Flame Characteristics of Biogas From Coffee Waste Materials

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Abstract. Biogas flame characteristic from coffee waste has been investigated. The biogas flame characteristics include the content of carbon dioxide in biogas, flame color, ionic behavior in flame, and caloric value. Biogas is made from coffee shell waste material mixed with cow dung on ratio 1:1. The reactor used is a continuous system with a floating system as biogas storage. The resulting biogas was purified by using 1 M and 4 M KOH solutions, and measured carbon dioxide content using a gas analyzer. Biogas turned on a bunsen burner and a flame recorded with a camera, on resolution 1280 x 720. The resulting image is analyzed for the color of the flame on several compositions mixed with air. To measure the behavior of ions, biogas and air mixes are ignited inside the combustion chamber Hele Shaw Cell (HSC) that made of acrylic with dimensions of 30 cm x 20 cm and 1 cm. The ion sensor is made of 1 cm wide aluminum foil mounted to 1 cm in length along the HSC. Flame will produce ions that indicated by the emergence of voltage of ion sensor. After the biogas composition is known, the calorific value can be calculated. The results showed that CO$_2$ content before purification was 37.22% and purification caused CO$_2$ content decrease to 23.01% in KOH 1M and 18.66% in KOH 4M. Decrease CO$_2$ composition causes an increased combustion reaction as indicated by increasingly blue flame color and larger ions. This result is reinforced by the calculation of calorific value, in which the decrease of CO$_2$ content in biogas causes the caloric value increase.

1. Introduction

The need for fossil energy such as petroleum continues to increase, on the contrary, its reserves on the earth are running low. Renewable alternative energy is a source of energy produced from energy resources that are naturally endless and sustainable if managed well, for example geothermal, hydropower, wind power, biomass and biogas $^1$. Indonesia with extensive agricultural area has the potential of various plants that have a large enough waste, namely coffee. In addition, livestock waste is one source of materials that can be utilized to produce biogas. One of the livestock waste that can be utilized as a source of biogas producer is cow dung $^2$.

Biogas is a mixture of several gases, classified as fuel gas which is the result of fermentation of organic material under anaerobic conditions. Biogas contains a number of dominant gases are methane (CH$_4$ 50-70%) and carbon dioxide (CO$_2$ 30-40%), hydrogen sulfide (H$_2$S 0% - 3%), water (H$_2$O 0.3%), oxygen (O$_2$ 0.1% - 0.5%), hydrogen (H$_2$ 1% -5%) and other gases in small quantities$^{3,4}$. According to Lastella$^5$, concentrations other than CH$_4$ and CO$_2$ are relatively small. In the combustion process, gases other than methane (CH$_4$) will decrease the biogas heat value and combustion efficiency. So to get a greater calorific value of biogas must be optimized percentage of methane gas (CH$_4$) by reducing other gas main CO$_2$ because its content is greatest after CH$_4$. CO$_2$ gas will be
detrimental to the combustion process because in combustion reaction CO\textsubscript{2} is a combustion gas product that could not burn again\textsuperscript{6}. Therefore it is necessary to purify biogas process to reduce CO\textsubscript{2} content.

Several studies on purification of biogas have been done. Asadi\textsuperscript{7} purified biogas with NaOH solution with flame velocity parameter on biogas flame. Purification of biogas by absorption method using KOH solution is done by Hamidi\textsuperscript{8}. In this study the solution of Potassium Hydroxide (KOH) was activated with zeolite stone. The duration of the test and the KOH composition on the zeolite absorber have an effect on the biogas heat value, in which the higher the KOH compound used, the zeolite adsorption capacity is increasing and the longer the testing time of the CH\textsubscript{4} and O\textsubscript{2} gas content is increased due to the increasing of CO\textsubscript{2} and gas H\textsubscript{2}S is absorbed in biogas.

Parameters to test the flame quality of fuel gas are still widely used relatively expensive equipment, such as compositional tests using Gas Chromatography and gas analysers, or testing calorific values with calorimeter bombs. Hadi\textsuperscript{9} conducted gasification research with variation of AFR to know flame quality of syngas in the form of flame temperature and composition and flammable gas calorific value using calorimeter bomb. Hosseini\textsuperscript{10} tested the composition of biogas with an ankle gas. The color had used as a quality parameter of biogas flame\textsuperscript{10, 11}.

This research was conducted to determine the quality of gas fuel with the thermal characteristics of biogas flame which include flame color and combustion ion compared with biogas composition and calorific value calculation.

2. Research Method

Biogas as research material obtained from digestor output with main ingredient of coffee skin mixed with cow dung with ratio 1:1. The biogas reactor as shown in figure 1 is made up of drums connected with a continuous system, in which materials can be inserted at any time and on other parts, materials that have not produced biogas out. The resulting biogas is accommodated on a drum that is fitted into one with a floating system reactor, where if the biogas starts to form then the drum will be lifted. This system allows biogas to be used for applications directly without having to apply pressure. The biogas from the reservoir was incorporated into several storage plastics of equal volume and then purified by using 1 M and 4 M potassium hydroxide (KOH) solutions. The carbon dioxide (CO\textsubscript{2}) compositions of biogas before and after purification were measured in composition with gas analyzers and tested its flame with color and ion observation parameters on flame.

![Figure 1. Continuous Biogas Reactor with Floating System Container](image-url)
The research equipment consists of one unit of biogas purifier circuit which is connected directly to biogas storage plastics. Biogas refining is carried out for 10 minutes for a single test (Fig.1). After the biogas testing process is re-measured volume to know the CO$_2$ that has been absorbed.

From the measurement of the composition, the calorific value of biogas was calculated. The resulting biogas contains H$_2$O in the form of gas/ vapor, so the calculated heat value is Lower Heating Value (LHV). The calculation of LHV is determined by equation according to

$$\text{LHV} = H_c = H_{\text{reactants}} - H_{\text{products}}$$

In biogas used dominant components, namely methane (CH$_4$) and Carbon dioxide (CO$_2$). By using the chemical equation of biogas combustion reaction with air, where x and y are the composition of CH4 and CO$_2$, we use the following equation to calculate the biogas heat value:

$$x\text{CH}_4 + y\text{CO}_2 + (\text{O}_2 + \text{N}_2) \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{N}_2$$

**Figure 2.** There was a flame on the Bunsen burner: a).bunsen burner; b).measuring the color of flame

Flame testing can be used to determine fuel quality. In this study, flame testing was used as a bunsen burner as shown in Figure 2 (a). The flame burned on the bunsen burner is recorded with a Fujifilm camera with a resolution of 1280 x 720. The obtained flame is then cut into several images and each image is taken sample data at some point to analyze the percentage of flame color as shown in Figure 2 (b) by using application software, so that the resulting flame color distribution that can be compared between the flame color red and blue.

**Figure 3.** Schematic of ion sensor in HSC
The magnitude of the resulting voltage of flame indicating the presence of ions on flame is measured with an sensor ion made of 2 pieces of aluminum foil with a width of 1 cm and a length of 30 cm, which is placed opposite the Hele Shaw Cell (HSC) at a distance of 1 cm to capture the signal of the ion occurring during The combustion reaction process takes place. The ion sensor scheme is shown in Figure 3.

In Figure 3 it is shown that an aluminum foil ion sensor is connected to an adapter as a current source, a resistor and a cable connected to a laptop that will read and record the voltage generated by flame at biogas combustion in HSC. To know the amount of voltage generated by the flame, used multi-instrument instrument sound virtin. In the application disetting 50x magnification calibration on probe 2 to know the voltage generated by burning ionization. After generating the graph, the voltage is taken the highest value for the data of the ionization voltage of the burning.

3. Experimental Results
A study of the biogas thermal characteristics of coffee leather has been done by purification using KOH 1 M and 4 M with thermal parameters including carbon dioxide, heating, flame, and ionization on biogas flame. The results of the research are biogas composition data, heating value, flame, flame color, and ion sensors are shown in Table 1-4. Biogas from coffee skin waste produced in this study contains 37.23% CO₂, so the content of methane and other impurities around 62.77%. CO₂ content decreased, after biogas was purified with KOH 1 M to about 23.01% and decreased again to 18.66% after being purified with KOH 4 M. These results are shown in Table 1.

| Biogas Condition | CO₂ (%) | CH₄ + Impurities (%) |
|------------------|---------|----------------------|
| Not yet purified | 37.22   | 62.77                |
| Purification 1 M | 23.01   | 76.99                |
| Purification 4 M | 18.66   | 81.34                |

The content of carbon dioxide in biogas affects the calorific value¹⁴, as shown in Table 2, where the table shows the biogas heat values before purification and after purification. Biogas before purification that still contains high carbon dioxide, average calorific value is low enough that only reach 21,670.47 kJ / kg. The decrease of carbon dioxide after purification caused increased heating value, named at 1M KOH purification, the calorific value to 27,585.30 kJ / kg and on KOH purification of 4M calorific value to 29,765.56 kJ / kg. This calorific value will increase with the decrease of carbon dioxide content, to close to 50,144.375 kJ / kg which is the heat value of pure Methane (CH₄)¹⁵.

| Biogas Condition | Low Heating Value – LH (kJ/kg) |
|------------------|-----------------------------|
|                  | data 1 | data 2 | data 3 | Average |
| Not yet purified | 21775  | 22358  | 20876  | 21670   |
| Purification 1 M | 25431  | 28798  | 28526  | 27585   |
| Purification 4 M | 29547  | 30330  | 29418  | 29765   |

Flame is a combustion chemical reaction. Burning is influenced by fuel quality. Carbon dioxide in gas fuel acts as an inhibitor⁶,¹⁶. One of the parameters that determine the quality of combustion is the flame color¹¹. Carbon dioxide content can be analyzed from flame characteristics including flame color and ionization of biogas flame combustion.
Table 3. Percentage of Biogas Flame Color Percentage

| Testing number | Biogas Condition | Percentage of Flame Color (%) | Blue Flame | Red Flame |
|----------------|------------------|-------------------------------|------------|-----------|
| 1              | Not yet purified | 57.67                         | 42.33      | 28.21     |
|                | Purification 1 M | 71.79                         | 28.21      | 28.21     |
|                | Purification 4 M | 68.81                         | 39.19      | 39.19     |
| 2              | Not yet purified | 63.50                        | 36.50      | 36.50     |
|                | Purification 1 M | 70.47                        | 29.53      | 29.53     |
|                | Purification 4 M | 70.39                        | 29.61      | 29.61     |
| 3              | Not yet purified | 60.40                        | 39.60      | 39.60     |
|                | Purification 1 M | 71.12                        | 28.88      | 28.88     |
|                | Purification 4 M | 75.86                        | 24.14      | 24.14     |
| 4              | Not yet purified | 74.28                        | 35.72      | 35.72     |
|                | Purification 1 M | 70.20                        | 29.80      | 29.80     |
|                | Purification 4 M | 71.12                        | 28.88      | 28.88     |
| 5              | Not yet purified | 54.96                        | 45.04      | 45.04     |
|                | Purification 1 M | 68.93                        | 31.07      | 31.07     |
|                | Purification 4 M | 70.20                        | 29.80      | 29.80     |
| Average        | Not yet purified | 60.16                        | 39.84      | 39.84     |
|                | Purification 1 M | 70.50                        | 29.50      | 29.50     |
|                | Purification 4 M | 71.28                        | 30.32      | 30.32     |

Table 4. Ion Sensor Test Results on Biogas Flame

| Biogas Condition | Ion Sensors (volt) (Average) |
|------------------|-----------------------------|
| Not yet purified | 14.69                       |
| Purification 1 M | 29.18                       |
| Purification 4 M | 33.08                       |

The result of the research has been done that the flame color in three conditions is before purification, after purification KOH 1M and after purification KOH 4 M as shown in Figure 4.

![Figure 4. Examples of Biogas flame: Before purification (a) Purification 1 M (b) and 4M (c)](image-url)
The picture shows the flame color biogas with three repetitions. In Figure 4.a seen flame biogas before purification, where the flame color is dominated by blue, but the top looks reddish color. From the calculation of the percentage of flame color on the three colors, the average flame blue color on flame before purification is reached 60.16% and the red color is high enough that is 39.84% as shown in Table 2. After purification on biogas, color The flame is shown in Figures 4.b and 4.c. Figure 4.b shows the biogas flame with 1M KOH purification, from which the red flame color looks very little on the inside of the flame and decreases in flame with KOH 4M purification indicated by the percentage of flame color with the percentage Red is 29.5% lower (at 1M KOH purification) and 28.75% (on KOH 4M purification). From this result shows the decrease of CO₂ content in the flame causes the combustion reaction to be better indicated by increasingly dominant blue color and decreasing the percentage of red color.

This result is reinforced by the result of the combustion ion, where in the biogas flame before purification where, when the red color is close to 50% (Table 2), the combustion ion shown with the average resulting voltage is about 14.79 volts (Table 3). In biogas flame after KOH 1 M purification, the voltage increased from 14.69 volts to 29.18 volts and in KOH 4 M purification increasing again to 33.08 volts. This shows that flame with high CO₂ content causes the combustion reaction to decrease due to collisions of fuel molecules inhibited by CO₂, causes the number of ions to decrease as indicated by the decrease of the voltage on the flame. When CO₂ decreases, collisions occur more frequently so that more and more ions are formed due to the larger combustion reaction as indicated by the higher voltage on the ion sensor.

4. Conclusion
Research on thermal characteristics of biogas flame with coffee leather waste with KOH 1M and 4M purification, with the result:

1. Purification KOH quite effectively reduce the carbon dioxide content in biogas, from 37% decreased to 18%.
2. The content of carbon dioxide determines the calorific value of biogas, where the higher the carbon dioxide content the lower the biogas heat value, and vice versa.
3. The quality of biogas fuel can be seen from the testing of flame, where on flame with high calorific value of low carbon dioxide content, the percentage of blue flame color is more dominant. This percentage increases with increasing calorific value.
4. Flame is a chemical reaction, resulting in an ion in a flame capable of conducting electrical current. The greater the combustion reaction, the more ions are formed, so the flow that flows is also higher which is indicated by the voltage captured by the ion sensor is greater.
5. The flame color and voltage of the ion sensor can be used as a parameter to determine the quality of the flame.

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