Biogas production from co-digestion of water hyacinth, banana peel and water spinach wastes using a horizontal anaerobic digester

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Abstract. Biogas is an alternative energy source that can replace fossil fuels. The residue of agricultural products in the form of water hyacinth, fruit, and vegetable waste is a source of an organic material having large cellulose, lignocellulose, and lignin content so that it has the potential as a raw material for biogas production. This study proposed to evaluate the influence of the composition of the mixture of water hyacinth (WH), banana peel (BP) and water spinach (WS) wastes to biogas production using a horizontal anaerobic digester. At the initial experiment, the amount of cow dung mixed with water at a mass ratio of 1:1 was introduced to the horizontal anaerobic digester as a starter and was incubated for 5 days. Furthermore, the raw material of WH, BP, and WS wastes was crushed/ground at a size of 1 cm. Two kg of mixed water hyacinth, banana peel, and water spinach with a mass ratio of 100 : 0 : 0 (WH), 0 : 50 : 50 (BP-WS) and 50 : 25 : 25 (WH-BP-WS) was mixed with water to a volume of 8 L and was fed per day into the horizontal anaerobic digester. The biogas output from the anaerobic digester was collected in tubular plastic, and the volume of biogas was measured using the displacement of water. The results showed the highest average yield of biogas production was 0.3145 ± 0.1 l/gVS.day with cumulative biogas of 620.368 l, and the lowest one obtained by WH-BP-WS (0.2463 ± 0.1 l/gVS.day) with cumulative biogas of 402.012 l. While for mono digestion of WH, biogas yield was 0.260 ± 0.1 l/gVS.day with cumulative biogas of 518.768 l. The composition of biogas showed the use of BP-WS produced CH4 (71.23%), CO2 (25.79%), H2S (1.71%) and NH3 (0.39%); WH-BP-WS was CH4 (71.97%), CO2 (25.91%), H2S (1.68%), NH3 (0.38%); while for WH was CH4 (70.97%); CO2 (26.77%), H2S (1.37%), NH3 (0.61%), respectively.

1. Introduction

Banana and water spinach wastes are produced in supermarkets and wholesaler's every day. These wastes are usually disposed into municipal landfills, spreading on land and feeding animals. The disposal waste becomes a serious problem in the environment, which results in pollution of soil, water, and air. Treatment of banana and water spinach waste using biological methods seems economical and can also control environmental pollution. Banana and water spinach waste is a very important residue, as they are produced in large enough quantities in agricultural activities, public markets, and supermarkets. The waste production increases market operating costs because of sales and transportation losses and disposal costs [1]. Banana and water spinach waste is an organic compound. When they dispose of in landfills the process of natural biodegradation of organic material, producing greenhouse gases and leachate [2]. Due to high water and organic content and biodegradability, banana and water spinach waste is a major contributor to greenhouse gas emissions and volatile organic compounds. A great
amount of organic waste is disposed of at the Surabaya landfill because it is the only location for disposing of solid wastes. Therefore, efficient technology is applied for waste treatment and waste volume reduction becoming increasingly important [3].

Water hyacinth *Eichhornia crassipes* is one type of aquatic plant floats. Water hyacinth has high growth speed so this plant is considered as weeds that can damage the environment in water. The acceleration of the growth of water hyacinth in the body of water because of many of the nutrients. However, water hyacinth biomass also has the potential to be developed as a raw material for making biofuels [4,5,6]. Water hyacinth has a fairly large hemicellulose content compared to other single organic components. Hemicellulose is a complex polysaccharide. When water hyacinth is hydrolyzed to produce two simple compounds in the form of methane (CH$_4$) and carbon dioxide (CO$_2$). In some previous studies, it was found that production yields were still small and not optimal so that they could not be utilized for the industrial scale of biogas manufacturing plants. There is an interest in producing and using alternative energy sources because of the limited supply of fossil fuels and their negative influence on the environment [7]. To obtain alternative energy, banana and water spinach wastes can be converted through the anaerobic digestion process. Anaerobic Digestion is a process of biochemical degradation in which microorganisms break down biodegradable material in an oxygen-free environment to produce a solid digestate along with biogas that is widely used for processing and obtaining energy from various types of biomass, mainly derived from agricultural residue and agro-industrial waste. Anaerobic digestion of organic waste for example cow dung, solid waste, organic fraction municipal solid waste (OFMSW), and fruit and vegetable waste (VFW) has a double benefit, which besides producing biogas and also simultaneously treating residues, to reduce their disposal in landfills [8,9]. Using OFMSW as a feedstock for anaerobic digestion is the right choice for environmental management of municipal solid waste [10]. The main profit of the anaerobic digestion process is biogas production as energy, which can be converted to electricity. Stable biosolids that can be used as a soil conditioner [11]. Some authors have carried out several studies on anaerobic digestion of VFWs [12,13,14,15]. However, they have obtained a few studies using FVWs as a single substrate, most of these studies were carried out in laboratory-scale reactors. The experiments only carried out on the industrial scale-up bioreactors using fruit and vegetable wastes in co-digestion with other materials [16]. Anaerobic co-digestion is an organic substrate processing method that is mixed and processed together in the biogas process, which gives a higher methane yield, that is, the amount of biogas produced per unit of organic material is fed into the digester, greater than when each - each substrate is fed into the digester separately. Therefore, co-digestion improves process stability and biodegradation performance of organic matter, optimizes biogas, and methane yields.

The objective of this experiments is to study the potential use of water hyacinth, banana peel, and water spinach waste as a substrate for biogas production and determine the varying conditions in anaerobic digestion systems using water hyacinth, banana peel, and water spinach waste; To evaluate waste from water hyacinth, banana peel, and water spinach waste as a potential substrate for biogas production through anaerobic digestion and anaerobic co-digestion.

2. Materials and Methods

2.1 Materials

The feedstocks used this experiment were as follows: residual wastes of banana peels and water spinach were obtained from Super Market, water hyacinth was obtained from the campus of Institut Teknologi Sepuluh Nopember, Surabaya. Cow dung used as a starter was obtained from slaughterhouses in Surabaya. Acetone (Smart Lab, 99.5%), sulfuric acid (Sigma-Aldrich, 95-97%), sodium hydroxide (Merck, 99%), used in this experiment were analytical grade and were commercially available.

2.2 Experimental Setup

A schematic diagram of an anaerobic digester is shown in Figure 1. The digester was made from stainless steel with an effective volume of 125 l (40 cm D x 100 cm L) and was equipped with a flat stirrer (10
cm W × 15 cm L × 2 cm T) to get a homogeneous slurry and to prevent biogas from being trapped in the slurry [17]. Operating conditions were conducted at room temperature. The digester was constructed for continuous mode, the feedstock flow rate was 8 l/day for 24 days. The thermometer and biogas pipe were located at the top of the digester. The motor was installed automatically to move the stirrer for 60 min and stop for 30 min.

**Figure 1.** Schematic diagram of anaerobic digester. *Note:* 1 = feedstock influent; 2 = flat blade; 3 = pressure parameter; 4 = temperature parameter; 5 = valve outlet gas; 6 = digestate collection; 7 = digestate effluent; 8 = disposal valve; 9 = digestate collection; 10 = motor

### 2.3 Experimental Procedure
In the initial experiment, a certain amount of cow dung was used as an inoculum, mixed with water in a volume ratio of 1:2 introduced to the digester. The digestion was then left for 7 days and observed biogas production. Then, some water hyacinths (WH), banana peel (BP), and water spinach (WS) were chopped or ground to get a fine size (1 cm). Two kg of a variety of feedstock with a volume of 8 l was then introduced to the anaerobic digester, which was shown in Table 1. Biogas production was collected and analyzed every day.

### 2.4 Analyses of Biogas
Moisture content, Total solids (TS), and total volatile solids (VS) of the feedstock were analyzed by Standard Methods 2540 G, and 5220 B, respectively [18]. Biogas production was collected in a plastic tube and the volume was then measured by the downward displacement of water. The composition of CH₄, H₂S, NH₃, CO₂, in biogas, was analyzed using gas chromatography. The methane and carbon dioxide content in the biogas is determined using a Gas Chromatograph (GC) (Shimadzu GC 2010) which was equipped with a thermal conductivity detector.

| Feedstock | Mass rate (kg/day) | Volume rate (L/day) | WH:BP:WS (mass ratio) |
|-----------|--------------------|---------------------|----------------------|
| WH        | 2                  | 8                   | 100:00:00            |
| BP-WS     | 2                  | 8                   | 50:50                |
| WH-BP-WS  | 2                  | 8                   | 50:25:25             |

### 3. Results and Discussions

#### 3.1 Physical and Chemical Characteristics of Biomass
Water hyacinth, banana peel, and water spinach wastes were used as a feedstock for biogas anaerobic digestion and had the physical-chemical characteristics shown in Table 2. These characteristics were
studied by analyzing organic compounds. Biogas production from degradation of organic feedstock mainly depends on their organic matter being degraded to CH₄ and CO₂. It was found the feedstock had C/N ratio, i.e. 5.82 (BP-WS), 9.03 (WH-BP-WS), and 12.42 (WH).

### Table 2. Physical characters of biomass as a feedstock

| Feedstocks | Content (%) |  
|-------------|-------------|
|             | MC          | TS       | VS       |
| WH          | 94.67 ± 0.58| 5.33 ± 0.58| 77.60 ± 0.42|
| BP-WS       | 88.38 ± 0.31| 11.62 ± 0.31| 77.52 ± 0.46|
| WH-BP-WS    | 91.43 ± 0.38| 8.57 ± 0.38| 77.75 ± 0.45|

#### 3.2 Effects of Various Feedstock on Biogas Production

Figure 1 shows the experiment was conducted on a horizontal continuous anaerobic digester for 24 days. In these studies, digestion was carried out by mono and anaerobic co-digestion with a variety of feedstock (Table 1). The feedstock was fed into the anaerobic digester at a concentration of 2 kg/l (0.25 kg/l). Biogas production was measured after the process achieved under steady conditions. The results showed in mono digestion of WH, see Figure 2(a), daily biogas production increased sharply up to on the 5th day and achieved a volume of 25.01 l. Afterward, the biogas formation was approximately stable during the 5th to the 24th day with an average daily biogas production of 24.026 ± 0.85 l/day and cumulative biogas of 518.768 l. While the co-digestion was carried out using BP-WS and WH-BP-WS as feedstock. Figure 2(b) shows biogas production from the co-digestion of BP-WS decreased up to the 5th day and achieved 16.4 l, then the formation was relatively stable during the 5th to the 24th day with an average daily biogas production of 28.304 ± 0.96 l/day with the cumulative biogas production of 620.368 l. Whereas, the co-digestion of WH-BP-WS, daily biogas production decreased up to 17.26 l on the 5th day, afterward the production was relatively stable during the 5th to 24th day and the average daily biogas production was 17,004 ± 0.45 l/day with a cumulative biogas production of 402.012 l, see Figure 2(c). These studies showed that biogas production has fluctuated per day for 24 days. This is because the anaerobic process is very dependent on the activity of microorganisms that are very susceptible to fluctuations. When the biogas production was expressed based on a volatile solid (VS), a yield of daily biogas production from WH was 0.260 ± 0.1 l/gVS.day, 0.3145±0.1 l/gVS.day (BP-WS), and 0.2463 ± 0.1 l/gVS.day (WH-BP-WS), respectively.

When compared to the other authors using water hyacinth as a feedstock, these results of this study were similar to those the results of other authors [19,20,21]. Patil et al. [20] showed a maximum biogas yield was 0.245 l/g VS using water hyacinth slurry in a ratio of 1:4, in the mesophilic temperature range of 30-37°C for 60 days. Rozy et al. [21] depicted biogas production was found to be 0.045 l/g water hyacinth, 0.3601 l/g TS, and 0.398 l/g VS in optimal conditions within 40 days. O’Sullivan et al. [19] indicated water hyacinth had biogas production potential in the range of 0.2–0.4 l/g VS. Nathoaa et al. [22] showed banana peel had a methane yield of 0.2513 l/g VS from banana peel. All of the authors mentioned above the results were obtained in batch cultures with fresh inoculum each time. However, all in these studies, the experiments were conducted in continuous culture. This sometimes caused organisms to become less active in the continuous culture than those in the batch cultures.
Figure 2. Daily biogas production and cumulative biogas production from three different feedstock. *Note:* (a) feedstock of WH; (b) feedstock of BP-WS; (c) feedstock of WH-BP-WS
3.3 Composition of Biogas Production

Figure 3 shows the concentration of gas components was produced from the three various feedstock. The results showed the composition of biogas production was different, this was because the composition was influenced by the use of feedstock. In this study, it was found the feedstock had a different C/N ratio, i.e. 5.82 (BP-WS), 9.03 (WH-BP-WS), and 12.42 (WH), respectively.

In this experiment the biogas was produced from BP-WS was CH$_4$ (71.23%), CO$_2$ (25.79%), H$_2$S (1.71%) and NH$_3$ (0.39%); from WH-BP-WS was CH$_4$ (71.97%), CO$_2$ (25.91%), H$_2$S (1.68%), NH$_3$ (0.38%); while for WH was CH$_4$ (70.97%), CO$_2$ (26.77%), H$_2$S (1.37%), NH$_3$ (0.61%), respectively.

![Composition of biogas production](image)

**Figure 3.** Effect of a variety of feedstock on the composition of biogas production

4. Conclusions

It is concluded from this study that water hyacinth, banana peel, and water spinach had a potential for biogas production. The stability of the process indicated microorganisms had already been adapted to the feedstock types. When the biogas production was expressed based on a volatile solid (VS), co-digestion of BP-WS showed the highest average yield of biogas production (0.3145 ± 0.1 l/gVS.day) with cumulative biogas of 620.368 l, and the lowest one obtained by WH-BP-WS (0.2463 ± 0.1 l/gVS.day) with cumulative biogas of 402.012 l. While for monodigestion of WH, biogas yield was an average 0.260 ± 0.1 l/gVS.day with cumulative biogas of 518.768 l.

It was obtained from the feedstock of BP-WS the composition was CH$_4$ (71.23%), CO$_2$ (25.79%), H$_2$S (1.71%) and NH$_3$ (0.39%); from WH-BP-WS was CH$_4$ (71.97%), CO$_2$ (25.91%), H$_2$S (1.68%), NH$_3$ (0.38%); while for WH was CH$_4$ (70.97%), CO$_2$ (26.77%), H$_2$S (1.37%), NH$_3$ (0.61%), respectively.

In future work yield of biogas production would be increased by hydrothermal pretreatment before the anaerobic digestion.

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