Harvesting biogas from wastewater sludge and food waste

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Abstract. Wastewater sludge and food waste are good source of biogas. Anaerobic treatment of sludge and food waste able to produce biogas which is a potential renewable energy source. This study looks into the potential biogas generation and the effects of temperature on biogas generation. A lab scale reactor was used to simulate the biogas generation. The results show that wastewater sludge able to produced upto 44.82 ml biogas/kg of sludge. When mixed with food waste at a ratio of 30:70 (food waste), the biogas generated were 219.07 ml/kg of waste. Anaerobic of food waste alone produced biogas amount to 59.75 ml/kg of food waste. Anaerobic treatment also reduces the volume of waste. The effect of temperature shows that higher temperature produces more biogas than lower temperature.

1. Introduction

Wastewater treatment and management is an essential part of preserving good public health for a country. Strict regulation had been enforced for proper treatment of wastewater and disposal of treated effluent. Since 1994, the management of wastewater in most of the states Peninsular Malaysia is under a private company named Indah Water Konsortium IWK Sdn Bhd. In recent sustainable report by IWK, it has operates and maintained 14342 km of public sewer networks, 5605 public sewerage treatment plants and 778 network pump stations [1]. The generation of wastewater sludge ranges from 60 to 90 g dried solids per population equivalent or PE in European Union [2]. Concentrated wastewater sludge contains high organic contents and has potential as biogas source if treated anaerobically. Previously, the treated sludge are used as fertiliser for crops or simply landfilled. Anaerobic digestion however can convert part of the organic sludge to methane, carbon dioxide and traces of other gases. The composition of the biogas and rate of generation is a function of the type and concentration of organic waste, reaction environment such as pH, temperature and moisture contents. The composition of biogas from wastewater sludge ranges from 50-75% CH$_4$ and 25 - 50% CO$_2$ plus traces of H$_2$S [13].

Generally, the anaerobic digestion follows: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The hydrolysis stage degrades both insoluble organic material and high molecular compounds such as fat and grease into soluble organic substances. The acidogenic bacteria further breakdown the soluble organic compound into volatile fatty acid. During the acetogenic stage, the volatile fatty acid was converted by acetogens into acetic acid and other gases such as CO$_2$ and H$_2$. The methanogenic bacteria digest the acetate into methane and CO$_2$. Within an anaerobic environment, parameters such as pH, temperature and retention time influence the biogas generation. Methanogenic bacteria prefer optimum pH between 6.5 and 7.2 [3]. Temperature affects substrate digestion, influences microorganism growth rates and metabolism and microbes population dynamic. High temperature enhances the biological and chemical reaction rates. The inhibition factor includes
the presence of ammonia, sulphide, sodium, potassium and heavy metals. Co-digestion of sludge with animal manure, food waste, fruit and vegetable waste and glycerol is another new approach to waste digestion. In a study by Chua et al, it was found that mixing food waste with chicken manure produces more biogas than anaerobic digestion of food waste alone [4]. Fountoulakis et al found that addition of glycerol in wastewater sludge at 1% v/v increases the CH4 production [5]. Recent report by IMeche had indicated that about 30 to 50% or 1.2 to 2 billion tonnes of the food produced globally never reach the consumers. 4.4 million Tonnes of avoidable food waste being dumped in UK [6]. In Malaysia, it was reported that Malaysian disposed 930 tonnes of food waste a day [7]. In a study by Kim et al shows that it is possible to treat the food waste anaerobically and generate 254 to 282 litre CH4 per kg COD degraded [8]. Higher temperature further improves the biogas generation from treating food waste anaerobically [9]. Co-digestion of cattle manure with food waste with sewage sludge in 70:20:10 ratios at 36°C yielded maximum biogas of 603 l CH4/kg Volatile solid feed [10].

This study looks into the co-digestion of sewage sludge with food waste taken from a site that operated hospitality and tourism business which also operate its own wastewater treatment plants. Co-digestion of sewage sludge and food waste presents a environmental friendly option to solve the waste disposal problem and also an opportunity to harvest the biogas for direct heating or other usage.

2. Methodology and Results

Samples were collected from site and delivered to an experimental laboratory to be analysed. Some of the samples chemical characteristics were given in Table 1. A series of laboratory scale reactor consists of circular PVC containers with volume of about 20 litres were prepared. Each reactor had a gas outlet and tube for gas collection. The chemical analysis followed Standard Method for the examination of water and wastewater by APHA. COD was measured using Hach Spectrophotometer 2100. BOD measurement was measured by YSI BOD meter. All the samples were subjected dilution as the concentration of BOD5 and COD are extremely high.

Table 1. Sample Characteristic

| Parameters                          | Sewage sludge | Food waste |
|-------------------------------------|---------------|------------|
| Biochemical oxygen demand, BOD5, mg/l | 29,524        | 162,086    |
| Chemical oxygen demand, COD mg/l     | 135,711       | 682,847    |
| Ratio of BOD5:COD                    | 1: 4.60       | 1: 4.21    |
| Moisture content,%                  | 68.9          | 94.3       |
| Biochemical oxygen demand, BOD5, mg/l | 29,524        | 162,086    |
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The proportion of co-digestion of food waste and sludge (w/w) and initial mass are given in Table 2. All the reactors were placed in a shaded area except Sample 3 which was placed under direct sunlight. The average temperature for shaded area and direct sunlight were 28.5°C and 30.5°C respectively. The reactors were monitored over 65 days.

Table 2. Proportions of food waste and sewage sludge

|             | Food waste | Sewage sludge | Total initial mass, kg |
|-------------|------------|---------------|------------------------|
| Sample 1    | 100        | 0             | 7.13                   |
| Sample 2    | 70         | 30            | 8.16                   |
| Sample 3 (O)| 70         | 30            | 7.97                   |
| Sample 4    | 30         | 70            | 9.77                   |
| Sample 5    | 0          | 100           | 9.75                   |

The effects of anaerobic digestion on BOD5 and COD removal after 65 days are given in Table 3 below. It shows that the percentage removal of BOD5 ranges from 93.24 to 97.63%. In term of COD, the percentage removal ranges from 35.4 to 59.42%. It shows that the percentage removal for food waste in terms of BOD5 and COD from anaerobic digestion is higher than sewage sludge.
Table 3. BOD₅ and COD Concentration and percentage removal

|                  | Initial BOD₅ con. mg/l | BOD₅ con. after 65 days, mg/l | % removal | Initial COD con. mg/l | COD con. after 65 days, mg/l | % removal |
|------------------|------------------------|------------------------------|-----------|-----------------------|-------------------------------|-----------|
| Sample 1         | 162086                 | 5510                         | 96.60     | 682847                | 277129                       | 59.42     |
| Sample 2         | 122298                 | 5890                         | 95.18     | 518706                | 335067                       | 35.40     |
| Sample 3 (O)     | 122560                 | 2906                         | 97.63     | 310000                | 310000                       | 40.31     |
| Sample 4         | 69287                  | 4650                         | 93.29     | 299851                | 147500                       | 50.81     |
| Sample 5         | 29524                  | 1997                         | 93.24     | 135711                | 62500                        | 53.94     |

This is expected as the sewage sludge is the residue from the biological treatment of wastewater which contains 0.8 to 1.2% dried solids of which 59% to 88% volatile solids and 32 to 41% protein [11]. Food waste however has higher biodegradable organic matter that allows microbes to digest. Comparison between Sample 2 and Sample 3 indicates that BOD₅ and COD removal correlate with ambient temperature. Higher removal for higher temperature indicates higher biological activities. The biogas generation is presented in the Figures below and Table 4. The accumulated biogas per mass of waste ranges from 13.41 ml/kg of waste to 219.07 ml/kg of waste. These are empirical values based on experimental set-up. On site, the generation of biogas ranges from 0.75 to 1.2 m³/kg volatile solid [11]. The laboratory scale result shows that sewage sludge able to generate more biogas per mass of total solids than food waste. Comparison between Sample 2 and Sample 4 indicated similar trend. Sample 5 has much higher moisture content than Sample 1 hence in terms of dried solids; it yields much higher gas generation.

Table 4. Biogas Generation

|                  | Initial Moisture content % | Volume of biogas accumulated, ml | Gas generation, ml /kg mass of waste | Gas generation ml /kg mass of total solids |
|------------------|---------------------------|----------------------------------|--------------------------------------|--------------------------------------------|
| Sample 1         | 68.87                     | 426                              | 59.75                                | 191.92                                     |
| Sample 2         | 75.48                     | 138                              | 16.91                                | 68.97                                      |
| Sample 3 (O)     | 76.12                     | 1746                             | 219.07                               | 917.38                                     |
| Sample 4         | 85.76                     | 131                              | 13.41                                | 94.17                                      |
| Sample 5         | 92.8                      | 437                              | 44.82                                | 622.5                                      |

The highest biogas generation is at Sample 3 where the reactor was under direct sunlight as compare with Sample 2. It is able to increase biogas generation by 13-folds. The proportion of sewage sludge to food waste was 30:70. Higher temperature enhances the microbial growth dynamic and allows more waste being converted to biogas.

Figure 1. Biogas Generation for Sample 1

The graphs indicate that the rate of biogas formation reaches plateau after almost 30 days. The generation rate per day shows that biogas generation from sewage sludge is faster than food waste. It takes almost 10 days to reach the 50% maximum potential biogas generation. The generation rate can be modelled using Monod equation as quoted by Appels et al [12].
3. Conclusion
This empirical study shows that temperature influence greatly the biogas production. Co digestion food waste with sewage sludge allows the microbial population in sludge to digest the food waste and enhance waste degeneration. If similar reactor is to be located at cooler temperature environment, a “greenhouse” concept approach is plausible where the reactor is exposed to direct sunlight in a confined place. It allows heat retention from direct sunlight without exposing to cooler air.

Acknowledgment
The authors would like to thank Genting World Resort especially Mr. Chia Chin Kuan, Vice President of Engineering Department for granting us permission to collect samples. The authors also like to thank Energy Commission for partial funding of the project.

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