilizing the biogas from the WWTP, including Peterborough, Hamilton and a recent project funding announcement in Kingston [4].

Future work will also include the development of a computer model for biogas fuelled SOFC systems in the HYSYS package. This will allow for more accurate predictions of potential electricity and heat generation to be made.

Alternative CHP Technologies

Combined heat and power (CHP) technologies produce electricity but also recover usable waste heat from the process. Table 2. is a comparison of CHP technologies for biogas fuel [5]

	Nat. Gas Engine	Gas Turbine	Micro-Turbine	SOFC
Elec. Eff. (LHV, %)	25-45	40-60	23-30	40-70
Fuel	Nat.Gas, High CH_4 Biogas	Nat.Gas, High CH_4 Biogas	Nat.Gas, High CH_4 Biogas	H_2, CO, Biogas
Fuel Pressure (psi)	1-45	120-500	40-100	0.5-45
Noise	Moderate to High	Moderate	Moderate	Low
NOx Emissions (kg/MWh)	1-12	0.1-2	0.2-1	<0.1
Installed Cost ($/kW)	800-1500	700-900	500-1300	1200-2000
Future Cost ($/kW)	n/a	500-900	500-1000	500-1200

Table 2. Comparisons of CHP technologies.

References

[1] Adapted from http://freeenergynews.com/Directory/FuelCell/SolidOxide/solid_oxide_fuel_cell_diagram_nasa.jpg

[2] Caners C., Wheeldon I., Karan K., Peppley B. Use of wastewater treament biogas as fuel for a solid oxide fuel cell. 10th World Congress on Anaerobic Digestion. August 2004.

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