

Optimization of biogas from corn stover using liquid and solid-state anaerobic digestion

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Abstract

The shortage of fossil fuel can be minimized by developing renewable energies such as biogas. The raw material of biogas can be derived from corn stover. Biogas was produced under solid-state anaerobic digestion (SS-AD) and liquid anaerobic digestion (L-AD). The objectives of this study were to compare the biogas yield and analyze the pH value and VS degradation. The results reported that the SS-AD generated a higher biogas yield than L-AD. SS-AD could improve the biogas yield of 71%. Both SS-AD and L-AD had a higher final pH than the initial pH. Moreover, the VS degradation was proportionate to the biogas yield. The highest VS reduction was achieved on SS-AD.

Keywords: anaerobic digestion, biogas, liquid state, solid state, volatile solid, renewable energy

Introduction

The use of energy from fossil fuel increases continuously, on the contrary, the conventional resources deplete gradually. Due to the issues of an energy shortage, a rule to discover green energy is being developed to minimize the consumption of fossil oil [1]. Utilization wastes into energy is a helpful solution to diminish greenhouse emission [2]. The anaerobic digestion (AD) decomposes organic materials into biogas as renewable energy. Biogas is a clean gas comprising mainly of methane, carbon dioxide and a trace amount of other gases [3]. Biogas can be utilized as heat and electricity, transportation fuel and digestate for biofertilizer manufacture [4].

Crops have been mainly used as a lignocellulosic biomass feedstock for biogas production through AD in the current year [5]. Corn stover is plentifully obtainable in Indonesia but it is only left in the fields, causing environmental pollution. The AD process contains four steps, viz. hydrolysis, acidogenesis, acetogenesis and methanogenesis that are performed by microorganisms such as acidogens and

methanogens [6]. AD is categorized into liquid (L-AD) and solid-state (SS-AD) concerning total solid (TS) content [7]. L-AD is conducted at TS varies from 0.5 to 15%, whereas SS-AD for TS content of higher than 15% [8].

The SS-AD has several benefits, e.g. smaller reactor, no need for stirring, higher methane productivity and less water consumption. The digestate of SS-AD can be utilized as a fertilizer [9]. However, SS-AD can lead to feeding and discharging problems, imbalanced mass transfer, and acid inhibition. Conversely, L-AD is simple to control, steady operation stages and produces in high methane production, but some disadvantages are found on L-AD, for example, larger digester, exaggerated energy through mixing and larger water consumption [10]. The previous studies on biogas production from corn stover have been completed before. However, no study has been investigated to produce biogas from corn stover by L-AD and SS-AD. Therefore, the current study aimed to compare biogas yield on L-AD and SS-AD.

The pH and VS reduction were also observed during the digestion.

Material and Methods

Anaerobic digestion process

Corn stover is a feedstock was collected from fields in Yogyakarta then it dried and cut into 1-2 cm. The dried corn stover was kept at room temperature before use. Fresh rumen fluid of cow was used as an inoculum to improve the microbe's efficiency. Feedstock and inoculum were mixed with water to adjust TS content of 5% (L-AD) and 22% (SS-AD). The mixture was fed to 2 L digester. Biogas volume was measured every 2 days using the water displacement method.

Analytical method

This analysis was used to determine TS and volatile solid (VS) content of feedstock and inoculum, respectively. The measurement of TS is to determine the amount of water that be loaded into the digester. To get the initial TS, 25-50 g of sample (corn stover and inoculum) were dried at 103-105°C for 1 hour, then dried samples were cooled and weighed until the weight of samples reduced to 4% or 50 mg from the initial weight.

$$\% \text{ Total solids} = \frac{A - B}{C - B} \times 100$$

A = weight of dried sample and dish (mg)

B = weight of dish (mg)

C = weight of wet sample and dish (mg)

VS was measured by igniting the sample in a furnace at 550°C. Repeat sequence of igniting, cooling and weighing until the weight of samples is less than 4% or 50 mg.

$$\% \text{ Volatile solids} = \frac{A - D}{A - B} \times 100$$

A = weight of dried sample and dish (mg)

B = weight of dish (mg)

C = weight of wet sample and dish (mg)

D = weight of ignited sample and dish (mg)

Results and Discussion

Composition of feedstock and inoculum

The characteristic of materials is displayed in Table 1.

Table 1. Properties of corn stover and rumen fluid

Parameters	Components	
	Corn stover	Rumen fluid
Initial TS (%)	90.5	17.56
Initial VS (%)	85	12.05

Total solid influences the pH, temperature, and efficiency microbes in the anaerobic digestion [11]. Volatile solid is associated with organic material that is digested by microbes into biogas.

Biogas production

Biogas yield (L/kg VS) is presented by dividing biogas volume to the initial VS of feedstock. Figure 1 expresses daily biogas yield. Biogas production initiated to produce on day 2 through SS-AD, whereas in L-AD, biogas volume was generated on day 4. This delay occurred due to the presence of a floating substrate at the bottom of the digester which constrained the transfer of nutrients to the microbes, consequently, the conversion of the substrate was slower and longer.

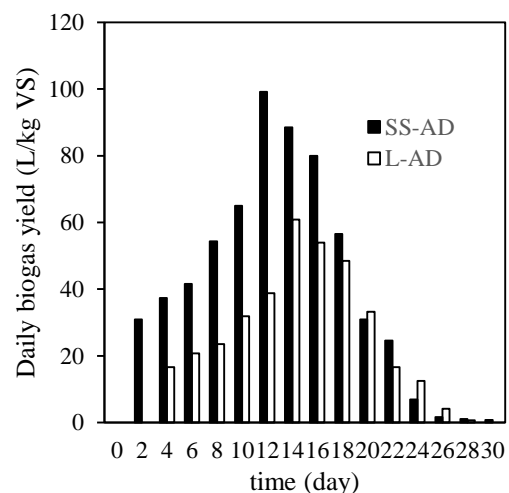


Figure 1. Daily biogas yield during 30 days of SS-AD and L-AD

The rate of biogas raised gradually until achieving a peak value of 99.15 L/kg VS on day 12 for SS-AD, while the L-AD

attained a climax yield of 60.90 L/kg VS on day 14. Afterward, biogas production decreased slowly until no measurable biogas volume. This condition happened due to the inhibition of methanogen.

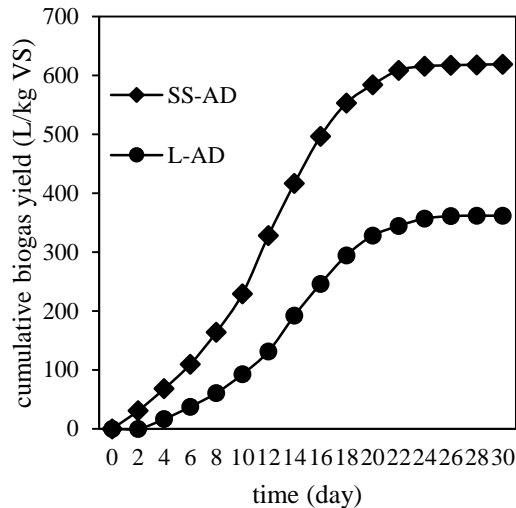


Figure 2. Cumulative biogas yield during digestion of corn stover in SS-AD and L-AD

Figure 2 demonstrates that the accumulative biogas yields at SS-AD and L-AD were 619.09 L/kg VS and 361.94 L/kg VS, respectively. This result shows that SS-AD could increase by 71% of biogas productivity. The higher yield in SS-AD was affected by the enhancement of hydrolytic and acidogenic microorganisms in initial phases of digestion which result in a high volatile solid degradation [12]. The Preceding study conducted by Chen et al.(2014) [13] also stated that biogas output from SS-AD was higher than L-AD during the digestion of food waste and green waste.

pH characteristic

A pH value is one of the important factors which affects the digestion process. The pH value affects the growth of methanogen and dissociation of compounds such as ammonia, sulfide and organic acids [14]. The pH depends on Volatile Fatty Acid (VFA) and buffering capacity. The pH decline with the increase of VFA production [15]. The optimum pH for methanogens varies from 6.8 to 7.6 [16]. Microbes in anaerobic digestion have

diverse pH requirements. Acidogens can work at pH above 5, while methanogens will inhibit their performance at an acidic condition [17]. A pH lower 6.6 disturbs methanogen activity which leads to toxicity [11].

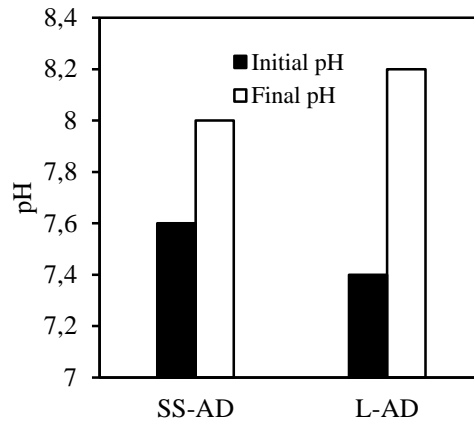


Figure 3. A pH variance during the digestion process

As seen in Figure 3, the initial pH was at the recommended pH range but the final pH was higher than 7.0. The greater pH indicated that ammonia inhibition occurred in the digester which stopped biogas production [18]. Ammonia inhibition increases with ascending pH value. Ammonium causes a potassium deficiency of methanogens [19]. The methanogen inhibition can induce the failure of the digester and cease biogas rate production.

Volatile Solid (VS) reduction

VS is described as the organic part of the total solid [20]. Calculation of VS can be used to manage the AD efficiency [21]. The VS reduction can be calculated by Equation 3 [22].

$$VS_{\text{reduction}} = 1 - \frac{VS_{\text{output}} \times (1 - VS_{\text{input}})}{VS_{\text{input}} \times (1 - VS_{\text{output}})}$$

Where,

$VS_{\text{reduction}}$ = volatile solid amount of degradation (%)

VS_{input} = volatile solid amount of the input (%)

VS_{output} = volatile solid amount of the output (%)

The VS reduction is shown in Figure 4.

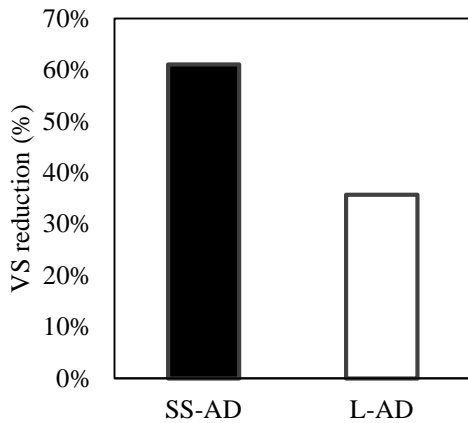


Figure 4. VS reduction during SS-AD and L-AD

The highest VS reduction of 61.05% was obtained on SS-AD. The VS reduction was related to the biogas yield. Consequently, the higher the biogas yield, the higher the VS reduction. L-AD obtained the lower VS reduction due to the low cumulative biogas yield.

Conclusion

Biogas production through SS-AD produces a higher yield than L-AD. The high rate during SS-AD due to the enrichment of microbes at the early stage. The pH value affects the performance of microbe activity and digester. The final pH is greater than the initial pH that indicates ammonia inhibition. The VS reduction is correlated with the biogas yield.

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