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Production of biogas from coffee husk waste with rumen fluid and mixture of rumen fluid and cow dung

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ABSTRACT

Coffee is the second largest traded commodity in the world and also produces by-products and residues. Coffee husk waste is an abundant lignocellulosic material and has the potential to be used as raw material for biogas production. This study compared the production of biogas from coffee husk using rumen fluid with a mixture of rumen fluid and cow dung. In the pretreatment process using ethanol, the waste consisted of 65.90% cellulose, 24.95% hemicellulose, 0.21% lignin, 2.16% pectin, 1.08% protein, 3.11% tannins, 0.91% caffeine, and 3.78% polyphenols. The decrease in TS (total solid) and VS (volatile solid) values for C-RC (coffee-rumen fluid-cow dung) was greater than for C-R (coffee-rumen fluid) as 32.20% and 42.47% were obtained for C-RC, while the values for C-R were 19.32% and 38.37 The VFA (volatile fatty acids) values for C-R and C-RC were 1.09% and 2.24%.. The biogas produced for C-R was CH_4 of 14.4%, CO_2 of 13.75%, and H_2 of 0.59%, while that for C-RC consisted of CH_4 of 22.3%, CO_2 of 4.11%, and H_2 of 0.36%. The yield of biogas for C-R was 0.48 Nm^3/(kg COD removal) and for C-RC was 1.95 Nm^3/(kg COD removal).

1. Introduction

Increased economic growth, followed by higher living standards, as well as rapid industrial growth, requires renewable energy sources [1]. The need for renewable energy sources is due to the limited and depleting amount of fossil fuels [2]. In addition, burning of fossil fuels is a global environmental problem due to the resulting greenhouse gas emissions [3]. Fossil fuels are not environmentally friendly and also expensive. The decline in the quantity of fossil fuels is an important problem and there is a need for new technology and renewable resources as a solution to this problem [4,5].

Indonesia is one of the 4th most populous countries in the world after China, India, and the United States. The large population can affect the number of available energy sources. If this problem is not accompanied by an increase in energy production, it is feared that Indonesia will face an energy crisis. Therefore, it is necessary to develop alternative energy sources that can reduce dependence on conventional fuels. One of the energy sources that can be used is biogas. Biogas production, containing CH_4 (45–75%), CO_2 (24–55%), and small amounts of other components (N_2, O_2, H_2, and H_2S), and is a promising renewable energy source [6,7].

Biogas is renewable energy produced from cow dung and other agricultural residues through anaerobic digestion. Biogas technology has the advantage of being an alternative energy source that can be stored and the residue from biogas production can be used as fertilizer (Bitrus, 2001). Biogas is a biofuel produced from the decomposition or fermentation of organic matter from plant and animal waste in an anaerobic digester [8]. There are two main functions of a biogas production system; the first is the digestion of organic matter into biogas and the subsequent use of the produced biofuels for energy generation [9].

Waste, including industrial, municipal, animal, and agricultural, can be used to produce biogas through anaerobic digestion [10]. Anaerobic digestion of organic and waste biomass is an alternative process to ensure the continuity of energy supply, and this has become a great concern because it can reduce greenhouse gas emissions. Biogas produced from this process is a good source of energy to replace fossil fuels in the generation of heat and electricity [11].

Agricultural waste is an abundant and potential raw material as a source of clean energy and bio-products for industrial purposes. For example, when processing coffee postharvest solid waste produced (pulp and husk) reaches 1 ton [12] and the amount of wastewater varies between 5000 and 15000 L per ton of coffee [13]. Disposal of coffee waste can cause environmental problems such as water eutrophication, soil acidification and salinization, and toxic effects. The toxicity of coffee grounds is due to the presence of polyphenols, compounds that can damage cell membranes and affect the enzymatic activity of microorganisms [14]. Its concentration can be higher than 9% in coffee grounds and husks and up to 1528 mg/L in coffee processing wastewater [15].

Coffee is the second largest traded commodity in the world and also produces products and residues. Coffee is a lignocellulosic material that is abundant and can be used as a raw material for biogas production. Lignocellulosic components present in coffee husk include cellulose (63%), hemicellulose (2.3%), lignin (17%), protein (11.5%), tannins (1.80-8.56%), pectin (6.5%), reducing sugar (12.4%) %), non-reducing sugar (2.0%), caffeine (1.3%), chlorogenic acid (2.6%) and caffeic acid (1.6%) [16,17].

The rumen is a rich and sustainable source of hydrolytic bacteria [18]. The addition of rumen fluid to the anaerobic digester increases methane yield in the hydrolysis process and lignocellulosic acidification increases the concentration of

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volatile fatty acids (VFA) [19]. The rumen is known as one of the most diverse microbes proven to reduce retention time for digestion of lignocellulosic biomass during anaerobic digestion [20-22].

Cow dung also has the potential to be a raw material for biogas production. Because in cow dung various types of bacteria acts as decomposers, such as hydrolytic bacteria, acetogenic bacteria, acetogenic bacteria, and methanogenic bacteria. All of these bacteria play an important role as decomposers in the degradation of organic matter to produce biogas [23].

The objective of this study is to produce biogas from coffee husk. The addition of rumen fluid and mixture of rumen fluid and cow dung were conducted. Both additional raw materials were compared to explore the performance.

2. Materials and Methods

The materials that will be used in this study are coffee husk waste obtained from Tanjung Jabung Barat district, Jambi Province. The type of coffee processed is Robusta coffee. Fresh rumen fluid and cow dung were collected from the Surabaya Pegirian slaughterhouse, 10 liters and three kilograms respectively. Rumen fluid is filtered with four layers of sterile gauze to remove coarse material, then put into a bucket that has been filled with nitrogen and stored at 37ºC in an incubator [24].

Three kilograms of cow dung were taken and then put in an airtight container. The cow dung obtained was diluted with aquadest in a ratio of 1:3, then filtered using gauze, and then put into the digester according to a predetermined volume of 15% of the working volume of the reactor. Effective microorganisms are purchased at a farm store. In addition, glucose, ethanol, $NiCl_2.6H_2O$, $MnCl_2.4H_2O$, $K_2Cr_2O_7$, NaOH, H_2SO_4, CH_3COONa, NH_4Cl, KH_2PO_4, $CaCl_2.2H_2O$, $MgCl_2.6H_2O$, Fe-EDTA, $CoCl_2.6H_2O$, and yeast extract were also used.

The equipment in this research is autoclave, hot plate & stirrer, water bath, Spectrophotometer, analytical balance, Incubator, furnace, oven, vacuum pump (Weich), vortex, manometer, gas chromatography (Hewlett Packard), COD tube, COD reactor, and gas chromatography (GC-2010 Plus-SHIMADZU). The batch reactor used is shown in figure 1.

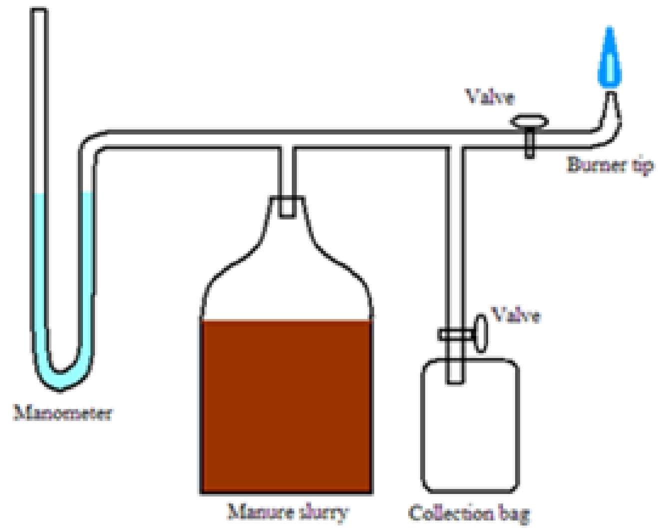

Figure 1. The equipment of anaerobic process from rice straw waste

2.1. Analysis of lignocellulosic

In this study, the analysis of cellulose, hemicellulose, and lignin used the Chesson method.

2.2. Hemicellulose

Hemicellulose content was analyzed using the Chesson Method (Isroi, 2013), namely by mixing 1-2 grams of a sample with 150 mL of distilled water, then heating at 100 ºC for 2 hours, then filtering using filter paper and finally rinsing with distilled water, then the solids were dried in an oven at 105 ºC to constant weight (a). Then the sample was mixed with 150 mL H_2SO_4 1 N, then the sample was heated at 100 ºC for 1 hour, filtered with filter paper, and finally rinsed with distilled water. Then the solids were put into the oven at a temperature of 105 ºC to constant weight (b). The hemicellulose content was calculated using equation (1).

$$\text{Hemicellulose content (\%)} = \frac{b-c}{a} \text{ x } 100\% \quad (1)$$

Noted:

a) Dry weight reduction of lignocellulosic biomass samples.
b) Reduction of the dry weight of reflux sample residue using hot water.
c) The Reduction dry weight of sample residue after refluxing using 0.5 M H_2SO_4.

2.3. Cellulose

Cellulose content was analyzed by the Chesson Method. The dried sample in hemicellulose analysis (b) was mixed with 10 mL of 72% (v/v) H_2SO_4 solution at room temperature for 4 hours, then H_2SO_4 was diluted to a concentration of 0.5 M. Then the sample was refluxed at 100 ºC for 2 hours. The cellulose content was calculated using equation (2).

$$\text{Cellulose content (\%)} = \frac{c-d}{a}\ x\ 100\% \quad (2)$$

Noted:

a) The reduction in dry weight of lignocellulosic biomass samples.
c) The reduction in the dry weight of the sample residue after refluxing using 0.5 M H_2SO_4.
d) The reduction in the dry weight of the sample residue after being mixed using 72% H_2SO_4 after which it was diluted to 4% H_2SO_4.

2.4. Lignin

Lignin content was analyzed by the Chesson method [25]. The dried sample in the cellulose analysis (c) was filtered and then washed with distilled water. Next, the solids were put into an oven at a temperature of 105 ºC to constant (d). Cellulose content is calculated using equation (3). Lignin content (%) = $\frac{d-e}{a}$ x 100% ….(3)

Noted:

a) The reduction in dry weight of lignocellulosic biomass samples.
d) The reduction in the dry weight of the sample residue after being mixed with 4% H_2SO_4.
e) Ash from sample residue

2.5. Biogas production

Biogas production was produced through an anaerobic process in a batch reactor with a working volume of 3.6 L. This study compared the yield and quality of biogas for waste of coffee with rumen fluid (C-R) and the mixture of rumen fluid and cow dung (C-RC). The parameters measured in this study were total solids, volatile solids, chemical oxygen demand (COD), volatile fatty acids (VFA), and biogas composition.

2.6. Analysis total solids (TS)

The porcelain cup is heated for 1 hour at 550 ^{0}C in the furnace, then cooled in a desiccator, after cold the empty cup is weighed (W_{dish}). Ten ml of sample was put into a cup that had been weighed previously and then weighed again (W_{sample}). The cup containing the sample was put into the oven and then heated for 12 hours at 105 C. Then the cup is cooled in a desiccator and weighed again until the weight remains constant (W_{total}).

$$\% \text{ Total solids} = \frac{Wtotal - Wdish}{Wsample - Wdish} \times 100\%$$

Noted:

W_{dish} = weight of the cup (g)
W_{sample} = weight of sample and cup (g)
W_{total} = weight of dry sample and cup (g)
This is described as EPA Method 1684 [26].

2.7. Analysis volatile solids (VS)

The cup containing the sample whose TS has been weighed is then reheated in the muffle furnace at a temperature of 550 ºC for 2 hours. After that, the porcelain cup was cooled to room temperature and the weight was re-weighed. Ash [mg/l] = a × (1000/v) a = the difference in weight of the evaporating dish after being heated at 550 ºC with the weight of the empty dish v = sample volume VS [mg/l] = TS [mg/l] - Ash [mg/l]. This is described as EPA Method 1684 [26].

2.8. Analysis COD

COD was measured by adding a digestion solution ($K_2Cr_2O_7$) with 3.5 mL of H_2SO_4 solution in a COD tube, then homogenized (the solution became hot), allowed to settle, then added 2.5 mL of distilled water as a blank, homogenized, then heated at 148 ºC for 2 hours using a COD reactor, let it come to room temperature and measure it with a spectrophotometer at a wavelength of 620 nm.

2.9. Analysis volatile fatty Acids (VFA) and biogas

Analysis of VFA content, the slurry sample was taken through a sampling valve digester using a syringe and a hose and then accommodated into 1.5 mL eppendoff, then homogenized with a centrifuge to separate the filtrate and precipitate. The resulting filtrate was analyzed using Gas Chromatography (GC) HP-6890 at an oven operating condition with an initial temperature of 170 ºC for 18.57 min. Injector operating conditions using Helium as carrier gas at an initial temperature of 275 ºC at a pressure of 17.21 psi. The composition of biogas such CH_4, CO_2, dan H_2 was analyzed using gas chromatography (Hewlett Packard, USA)

3. Results and Discussion

3.1. Coffee husk lignocellulosic composition

Table 1 shows the results of the analysis of the lignocellulosic composition after the delignification process with chemical pretreatment using ethanol. The results of lignocellulosic components of coffee husk waste after pretreatment using ethanol are 65.90% cellulose, 24.95% hemicellulose, 0.21% lignin, 2.16% pectin, 1.08% protein, 3.11% tannins, 0.91% caffeine, and 3.78% polyphenols.

Table 1. Lignocellulosic composition of coffee husk

Coffee husk components	Percent
Cellulose	65.90%
Hemicellulose	24.95%
Lignin	0.21%
Pectin	0.42%
Protein	0.81%
Tannin	1.05%
Caffein	0.0%
Polyphenol	0.81%

The delignification process is an initial step that aims to reduce the lignin content in lignocellulosic materials. The delignification process will dissolve the lignin content in the material, thus facilitating the process of separating lignin from cellulose fibers. Delignification will open the lignocellulosic structure so that cellulose becomes more accessible to microbes. Thus, the process of degrading organic compounds is easier for microorganisms to carry out [27].

3.2. Total solids (TS) and volatile solid (VS)

Based on the TS and VS analysis, it was carried out every 5 days for 30 days during the anaerobic digestion process. The results of the TS and VS analysis can be seen in figures 2 and 3.

Based on the results of the TS and VS analysis shown in Figures 2 and 3, it can be seen that the TS and VS values on the C-R and C-RC decreased significantly during the 30 days of anerobic fermentation time. The decrease in TS and VS values for C-RC was greater than for C-R, namely 32.20% and 42.47%, while for C-R the resulting TS and VS values were 19.32% and 38.37%.

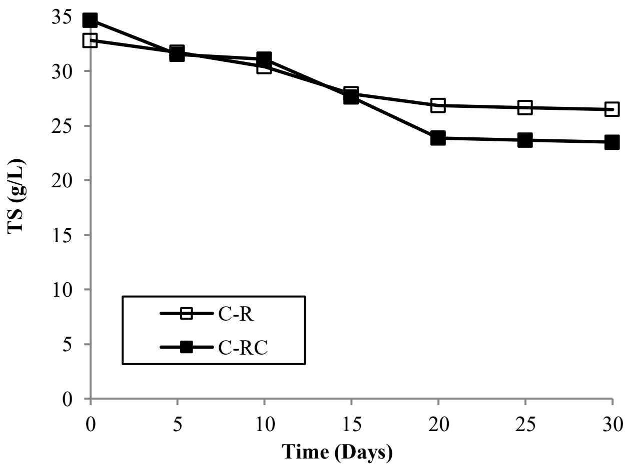

Figure 2. Total solids profile for anaerobic digestion from C-R and C-RC

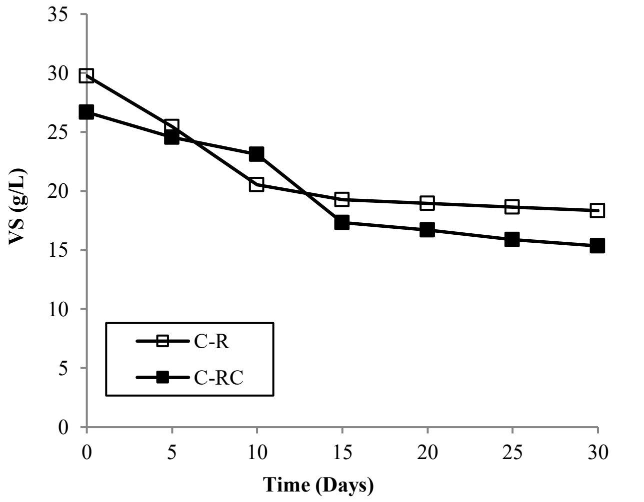

Figure 3. Volatile solids profile for anaerobic digestion from C-R and C-RC

TS and VS values are affected by the increased growth of microorganisms from degraded organic compounds. The significant decrease in TS and VS was due to the increased growth of the microorganism cells which was supported by an adequate supply of nutrients so that the microorganisms were able to degrade organic compounds.

3.3. Chemical oxygen demand (COD)

Figure 4 shows the results of the COD analysis for the two treatments, namely C-R and C-RC, which decreased during the anaerobic fermentation process. The decrease in COD in each treatment was a C-R of 28.23% and a CR-C of 48.92%. Based on the analysis results, the COD value decreased from day 5 to day 30. Decreasing the COD value identifies the methane gas product formed.

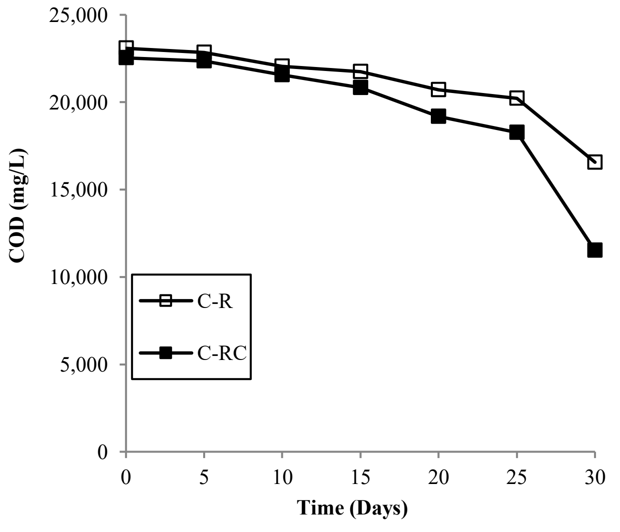

Figure 4. COD profile for anaerobic digestion from C-R and C-RC

3.4. Volatile fatty acids (VFA)

In this study, volatile fatty acids such as acetic, propionic, and butyric acids were analyzed by gas chromatography (GC). Acetic, propionic, and butyric acids are the main products in biogas production. The results of VFA analysis on C-R and C-RC are shown in figure 5.

Increased production of acetic, propionic, and butyric acids on C-R and C-RC indicates increased growth of acetogenic bacteria while decreased production of acetic, propionic, and butyric acids indicates the conversion of these three volatile fatty acids into biogas. The concentration of these volatile acids (acetic, propionic, and butyric acids) indicates the production of biogas has been produced [28].

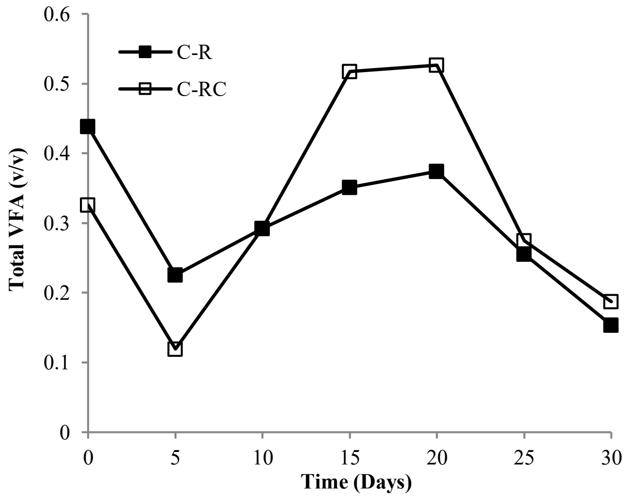

Figure 5. VFA profile for anaerobic digestion from C-R and C-RC

3.5. Biogas result

The composition of biogas (CH_4, CO_2, H_2) was analyzed for 30 days of anaerobic fermentation. Table 2 shows the comparison of biogas composition between C-R and C-RC.

Table 2. Comparison of biogas composition in C-R and C-RC

Compounds	C-R (%)	C-RC (%)
CH_4	14,4	22,3
CO_2	13.75	4,11
H_2	0,59	0,36

The highest CH_4 composition (22.3%) was yielded for C-RC as CO_2 of 13.75% and H_2 of 0.36% was obtained. The highest methane yield was produced in C-RC about 1.95 Nm^3/(kg COD removal). The presence of cow dung results in greater methane production [29, 30]. Cow dung is a habitat for various microorganisms that function to accelerate component degradation. Thus, it can degrade organic matter through a hydrolysis process, in which complex organic polymers are converted into short organic components [31]. However, the amount of carbon dioxide decreased significantly with the addition of cow dung; this may be due to the slight increase in alkalinity limiting the hydrolysis of organic matter to produce carbon dioxide [30,32].

4. Conclusion

The mixing of cow dung and rumen fluid in biogas production of coffee husk waste is more effective than using only rumen microorganisms. In addition to increasing the methane yield, it also improves the quality of the biogas produced. This is indicated by the carbon dioxide gas produced which is an impurity, which is 4.11% less in C-RC compared to C-R which is much larger, which is 13.75%.

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