Comparison of Biogas Productivity in Thermophilic and Mesophilic Anaerobic Digestion of Bioethanol Liquid Waste

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Abstract. Most of the anaerobic digesters in Indonesia are run under mesophilic conditions because the Indonesian climate is sufficiently pleasant to maintain mesophilic conditions easily. On the other hand, thermophilic anaerobic digestion offers an advantage of a much higher biogas production rate, although it needs more tedious control and energy supply to achieve the thermophilic temperature of 50-60°C. We run laboratory-scale experiments to compare the process performance of anaerobic digestion of bioethanol liquid waste (vinasse) at mesophilic and thermophilic conditions. Inoculum on this test using digested cow manure. Start-up was conducted with only the inoculum inside the reactors. After the reactor passed through the starvation period, the vinasse feeding was started. The hydraulic retention time (HRT) was gradually decreasing from 60, 42, until 30 days. Each step of HRT took 7 up to 14 days for stabilization. At the same HRT, thermophilic reactors produced biogas at the rate of four times faster than the mesophilic reactors. The methane concentration in the biogas for the thermophilic process was relatively the same as the mesophilic one. With such a higher rate of biogas production, the energy cost for thermophilic can be possibly better compensated.

1. Introduction

Anaerobic digestion for waste processing has been applied worldwide for quite a long time. The process has been proven to exhibit several functions for reducing pollution from air, soil, and water, and more importantly, it produced biogas as a renewable energy source while converting the pollutants [1]. Anaerobic digestion uses anaerobic microorganisms that will consume the organic pollutants such as carbohydrate, fat, and protein [2]. For the sake of process design and optimization, the complicated process of anaerobic digestion is generally simplified into four steps. Those are hydrolysis, acidogenesis, acetogenesis, and methanogenesis, as illustrated in figure 1 [3].
Several factors influence anaerobic digestion performance, such as pH, macronutrient, micronutrient, and temperature. On top of that, most of the established bioreactors running under mesophilic conditions. The mesophilic system has weaknesses because of its long hydraulic retention time (HRT) [4]. In this study, we explore the possibility of applying the thermophilic system as an opportunity to make biogas production more profitable than the mesophilic one.

The thermophilic condition of anaerobic digestion usually ranges between 50-60°C. An experiment comparing thermophilic and mesophilic anaerobic digestion performance had been conducted using food waste and wheat straw as a substrate [5]. It was found that the gas production rate in thermophilic digestion is 4.9-14.8% higher than the mesophilic one. For large scale biogas production, thermophilic anaerobic digestion is more attractive than mesophilic one because the production scale will be sufficient to compensate for the additional investment for elevating process temperature.

This study used vinasse as the substrate for the anaerobic digestion. Vinasse is the waste from bioethanol production with molasses as the raw material. It comes as the bottom product of the distillation process with 90°C of temperature. The COD and BOD are usually in the range of 104.000-134.400 mg COD/L and 46.100-96.000 mg BOD/L, respectively [6]. The characteristic of vinasse used in this research is shown in table 1.
Table 1. Physical and Chemical Properties of Vinasse [7]

| Parameters | Unit | Value   |
|------------|------|---------|
| COD        | mg/L | 96,650  |
| BOD        | mg/L | 30,450  |
| TDS        | mg/L | 8,050   |
| Phenol     | mg/L | 1.0286  |
| Phosphat   | mg/L | 1.5240  |
| Kalium     | mg/L | <1      |
| Sulphate   | mg/L | 5       |
| Nickel     | mg/L | <0.0130 |
| Zinc       | mg/L | 0.077   |

The temperature of vinasse emitted from the distillation process is already high. This condition is beneficial for thermophilic digestion because it does not need excessive effort to increase the temperature. Thermophilic anaerobic digestion has a high possibility of being successful if the temperature of the substrate is around 55°C [4], which is about the heat of the vinasse in the cooling pond. Based on the consideration, as mentioned earlier, vinasse was taken as the substrate for this study.

This study was the preliminary phase under the research umbrella to design a highly efficient reactor to convert abundant agro-industrial wastes into renewable energy. More specifically, this study aimed to compare the biogas production rate of thermophilic and mesophilic conditions. The results of this study would serve as the fundamental consideration for further research on kinetics and techno-economic analysis of the thermophilic process, especially in deciding whether the amount of biogas production in the thermophilic process can compensate the additional investment required to maintain the thermophilic conditions.

2. Material and method

2.1. Inoculum
The inoculum used in this research was digested cow manure. The digested cow manure was taken from the effluent of cow manure biogas reactor in Kaliurang, Yogyakarta, Indonesia. The cow manure biogas reactor has been steadily operated for years. The inoculum was firstly filtered to remove large debris. The volatile suspended solid (VSS) was then adjusted to 30,000 ppm, and pH was ensured to be seven before use.

2.2. Substrate
Vinasse used for the substrate was taken from the bioethanol plant in PT Madubaru, Yogyakarta, Indonesia. The substrate was also filtered to remove large debris. The substrate was stored at 4°C. The COD and pH was then adjusted to 12,000 mg/L and seven respectively before use.

2.3. Anaerobic experiment
The experiment apparatus is shown in figure 2. As much as 800 mL of inoculum was put in the reactor. The reactor was then flushed by nitrogen gas to ensure the absence of oxygen in it. The thermophilic reactors were then placed in a water bath to maintain the temperature at 50-60°C. The mesophilic reactors were kept at room temperature (28-29°C). After the reactor passed through the starvation period, which was marked by decreasing gas production, vinasse feeding was started. The hydraulic retention time (HRT) was firstly 60 days, and after the gas production had been stable for
about 7 until 14 days, the HRT was then changed to 42 days. This step was repeatedly done step by step from the HRT of 60, 42, up to 30 days.

2.4. Analytical methods
Gas production was daily measured using a liquid displacement gasometer. The gasometer was custom-made, a basin and scaled cylinder filled with saturated salt solution acidified to the pH of 2. Methane concentration was measured twice a week using Gas Chromatography Shimadzu GC 8A Japan. The liquid sample was taken twice a week and analyzed for the values of chemical oxygen demand (COD), soluble chemical demand (sCOD), and volatile fatty acids (VFA). The COD and sCOD concentration were analyzed using colorimetry procedure, while the VFA was analyzed using the titration method (APHA standard methods). All measurements were conducted in duplicates with two identical reactors.

Figure 2. Experiment apparatus: mesophilic (a) and thermophilic (b) condition.
3. Result and discussion

3.1. Biogas production

Figure 3 implies that at thermophilic conditions, gas production is much higher than the mesophilic condition. In all HRTs, the gas production of the thermophilic was always more significant than the mesophilic. At 60 days of HRT, the gas production in thermophilic conditions could reach 192 mL/day, while the mesophilic is just 39 mL/day. Methane concentration between thermophilic and mesophilic is not so much different, but the methane production rate of the thermophilic is still higher than the mesophilic.

Furthermore, it is noticeable, especially on thermophilic data (figure 3b), that there is a pattern of increasing gas production after HRT reduction followed by decreasing biogas production after several days of operation with the same HRT. This phenomenon could be an indication of the fast growth of microorganisms, which consumed the substrate very quickly, and hence the same organic loading was not sufficient to feed them after several days. When the organic loading was increased at reduced HRT, the microorganisms started growing fast again, and the increased biogas production marked this after we shorten the HRT. When the HRT was short enough to maintain high organic loading rate, such as at HRT 30 days, the amount of substrate was sufficient for feeding the fast-growing microorganisms so that the gas production was quite stable for a longer time, although a little bit lower than the peaks observed at longer HRTs. The experiment is currently still on-going to reduce the HRTs even more to find the optimum organic loading rate, which will be sufficiently feeding the fast-growing thermophilic microorganisms while, on the other hand, still manage to have high biogas productivity and high sCOD removal as well.
3.2. Effluent composition

Both thermophilic and mesophilic have the same trend of COD and COD, as shown in figure 4. As time goes by, the tCOD decreased, and sCOD increased because of the dissolution of COD, which then measured as sCOD. After ten days of feeding, at 42 days of HRT, the value of tCOD in thermophilic was around 22,000-23,000 ppm, but in mesophilic, it was still 37,000-38,000 ppm. Both thermophilic and mesophilic started with the same tCOD amount, 46,000 ppm, but almost all the time, the tCOD in the thermophilic reactor was lower than the mesophilic one. This indicates that the digestion rate of thermophilic digestion was higher than the mesophilic one. A published work of similar research stated that the reaction rate in the thermophilic conditions was 1.5 times higher than the mesophilic one [8].

As shown in figure 4, the VFA accumulation is much higher in the thermophilic than the mesophilic. Several research conducted by [9][10][11] were in good accordance with this finding. In the study conducted by [12], the VFA concentration in thermophilic conditions was even almost six times that in mesophilic conditions.
4. Conclusions
The digestion of COD in the thermophilic anaerobic digestion is faster than in the mesophilic condition. At the same HRT, thermophilic reactors produced biogas four times faster than the mesophilic reactors. With such a higher rate of biogas production, the energy cost for thermophilic heating can be possibly compensated. The high rate of energy production in the form of biogas and also higher COD removal makes thermophilic anaerobic digestion more attractive than the mesophilic one, primarily to process a high rate of organic waste emission.
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