Two Stage Anaerobic Reactor Design and Treatment To Produce Biogas From Mixed Liquor of Vegetable Waste

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Abstract. Municipal solid waste has become a common challenged problem to be solved for developing countries including Indonesia. Municipal solid waste generating is always bigger than its treatment to reduce affect of environmental pollution. Research tries to contribute to provide an alternative solution to treat municipal solid waste to produce biogas. Vegetable waste was obtained from Gedebage Market, Bandung and starter as a source of anaerobic microorganisms was cow dung obtained from a cow farm in Lembang. A two stage anaerobic reactor was designed and built to treat the vegetable waste in a batch run. The capacity of each reactor is 20 liters but its active volume in each reactor is 15 liters. Reactor 1 (R1) was fed up with mixture of filtered blended vegetable waste and water at ratio of 1:1 whereas Reactor 2 (R2) was filled with filtered mixed liquor of cow dung and water at ratio of 1:1. Both mixtures were left overnight before use. Into R1 it was added EM-4 at concentration of 10%. pH in R1 was maintained at 5 – 6.5 whereas pH in R1 was maintained at 6.5 – 7.5. Temperature of reactors was not maintained to imitate the real environmental temperature. Parameters taken during experiment were pH, temperature, COD, MLVSS, and composition of biogas. The performance of reactor built was shown from COD efficiencies reduction obtained of about 60% both in R1 and R2, pH average in R1 of 4.5 ± 1 and R2 of 7 ± 0.6, average temperature in both reactors of 25 ± 2°C. About 1L gas produced was obtained during the last 6 days of experiment in which CH₄ obtained was 8.951 ppm and CO₂ of 1.087 ppm. The maximum increase of MLVSS in R1 reached 156% and R2 reached 89%.

1. Introduction

Bandung, the capital city of West Java, Indonesia generates municipal solid waste around 1,500 tons per day. From this municipal solid waste generating only around 1,100 tons could be transported and dump in the Final Disposal of Municipal Solid Waste (TPA) in this city [1]. Municipal solid waste has become a common challenged problem to be solved for developing countries including Indonesia. Municipal solid waste generating is always bigger than its treatment to reduce affect of environmental pollution. The research that has been conducted tries to contribute to provide an alternative solution to treat anaerobically municipal solid waste to produce biogas.

The application of anaerobic digestion to degrade high organic contents of wastewater has widely been cited in literature. The benefits of applying such system include lower energy consumption (as aeration is not required), production of low quantity of well stabilized sludge, and odor-free treatment (as anaerobic digestion has to be carried out in sealed vessels), as well as methane gas produced which can be used as energy alternative [2, 3, 4]. The improvement which has been made towards the anaerobic treatment is addition of stage to become two stage anaerobic treatment. In a single stage anaerobic treatment, the three steps of degradation reaction, i.e. hydrolysis, acetogenesis, and
methanogenesis occur in the same reactor whereas in a two stage anaerobic treatment, the hydrolysis step occurs in the first reactor and the other two reaction steps occur in the second reactor. The pH conditions maintained in each reactor result in different microorganisms’ growth in each reactor. The pH range of 4.5 – 6.5 in the first reactor provides favorable conditions for hydrolytic bacteria. The pH range of 6.5 – 7.0 in the second reactor provides favorable conditions for acetogenic and methanogenic bacteria [5, 6].

Based on that improvement, research by Budiastuti [7] observed that two stage anaerobic digestion was found to be more susceptible in responding to organic shock loads compared to single stage anaerobic digestion. Therefore, further research [8, 9] proved that shock load conditions could be avoided by introducing correct feeding applications. The two stage anaerobic system was continued to be researched in degrading leachate of municipal solid waste. The two stage anaerobic reactors resulted in 70% increase in treatment efficiency compared to the single stage reactor [10]. This finding was confirmed by conducting a fundamental research by applying glucose synthetic wastewater. Budiastuti et al. [11] proved superiority of two stage anaerobic system in terms of degradation efficiency and methane gas produced. Effect of temperature was also observed and it showed that temperature has to be controlled at around 35 °C to produce higher COD efficiencies and methane gas production [12]. However, in real application especially treatment application which is done by rural community, temperature control is usually considered as too complicated to be conducted. Therefore, this research tries to imitate the real environmental temperature for the observed anaerobic treatment in degrading mixed liquor of vegetable waste without temperature control.

2. Methodology

2.1. Seed Sludge, Vegetable Waste Mixed Liquor, Reactor Design and Start Up

The seed sludge was cow dung obtained from a cow farm in Lembar. Ratio of water and cow dung was 1:1. This mixture was left over night and then filtered to obtain seed sludge filtrate. The high strength wastewater was mixed liquor composed of vegetable waste obtained from Gedebage Market, Bandung. The vegetable waste was blended for about 3 minutes, the waste was then mixed with water at ratio 1:1, and the mixture was left over night.

The reactor design followed the design of two stage anaerobic reactor possessed by Chemical Engineering Laboratory, Politeknik Negeri Bandung. Each reactor was made from plastic of 20L used chemicals container. The feed drum and gas collection tank were the same used plastic containers with 20L volume. The feed drum was then completed with aquarium pump at a flow rate of 1.7 L/min. The capacity of each reactor is 20 liters but its active volume in each reactor 15 liters. All valves needed were attached and leakage test was then performed. Gas leakage was also performed by introducing compressed air through the outlet gas at backward stream in which both reactors were filled with water. Temperature of both reactors was not maintained using temperature control instead of adding kapok insulation at outer side of each reactor and covered with kapok insulation drums.

Start up of the reactors was conducted by circulating the mixed liquor in each reactor by opening or closing the corresponding valves. When circulation of mixed liquor in reactor 1 (R1) was performed, valve 2 (V2) and 3 (V3) were open but V5 and V9 were closed (see Figure 2) and vice versa. This start up step was stopped when pH range of each reactor was obtained and addition of Na₂CO₃ into reactor 2 (R2) was done when pH of R2 dropped to acid pH.

2.2. Feeding Strategy, Experimental Set Up, and Measured Parameters

R1 was filled with 15L vegetable waste mixed liquor and pH was adjusted to 5 to 6.5. EM-4 at concentration of 10% was then introduced to R1. R2 was fed up with seed sludge and pH was adjusted to neutral pH (6.5 – 7.5) by addition of Na₂CO₃ when needed. Feeding of mixed liquor from R1 to R2 was conducted for 30 seconds at a flow rate of 1.7 L/min/day. Parameters measured during experiment were pH, chemical oxygen demand (COD), mixed liquor volatile suspended solids (MLVSS), and gas
produced. Such performed during start up, corresponding valves were open or closed based on the purpose of parameter analysis, circulation, feeding or discharge.

3. Results and Discussion

3.1. Design of the Reactor
Figure 1 shows the design of the reactors. Both R1 and R2 were insulated with kapok around outer space of the plastic drum. Reactor bottom diameter is 26.5 cm whereas top diameter is 30 cm and the height of the reactor is 37 cm. Kapok insulator was placed in a plastic drum with diameter of 40 cm and height of 40 cm.

![Figure 1. Reactor Design. Bottom view (a), top view (b), side view (c)](image)

The purpose of adding insulation kapok around outer side of the reactors and inside the container plastic drums is to avoid heat loss to the environment. By applying this insulation, it was obtained the average reactor temperature of 25 ± 2°C. Figure 2 shows the schematic diagram of the equipment designed. It shows that feed tank (a) was located higher than the reactors so that the mixed liquor feeding was performed by gravitation. The feeding pipe in R1 was placed up to the base of the reactor to avoid introducing air into the reactor. The feeding of R2 from R1 was done by using an aquarium pump. This pump was also function for circulating the mixed liquor in each reactor to homogenize the mixture as well as to avoid blockage (see Figure 2). The corresponding valves were open or closed depending on the purpose of circulation into the reactors. Valve 8 (V8) was open when gas sampling was taken. V3 and V9 were open when sampling of mixed liquor of R1 was conducted but V5 and V9 were open when sampling of mixed liquor of R1 was taken. Different colors were shown in Figure 2 to show different streams of feeding, biogas, circulating or analysis and discharge.

3.2. Start Up of the Reactor
Such mentioned in Methodology, start up of R1 and R2 was conducted by circulating the mixed liquor in each reactor. This was conducted for 17 days. During start up periods, measured parameters were taken as shown early periods in Figure 3 to 6. These parameters, during start up periods, were not taken as often as parameters measurement during experiment. This strategy is to allow adaptation of corresponding microorganisms in each reactor. In R1 is expected to be fulfilled with hydrolytic microorganisms whereas in R2 is to be fulfilled with acetogenic and methanogenic microorganisms. Budiantuti and Rahayu [13] obtained Bacteroides ruminicola like bacteria during start up periods and Streptococcae and Methanaococus like bacteria during steady state periods.
3.3. Experimental Results

After start up periods were achieved, circulation of the feeding or mixed liquor was performed intermittently. Analyzed parameter measurements were done almost every day. Experiment was conducted for more than 60 days. pH measurements are shown in Figure 3. pH measurements taken during start up (up to 17 days) are lower than pH measurements afterwards. It shows that during start up, adaptation of microorganisms into new operating conditions occur. During the start up periods pH adjustment to corresponding stage was not conducted. It is predicted that both reactors are fulfilled by hydrolytic bacteria [13]. Therefore, feeding of R2 from R1 was then conducted and addition of Na₂CO₃ into R2 to obtain normal pH range was performed. It shows in Figure 3, adaptation periods have already passed and relatively constant pH range in each reactor was obtained. The reactor pHs could be stable in the pH range corresponding to its stage when reactors achieved stabilize conditions [10, 12]. It is predicted that pH buffer in R2 is capable to stabilize the reactor pH at normal pH range.

![Schematic Diagram of Two Stage Anaerobic Reactor](image)

**Figure 2. Schematic Diagram of Two Stage Anaerobic Reactor**

Stabilized conditions were confirmed by the increase trends of MLVSS obtained in each reactor (Figure 4). MLVSS represents the concentration of bacteria which grow in each reactor. The increases of MLVSS both in R1 and R2 were obtained up to 39 days showing the growth of corresponding bacteria in both reactors. During this period, around 156% MLVSS increase occurs in R1 whereas around 89% MLVSS increase occurs in R2. However, a drastic decrease of MLVSS in both reactors occur in the 43rd day and the fluctuated increase trends occur in the next period. Wash out of bacteria might have partially occurred as a result of continuous feeding into both reactors. The growth of bacteria might not proportional to bacteria wash out [5, 14].
In terms of temperature measurements, it is shown in Figure 5, that up to day 37, the temperature decrease trends occur but fluctuating constant temperature trends occur afterwards. It might affect the decrease of MLVSS in day 43 (Figure 4). The fluctuated increase trends of MLVSS in the next period may result from the occurrence of fluctuating temperature (Figure 5). However, comparing both figures during period of 43 to 62 days, it shows proportional conditions. Almost constant temperatures in the range of 25 ± 1°C resulted in increase trends in MLVSS in both reactors. Budiastuti et al. [12] suggest that temperature has to be maintained around 35°C to obtain the optimum degradation.

The decrease of COD efficiencies is expected to be obtained, such as shown in curve R1 in Figure 6. Up to 37 days the decrease of COD from 7,872 to 5,366 mg/L occurs. It suggests that during this period, temperature in the range of 25 ± 2°C and pH in the range of appropriate pH of 4.5 – 5.5 as well as the increase of 156% MLVSS for 37 days support the COD decrease during this period [2, 15]. However, the increase of COD values after 37 days and also the increase of COD values in R2 during
experiment could not be explained. To check the objective of COD degradation, therefore, experiment was continued to be conducted for another 6 days with the focus of obtaining the accurate COD measurements. During this period, the decrease of COD in R1 accounted to 68.2% and the decrease of COD in R2 accounted to 61.5%.

**Figure 5. Temperature Measurements during Experiment, (▲ R1), (■ R2)**

Gas produced during 37 days of experiment was very less so that the gas production could not be detected by floating drum gas catcher system. To prove this condition, experiment was conducted in 1L reactors and the same operating conditions were applied. During 6 days, it was obtained about 30 mL cumulative gas from this trial. Based on this result, leakage of gas valve and the system of floating drum gas catcher were repaired. By repairing the gas measuring system, it was obtained about 1L gas within 6 days of experiment. From the gas produced, it resulted in 8.951 ppm of CH$_4$ and 1.087 ppm of CO$_2$.

**Figure 6. COD Measurements during Experiment, (■ R1), (▲ R2)**
4. Conclusion
A two stage anaerobic reactor completed with a feeding tank and floating drum gas catcher was successfully designed and built. This reactor type was used to treat mixed liquor of vegetable waste to produce biogas. During 62 days of experiment, it was obtained pH average of 4.5 ± 1 in R1 and of 7 ± 0.6 in R2, increase of MLVSS in R1 reaching 156% and R2 89%, and average temperature in both reactors was 25 ± 2°C. About 1L of produced gas was obtained during the last 6 days of experiment containing CH₄ of 8.951 ppm and CO₂ of 1.087 ppm. COD efficiencies reduction of about 60% both in R1 and R2 was resulted from this period of experiment.

5. Acknowledgments
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