J. T. K. L.
JURNAL TEKNIK KIMIA DAN LINGKUNGAN

*J. Tek. Kim. Ling. 2020, 4 (1), 44-52*
p-ISSN : 2579-8537, e-ISSN : 2579-9746
www.jtkl.polinema.ac.id

# Biogas Production from Corn Stover by Solid-State Anaerobic Co-digestion of Food Waste

**Lukhi Mulia Shitophyta*, Gita Indah Budiarti, Yusuf Eko Nugroho, Dika Fajariyanto**

Department of Chemical Engineering, Universitas Ahmad Dahlan, Jl. Ringroad Selatan, Kragilan, Bantul, Yogyakarta, Indonesia

*E-mail: lukhi.mulia@che.uad.ac.id

**ABSTRAK**

Biogas telah menjadi bahan bakar alternatif untuk mengurangi kelangkaan bahan bakar fosil. Biogas dapat dihasilkan dari limbah makanan seperti tongkol jagung. Tongkol jagung merupakan biomassa lignoselulosa dan mengandung kandungan total *solid* (TS) >15%. Produksi biogas dilakukan dengan *solid-state anaerobic digestion* dengan penambahan *co-digestion* limbah makanan. *Co-digestion* berfungsi untuk membantu proses pemecahan tongkol jagung. Tujuan penelitian ini adalah untuk mengkaji pengaruh persentase limbah makanan, reduksi *volatile solid* (VS), dan model kinetika produksi biogas dari tongkol jagung. Hasil peneltiian menunjukkan bahwa limbah makanan berpengaruh signifikan terhadap *yield* biogas ($p < 0{,}05$). *Yield* biogas tertinggi sebesar 584,49 mL $g^{-1}$ $VS^{-1}$ dan reduksi VS tertinggi sebesar 40% diperoleh pada limbah makanan 20%. Model kinetika produksi biogas dari tongkol jagung dan limbah makanan mengikuti model kinetika orde pertama.

***Keywords***: Biogas, biomassa lignoselulosa, model kinetik, *solid state*, *volatile solid*.

**ABSTRACT**

Biogas has become an alternative fuel to reduce the lack of fossil fuel. Biogas can be produced from organic wastes such as corn stover. Corn stover is a typical lignocellulosic biomass and contains a total solid (TS) content higher of 15%. Biogas production was conducted by solid-state anaerobic digestion with addition co-digestion of food waste. Co-digestion is useful to help the digestion of corn stover. The purposes of this study were to investigate the effect of the percentage of food waste, volatile solid (VS) reduction, and kinetic model on biogas production from corn stover. Results showed that food waste had a significant effect on biogas yield ($p < 0.05$). The highest biogas yield of 584.49 mL $g^{-1}$ $VS^{-1}$ and the highest VS reduction of 40% was obtained at food waste of 20%. The kinetic model of biogas production from corn stover and food waste followed the first-order kinetic model.

***Keywords***: biogas, lignocellulosic biomass, kinetic model, solid state, volatile solid.

## 1. INTRODUCTION

The rising of fossil fuel consumption and gas emission has become a critical issue recently [1]. Dependence on fossil fuel has led to big problems such as climate change, global warming, health hazards and scarcity of natural resources [2]. The shortage of fossil fuel and the concern of energy security have led to an investigation to develop renewable energy resources [3]. According to IRENA [4], the total production of renewable energy in the world is 5,537,179 GWh in 2015. Therefore, the production of renewable energy has a positive trend to be developed persistently. One of the renewable energies is biogas. Biogas can reduce fossil energy like coal, oil, and gas. Biogas also has a substantial ecological role in heat and electricity production [5]. Production of biogas does not need any advanced technology [6]. Biogas contains 50-70% of methane and 30-50% of carbon dioxide [7]. Biogas can also contain nitrogen, organic silicon, and hydrogen sulfide [8].

Corresponding author: Lukhi Mulia Shitophyta
Department of Chemical Engineering, Universitas Ahmad Dahlan
Jl. Ringroad Selatan, Kragilan, Bantul, Yogyakarta, Indonesia
E-mail: lukhi.mulia@che.uad.ac.id

Diterima: 16 September 2019
Disetujui: 11 Februari 2020

The use of renewable fuels such as biogas can reduce fossil fuel dependence and mitigate the social and environmental impacts of fossil fuel degradation [9]. Currently, the biogas demand has a positive trend in the global market for various energy needs [10]. The capacity of biogas production in the world reached 14,214 MW in 2015 [4].

Biogas is produced by anaerobic digestion (AD) utilizing the amounts of organic waste [11]. The by-product of anaerobic digestion can be used as a fertilizer or nourishment for farming [12]. The stages of anaerobic digestion (AD) comprise hydrolysis, acidogenesis, acetogenesis, and methanogenesis [13]. The AD can be categorized into liquid anaerobic digestion (L-AD) and solid-state anaerobic digestion (SS-AD) based on total solids (TS) contents. L-AD is conducted at a TS content of less than 15%, while SS-AD is generally carried out at TS higher of 15% [14]. SS-AD offers many advantages over L-AD such as producing a compost, lower energy inputs for heating and mixing, fewer moving parts. Floating and stratification of fats, fibers, and plastics will not be found in SS-AD [15].

Biogas can be produced from agricultural wastes such as corn stover. Corn stover is abundantly obtainable in Indonesia. According to Statistics Indonesia [16], the total production of corn is 19,612,435 tons in 2015. Corn stover is typical lignocellulosic biomass and contains carbohydrates that are not easily degraded by the microorganism [17]. Corn stover has a high total solid content. Hence, co-digestion is required to help the digestion of corn stover. Co-digestion may enrich the anaerobic digestion process. Furthermore, the digestion of more than one substrate can create positive synergism and the additional nutrient can sustain the growth of the microorganism [18].

Food waste (FW) can be used as co-digestion due to it has an abundant organic material. Food waste contains natural fibers, carbons, proteins, fats, lipids, vitamins, and minerals that are readily biodegradable [19]. Food waste contains a lot of organic material which can be degraded to produce biogas [20]. Data from FAO [21] shows that the volume of global food waste is estimated 1.6 billion tons, while total $CO_2$ from food waste is estimated at 3.3 million tons per year. Food waste can produce two types of clean gas, i.e. hydrogen and methane [9].

Food waste contains 7-31 wt% of total solid is estimated to produce 0.44-0.48 $m^3$ $CH_4$/kg VS [22]. The previous study which was conducted by Brown and Li [13] stated that the increase in the percentage of food waste to 10% and 20% enhanced the volumetric productivity for SS-AD from yard waste. Liu et al. [23] also reported that biogas production from food waste had a higher volume than biogas production from green waste and the mixture. However, no study has been designed to refer to the interaction between food waste as co-digestion on biogas production from corn stover by SS-AD. Consequently, the objectives of this study were to investigate the effect of food waste on biogas production from corn stover and observe the volatile solid reduction on biogas production from corn stover. The kinetic model of biogas production was also studied in this study.

## 2. METHODS

### 2.1. FEEDSTOCK AND INOCULUM

Corn stover as a feedstock was obtained from a farm in Sleman, Yogyakarta and then air-dried and ground to pass through a 10 mm screen. The ground corn stover was stored in airtight bags at room temperature until used. The food waste was collected from the eateries in Yogyakarta. Then the food waste was ground up using a blender and stored in plastic bags in a freezer before usage. Cow's rumen as inoculum was obtained from a slaughterhouse in Yogyakarta.

### 2.2. SOLID-STATE ANAEROBIC DIGESTION

The effect of the percentage of food waste (0%, 5%, 10%, and 20% based on dry VS) was studied on the performance of SS-AD. 1.5-liter digester was loaded with feedstock/inoculum (F/I) ratio of 2 and food waste (FW). Water was added to adjust the total solid (TS) content of 22%. All experiments were conducted at room temperature.

### 2.3. ANALYTICAL AND STATISTICAL ANALYSIS METHODS

Total solids (TS) and volatile solids (VS) were measured by APHA-standard methods [24]. The calculation of the initial total solid was used to determine the operational TS content (22%) on biogas production, while VS was analyzed to find the VS reduction before and after digestion. The pH value was measured by a pH meter. Biogas volume was measured every 2 days by the water displacement method as illustrated in Figure 1.

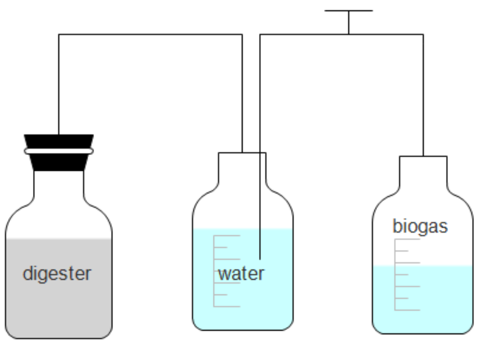


**Figure 1**. Biogas volume measurement by the water displacement method.

Biogas yield was calculated by daily biogas volume divided by the initial total volatile solids (VS) of corn stover.

Analysis of variance (ANOVA) was performed by Microsoft Excel to determine the significance of differences with a threshold p-value of 0.05.

### 2.4. KINETIC MODEL CALCULATION

The specific rate constant ($k$) was calculated by plotting a linear graph between biogas yield and digestion time using first-order kinetic equation. The graph gave the equation $y = ax + b$. The specific rate constant can be determined from the slope ($a$).

## 3. RESULTS AND DISCUSSIONS

### 3.1. EFFECT OF PERCENTAGE OF FOOD WASTE ON BIOGAS PRODUCTION

The daily biogas yield at the variation percentage of food waste is presented in Figure 2. The biogas production was conducted for about 30 days until no more biogas was produced. Biogas production began to produce immediately on day 1 for all the percentage of food waste. After that, the small peak appeared on day 2 for all food waste percentages. Thereafter, biogas yield increased intensely and reached peak values of 74.66, 103.38, and 147.03 mL $g^{-1}$ $VS^{-1}$ on day 14 for food waste of 5%, 10%, and 20%, respectively. However, food waste of 0% attained the peak value of 45.95 ml $g^{-1}$ $VS^{-1}$ on day 16. It was maybe caused by the faster hydrolysis of simply digestible material, which initially led to the overproduction of fatty acids which inhibit methanogenesis [15]. After reaching peak values, biogas production decreased gradually until no more biogas was produced.

Addition of food waste could improve the biogas yield because there was more microorganism in food waste that degrade corn stover, as a result, the biogas production was high.

Statistical analysis also showed that an increase in food waste from 0% to 20% had a significant effect on biogas yield ($p < 0.05$).

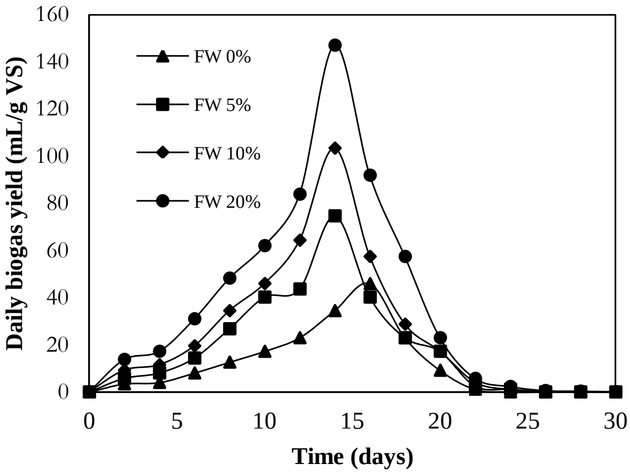


**Figure 2**. Daily biogas yield during digestion of corn stover at the difference percentage of food waste.

As presented in Figure 3, the highest cumulative biogas yield of 584.49 mL $g^{-1}$ $VS^{-1}$ was obtained on food waste of 20%, then followed by the cumulative yield of 396.63, 297.39, 182.06 mL $g^{-1}$ $VS^{-1}$ on food waste of 10%, 5%, and 0%, respectively.

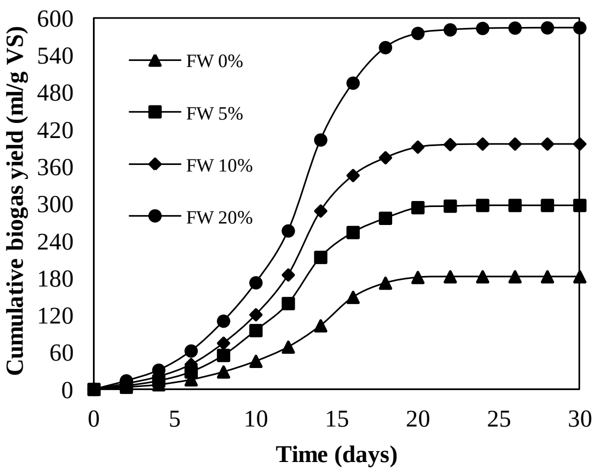


**Figure 3**. Cumulative biogas yield during digestion of corn stover at the difference percentage of food waste.

Food waste of 20% had higher biogas yield than other percentages of food waste because the higher food waste may contain high protein, as a result, the degradation of higher food waste produces the higher biogas [25]. The previous study by El-mashad and Zhang [18] also found that a higher biogas yield was obtained at the higher percentage of food waste. Liu et al. [23] also stated that biogas yield on the digestion of food waste was higher than the digestion of green waste and mixture. Co-digestion of food waste can improve the biogas yield due to the food waste has essential nutrient contents for anaerobic microorganism [26].

## 3.2. VOLATILE SOLID (VS) REDUCTION

The volatile solids reduction can be seen in Figure 4. It shows that VS reduction increased when the percentage of food waste increased. The higher VS reduction of 40% was obtained at the higher of the percentage of food waste, whereas the lower VS reduction was found at the lower of the percentage of food waste.

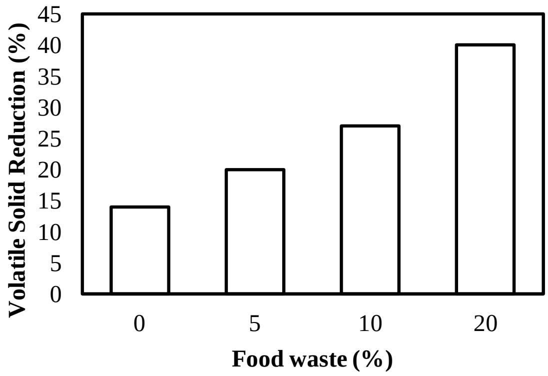


**Figure 4**. Reduction of volatile solid (%) during 30-day SS-AD of food waste and corn stover.

The VS reduction was correlated with the biogas yield. The higher VS reduction value was attained in the digester with the higher biogas yield. The highest biogas yield and VS reduction value were obtained at the food waste of 20%. These results were comparable to a study conducted by Brown and Li [15] who reported that the rise of VS reduction was achieved by the increase of food waste.

## 3.3. pH VALUES

The pH value was measured at the beginning and end of biogas production. pH is one of the crucial factors in anaerobic digestion due to it can affect the activities of acetogenic and methanogenic microorganisms [27]. The change in pH values can be seen in Figure 5.

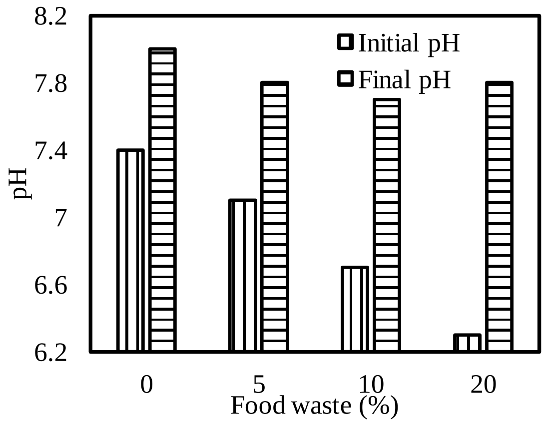


**Figure 5**. pH values at the beginning and end of biogas production during SS-AD of corn stover and food waste.

The initial pH values were varied between 6.3 and 7.4. The initial pH values at the variation of food waste (5%, 10%, and 20%) had a smaller pH value compared to the food waste of 0%. At the higher food waste percentages, the initial pH values were smaller. This was generally caused by the increasing of an organic fraction which leads to volatile fatty acids (VFA) production in the initial stage of digestion [28]. Production of VFA can cause microorganisms stress which results in a pH decrease [29].

The growth performance of methanogens will decrease below the pH value of 6.6 [30]. Accumulation of organic acid can cause the decline of pH value, inhibition of methanogens activity, failure of the reactor, and decrease of biogas yield [31].

The final pH values were 8, 7.8, 7.7, and 7.8 for food waste of 0%, 5%, 10%, 20%, respectively. The final pH values were higher due to the conversion of VFA to methane by methanogenic microorganisms [32]. The optimum pH for methanogens is 6.5-7.2 [33]. The final higher pH value affected inhibition of methanogen activity which leads to the low biogas conversion, thus the higher the final pH, the lower the biogas yield.

## 3.4. FIRST-ORDER KINETIC MODEL OF BIOGAS PRODUCTION

The kinetic of biogas production from corn stover and food waste was estimated using a first-order kinetic model due to the anaerobic digestion kinetic follows the first-order hydrolysis rate constant [34]. Hydrolysis is considered the rate-limiting step in biogas production [35].

The first-order kinetic model has been used by Brown et al. [36], Mirmohamadsadeghi et al. [37], Liew et al. [38]. The first-order kinetic model can be linearized as presented in equation (1):

$$\ln\left(\frac{y_u}{y_u - y_t}\right) = kt \qquad (1)$$

The specific rate constant (*k*) of biogas production from corn stover and food waste can be seen in Table 1.

**Table 1.** The rate constants and regression values on biogas production from corn stover and food waste.

| Food waste (%) | k ($day^{-1}$) | $R^2$ |
|---|---|---|
| 0 | 0.1287 | 0.9022 |
| 5 | 0.1183 | 0.9236 |
| 10 | 0.1456 | 0.9140 |
| 20 | 0.1768 | 0.9144 |

The value of k is the proportionality constant correlating the rate of biogas production. The greater of the k value, the faster the biogas production rate. The highest rate constant was obtained at food waste of 20%. The regression values ($R^2$ >

0.9) reveal that biogas production follows the first-order kinetic model [37]. As shown in Table 1, the regression values are larger than 0.9. Consequently, the kinetic model of biogas production from corn stover and food waste followed the first-order kinetic model because the range value of $R^2$ was 0.9022 to 0.9144 ($R^2$ > 0.9).

## 4. CONCLUSION

The increase of the co-digestion of food waste from 0% to 20% can enhance biogas yield ($p < 0.05$). In other words, the addition of food waste on biogas production from corn stover can increase biogas yield. The VS reduction is proportional to the biogas yield. The higher biogas yield generates a higher VS reduction. The highest biogas yield of 584.49 mL $g^-$ is obtained at a food waste of 20%. The highest VS reduction of 40% is also obtained at a food waste of 20%. The kinetic model of SS-AD from corn stover and food waste follows the first-order kinetic model ($R^2$ > 0.9).

## NOMENCLATURE

$t$ = time (day)
$y_u$ = biogas yield obtained in 30 days (mL/g.VS)
$y_t$ = biogas yield obtained at time t (mL/g.VS)
$k$ = the specific rate constant (1/day).

## ACKNOWLEDGMENT

The authors would like to thank the Ministry of Research, Technology and Higher Education of the Republic of Indonesia for financial supporting through the Research Grant for Novice Lecturers.

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