An application of anaerobic baffled reactor to produce biogas from kitchen waste

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Abstract

The tremendous increase in solid waste generation is an unavoidable occurrence due to the fast growing urbanisation and industrialisation in Malaysia. Anaerobic digestion of organic wastes is receiving more attention in recent years throughout the world because the biomethanogenesis process decomposes organic matter to produce methane gas, which is an excellent energy source as fuel in combined heat and power units. In this study an application of an Anaerobic Baffled Reactor (ABR) for the production of biogas from kitchen waste was carried out to identify the optimum efficiency of methane gas generation and the potential usage of sludge as organic fertiliser. Different proportions of kitchen waste and activated sewage sludge were mixed and tested in the reactor to achieve the best amount of methane production in the shortest time. Results showed that the combination of 75% of kitchen waste and 25% of activated sewage sludge presented as the best result, which was 74.1% of methane gas. Further, determination for fertiliser value from tests on the sludge in the reactor showed its potential for future use in composting. The amounts of N, P and K were 0.95, 0.80 and 0.45% respectively. According to the observation, anaerobic digestion of kitchen waste in the ABR is able to provide a vital element in an integrated solid waste management and the energy production from this system could be a good reason for many communities to start recycling valuable resources, and hence achieving zero waste production.

Keywords: anaerobic baffled reactor, kitchen waste, biogas production.

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1 Introduction

In many countries such as Malaysia, it is increasingly more difficult to find suitable locations for landfills, which are accepted by the population. These circumstances are to be found all over the world and make new strategies for waste management necessary. In addition, the promotion of waste minimization and recycling are important components of modern waste management strategies [1].

There are perceptible advantages of anaerobic systems over aerobic metabolic systems, and these have been widely reported in the last four decades [2]. There are three clear advantages of the anaerobic treatment over aerobic degradation of organic substrates: the high product and low biomass yield resulting in a limited generation of waste sludge as an unwanted side product; the *in situ* separation of the product as biogas, limiting costs for product separation; and the use of simple technology, as mixing by the biogas produced circumvents the need for other mixing requirements [3].

Currently, digesters are concentrated in developing countries, with over 5 million household digesters constructed in China and India alone [4]. Digesters built around the world vary in their design complexity, construction materials, and costs. In developed countries, digesters often are concrete stirred tank reactors (CSTRs), in which a portion of the produced biogas is utilized to heat the digester [5]. In developing countries, many of the digesters do not have mixing components, do not require continuous monitoring, and are adaptable to any tropical climate [6]. Anaerobic Baffled Reactor initially receives the organic fraction of municipal solid waste (OFMSW) followed by decomposition process of the materials and eventually produces biogas by microorganisms' activities. Biogas is an excellent source used as fuel in combined heat and power units. The sludge that produced from this system includes body of microorganisms, which can be applied as a source of organic fertilizer [7].

In this study an anaerobic baffled reactor was proposed for the recovery of energy and production of organic fertilizer. A modified design of Anaerobic Baffled Reactor (ABR) was carried out with using different combination of kitchen waste and activated sewage sludge to achieve the highest biogas and methane generation in the shortest time. The sludge produced in the anaerobic system is examined based on its usage as a source of organic fertilizer and to make the ABR a system by completely using all of the materials throughout the system.

2 Methods

2.1 Reactor configuration

Additional vertical baffles in a plug-flow reactor constitute an ABR, which enhances solids retention to allow better substrate accessibility to methanogens [8]. The laboratory-scale unit shown in Figure1 was made with a total volume of 85 liters. Two tanks as influent tank and effluent tank were designed for feeding and removing the materials to and from the reactor. A gas collector was also provided for collection, calculation and analysis on the amount of biogas. The dimension of the laboratory-scale unit was 75 cm length, 42 cm height and 27 cm depth. The down-flow chambers were 3 cm above the reactor's bottom to route the flow to the center of the up-flow chamber to achieve better contact and greater mixing the feedstock and solids.

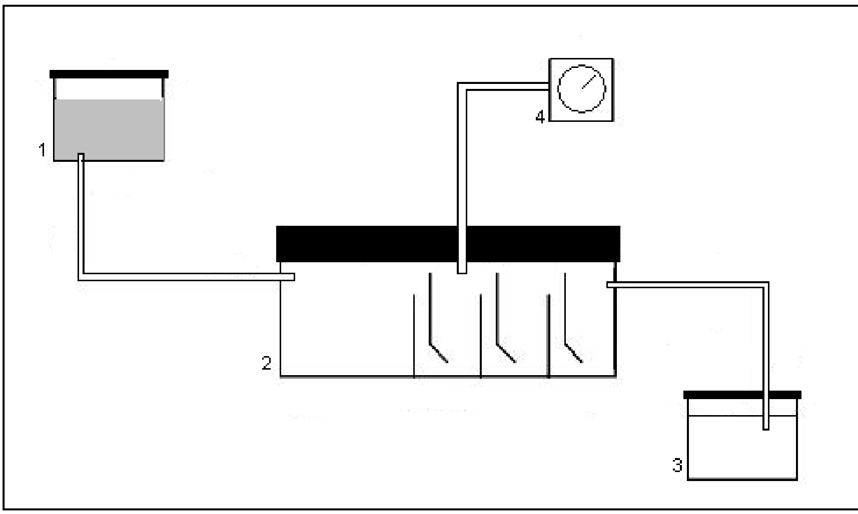

Figure 1: Laboratory scale anaerobic baffled reactor (1: influent tank, 2: ABR system, 3: effluent tank, 4: wet gas meter).

The first compartment of a four-chamber unit was bigger in size, which was 34 liters, while the following compartments were 17 liters. This physical modification provided longer solids retention time and superior performance as compared to the reactor with similar size compartments. The larger compartment in the reactor acted as a natural filter and provided superior solids retention for the small particles. This configuration collected more solid materials than the reactor with four of the similar size chambers [8]. The edges on baffles slanted on 45^{o} to route the flow towards the center of the compartment and, hence, encourage mixing.

2.2 Feed stock preparation

Based on characteristics of kitchen waste and its high C/N ration [1], different percentage of kitchen waste was mixed with sewage sludge as a source of Nitrogen to normalize the value of C/N. The sewage sludge was collected from a wastewater treatment plant sewage sludge return pipeline and immediately brought to the laboratory. The C/N ratio of sewage sludge, which used in the experiments, was 11/1 with 5% N of dry weight. Four different combinations of kitchen waste and sewage sludge were compared to determine the best efficiency of methane gas generation in the shortest time (Table1).

Table 1: The percentages of kitchen waste and sewage sludge.

Sample No.	Kitchen waste (%)	Sewage sludge (%)
1	100	0
2	75	25
3	50	50
4	25	75

2.3 Analytical methods

The characteristics of kitchen waste were initially determined. The wastes were taken from kitchen refuse of a cafeteria located at university. “Part and quarterly methods” were used as standard procedures to prepare samples. Then, they were collected and combined in an approximately equal proportion and mixed thoroughly in the laboratory, shredded and grounded into a size of approximately 1 x 1 x 0.5 cm prior to analysis for chemical composition. Samples were analyzed for moisture content, total solids, total volatile solids, ash content, total organic carbon, Kjeldahl nitrogen, fat, protein, cellulose, hemi cellulose and lignin using analytical methods given by USEPA [9]. The pH of the slurry was measured using a digital pH meter having an accuracy of ± 0.01 pH unit and the reactor was run in mesophilic conditions. Totally, 40 samples were measured and finally the average of each parameter was calculated. Gas samples were collected by gas sampling injectors and a sample of 100 μl was used for each run. The biogas composition (CH_4+CO_2) was determined by using a Gas Chromatograph (NUCON 5700) equipped with a thermal conductivity detector and stainless steel column of length 6 ft, OD 1/4 inch, ID 2 mm, containing Porapak Q 100 having mesh range 80–100. The carrier gas used was H_2 and the analysis was carried out at a carrier gas flow rate of 30 ml/min with the injector, column and detector temperatures maintained at 120, 90 and 120°C, respectively. Gas volume was measured using a water displacement method. To measure the fertilizer values, concentration of Nitrogen, Phosphorus and Potassium in produced sludge in the Anaerobic Baffled Reactor (ABR), using analytical methods given by APHA [10].

3 Results and discussion

3.1 Kitchen waste characteristics

Table 2 shows the chemical composition of kitchen waste. For the purpose of gas generation the solid content of feed material should be approximately 10-15 percent [11]. Total solids were found between 10.4 to 20.7% with the average of 14.8%. C/N ratio was another value that was calculated. Bacteria normally use up carbon 25-35 times faster than they use nitrogen. Therefore, at this ratio of

C/N (25-35 /1) the digester is expected to operate at an optimal level for gas production. The C/N ratio for kitchen waste was found 38.2/1.

Table 2: Chemical composition of kitchen waste.

Parameters	Weight fraction (%) or ratio
Total solids	14.8
Total volatile solids	89.5
Ash	10.5
Total organic carbon	49.7
Kjeldahl nitrogen	1.3
C/N weight ratio	38.2
Fat	8.7
Protein	6.7
Cellulose	14.9
Hemi-cellulose	9.9
Lignin	8.5
Moisture content	84.5

The substrate consists of complex organic polymers, these organic polymers have very important role in the first stage of anaerobic digestion of organic compounds and their present is vital, because these organic polymers are broken down by extracellular enzymes produced by hydrolytic bacteria, and dissolved in the water. The moisture content of kitchen waste was found 84.5%. The high moisture content verified that kitchen waste was not ideal for incineration or landfill.

3.2 Volatile fatty acid profile and pH

Changing of pH during anaerobic digestion for all mixtures illustrated in Figure 2. After 16 days of digestion, the kitchen waste alone was still in its acid formation phase, as indicated by the slightly acidic leachate collected (pH = 5.92). High CO_2 and low CH_4 contents are the best indicators reflecting that the digestion process has not reached active methanogenesis [12]. For other samples (Sample 2 to 4) the pH variation could be categorized into 3 main zones. The first zone started from the first day till 4^{th} day, which showed a drastic drop of the pH. This is due to high development rate of volatile fatty acid by the microorganism. The second zone started from the 5^{th} till the 12^{th} day of the experiment. In the second zone, the pH was in the range of 6.9 to 7.3. This is due to the development of CO_3HNH_4 from CO_2 and NH_3, which were produced during the anaerobic process. The percentage of CO_3HNH_4 had caused the increase alkalinity of the samples. Due to this, any differences in the volatile fatty acid content did not affect the pH value. The third zone started on the 13^{th} till the last day of the experiment. In this zone, it was found that the pH value of the samples started to increase. This is due to the development of CO_3HNH_4 still continuing, but no more volatile fatty acid was produced.

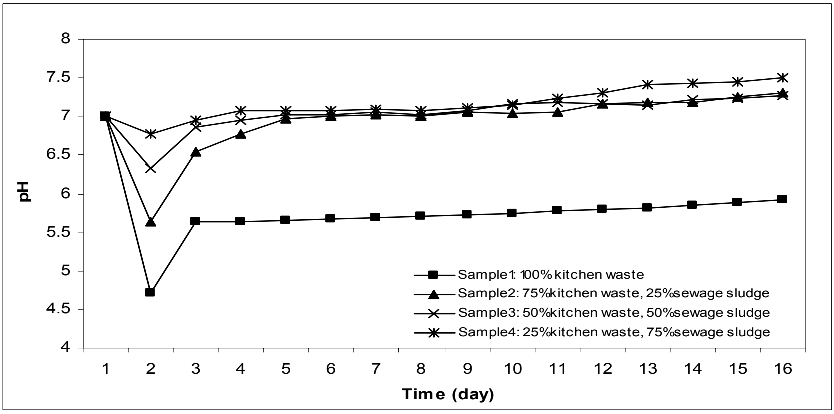

Figure 2: pH variation of the samples during anaerobic process.

3.3 Gas production and composition

Gas production in each sample is illustrated in Figure 3. Kitchen waste alone produced 0.050 m^3/kg VS biogas after 16 days. The combination of 75% kitchen waste 25% sewage sludge had relatively high gas production rate of 0.594 m^3 per kg VS, while the gas production for sample 3 and 4 was 0.201 and 0.151 m^3/kg VS respectively.

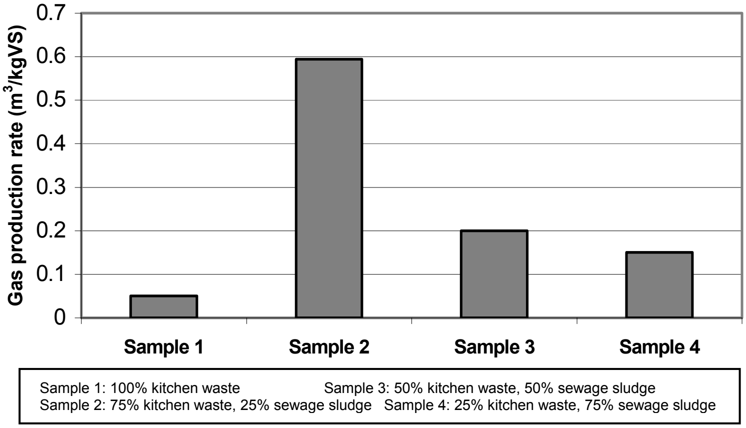

Figure 3: Gas production in the mixtures after 16 days.

After 16 days of digestion, the kitchen waste alone was still in its acid formation phase, as indicated by the slightly acidic leachate collected. Furthermore, the relatively high level of CO_2 and low level of CH_4 from kitchen waste alone throughout the whole experimental period (Figure 4) indicated that a longer period was needed for the kitchen waste to go through the acidogenic and acetogenic phases. High CO_2 and low CH_4 contents are the best indicators reflecting that the digestion process has not reached active methanogenesis [12].

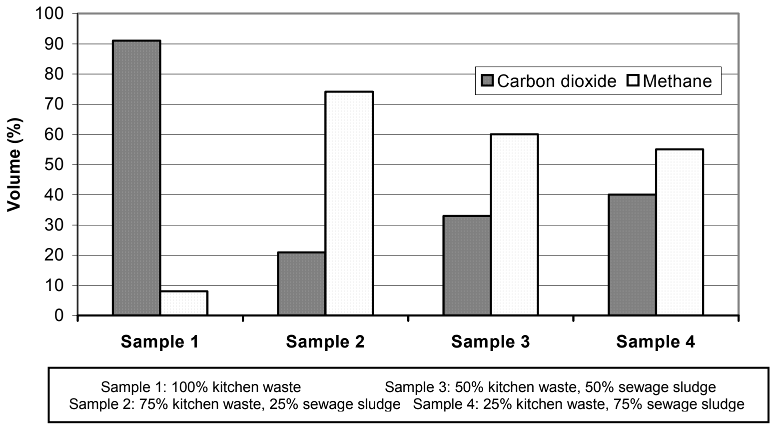

Figure 4: Level of CH_4 and CO_2 in the mixtures after 16 days.

The waste mixtures (Sample 2, 3 and, 4) produced biogas with high methane contents, indicated that the slurries had the proper microbial populations to start the anaerobic degradation. Among them Sample 2 had the best performance, which may depend on food-to-microorganisms ratio (F/M). The growth of microorganisms in a system is depended on the F/M ratio and if it is decreased, thus the microorganisms will go to death phase and flocs will be formed [13]. In microbiological point of view the sewage sludge contains mixture of microorganisms that need food to continue their life and when compared with kitchen waste, sewage sludge has low potential for gas production, as most chemical energy in the sludge has already been depleted in the aeration tank. Polprasert have confirmed that mixing waste at a proper ratio can enhance the digestion process and shorten the time to reach the final phase of anaerobiosis [11]. While gas production for the mixture at 75-25 had started immediately after running the reactor and reached the highest amount of 0.594 kg/m^3 VS after 16 days, the sample with 100% kitchen waste could only produce 0.05 kg/m^3 VS at the same duration (Figure 5).

3.4 NPK values determination

The amounts of N, P, and K as the three essential plant microelements were found 0.95, 0.80, and 0.45% respectively. A comparison between the value of NPK in the ABR and other sources [14] shows, except city refuse the NPK value in produced sludge in ABR is higher than rural refuse and also plant residues (Figure 6). But to compare to chemical fertilizer the amounts of N, P, and, K even in city refuse is several time lower and for better efficiency needs to be mixed with chemical fertilizer.

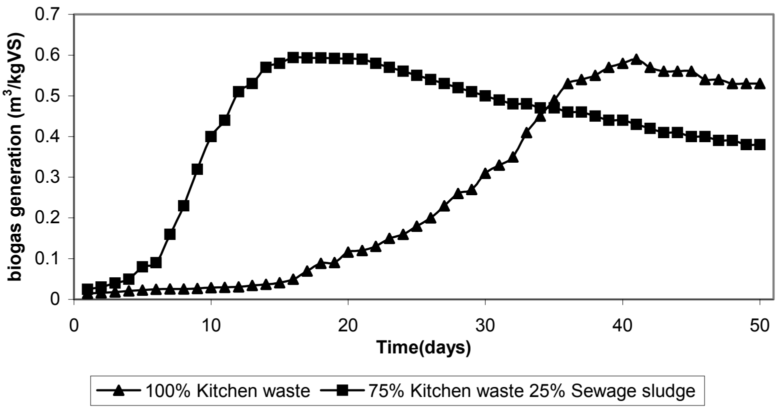

Figure 5: Comparison between 100% kitchen waste and mixture of 75% kitchen waste and 25% sewage sludge.

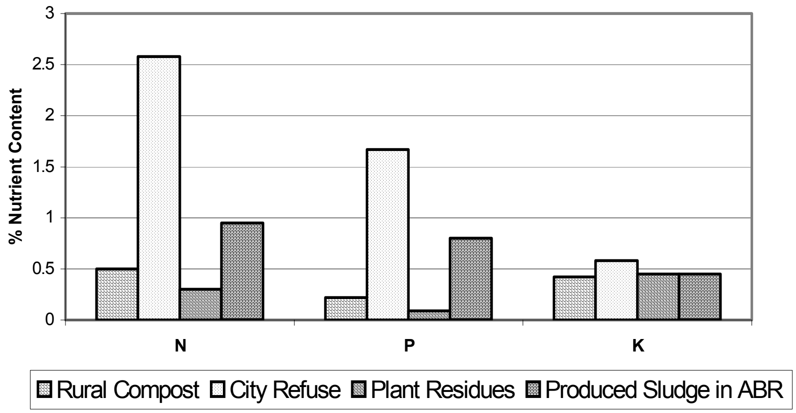

Figure 6: Comparison between NPK values in ABR system with other sources.

4 Conclusion

The environmentally acceptable management of municipal solid waste has become a global challenge due to limited resources, ever increasing population, rapid urbanization and industrialization worldwide. The modified ABR showed the proper performance in biogas production and could be a reasonable choice for energy production as well as a system for the processing of organic parts of produced solid waste. Among all the samples the mixture with 75% of kitchen waste and 25% of sewage sludge had the best biogas and methane production competence due to its suitable C/N and F/M ratio. NPK value in produced sludge in ABR is lower than those present in chemical fertilizers and thus needs to be mixed with chemical fertilizer prior to being used as fertilizer.

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