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Effect of Combustion Air Flow Rate on Syngas Product in Updraft Gasifier System with Bamboo Charcoal Feedstock

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ABSTRACT

The potential utilization of biomass gas generation as an alternative to petroleum has attracted attention in Indonesia. One type of biomass that can be utilized as an energy source is bamboo. Bamboo is a group of plants that have the ability to absorb high amounts of CO_2, thus bamboo can be used as an effective plant in reducing the increase in carbon emissions in the atmosphere and also as a substitute for diesel and gasoline in power plants. One of the methods used in such processing is gasification technology. Gasification is the process of converting solid fuels into combustible gases, such as CO, CH_4, and H_2. In this study, an updraft gasification system was carried out using 5 kg of bamboo charcoal raw material with variations in the combustion air flow rate of 2 m/s, 3 m/s, 4 m/s, 5 m/s, and 6 m/s. The results showed that the highest syngas composition was obtained in the variation of the combustion air flow rate of 6 m/s, namely CH_4 22%, CO 0,17%, CO_2 0,26%, and H_2 0,12% with a heating value of 7925.32 kJ / kg and a thermal efficiency of 28,67%.

Keywords: *Biomass, Gasification, Bamboo Charcoal*

1. INTRODUCTION

Biomass is a renewable energy source that is abundantly available in Indonesia. Various types of biomass such as wood, wood processing residues, sawdust, rice husks, coconut shells, palm shells, coconut fibers, palm fibers, corn cobs, bagasse, and bamboo [1]. Can be utilized as energy sources. These biomasses are generally widely available in various parts of Indonesia. However, the lack of information on how to properly utilize biomass to produce energy has caused this biomass potential to be underutilized.

Biomass utilization technology to produce energy can be done through various processes, one of which is a thermochemical process, namely gasification. Gasification is the process of converting solid fuels into gases that can be used as fuel (CO, CH4, and H_2) through a combustion process with a limited air supply (20% - 40% stoichiometric air). The gasification process is a chemical process to convert carbon-containing materials into gases that can be used as fuel. In this definition, the fuel used for the gasification process uses hydrocarbon-containing materials such as coal, petcoke (petroleum coke), and biomass. The gasification process occurs in a gasification reactor called a gasifier. In this gasifier there is a heating process with a certain reaction temperature then the fuel used undergoes a combustion process reacting with oxygen to produce gas fuel and other combustion residues [2]. Gasification consists of three types, namely Downdraft Gasifier, Updraft Gasifier, and Crossdraft Gasifier. Downdraft Gasifier is a gasification method where the biomass and gasification airflow move in the same direction downward towards the fuel layer.

Updraft Gasifier is a gasification method where the air flow direction enters from below and the gas exits from above. And Crossdraft Gasifier is a method where the reactor with layers moves in the same direction where fuel is supplied from the top and air is injected from the side through the nozzle. One of the advantages of gasification technology over other technologies is its high efficiency and low pollution [3].The gasification process has four stages: drying, pyrolysis, combustion (oxidation) and gasification (reduction).

Drying Process

The drying process is carried out to reduce the moisture content contained in the raw materials. The temperature in this process is between 100-200°C. The moisture content in the feedstock is removed through a convection process because heating occurs in the reactor and the relatively low humidity of the moving air allows the loss of water content in the feedstock. The higher the heating temperature, the faster the diffusion process of water vapor contained in the raw material and the faster the drying process [4].

Pyrolysis Process

Pyrolysis is proocess that breaks down the structure of fuel using a small amount of oxygen into gas through heating. The pyrolysis process takes place in a reator at temperature between 250 °C-500 °C. The pyrolysis produces product such as charcoal or carbon, tar, and gas. If the tempetarute in the pyrolysis zone is low, a large amount of charcoal and some liquids (water, hydrocarbons, tar) will be produced. On the contrary, high pyrolysis temperature produces little charcoal but contains more liquid. Systematically, the pyrolysis process will produce reactions such as:

Raw materials $\longrightarrow H_2 + CO + CO_2 + CH_4 + H_2O$ + Tar [5]

Oxidation Process

Oxidation is the most important reaction in a gasification reactor as it provides all the heat and energy. The oxygen supplied to the reactor reacts with the combustible material to produce products in the form of CO_2 and H_2O, which continue to be reduced when in contact with the char produced in the pyrolysis process. Occurs at temperatures of 1000 - 1200°C.

Reduction Process

The reduction process is a heat absorption reaction (endothermic). During this process, several chemical reactions occur. These include Bourdouard reaction, water-carbon vapor reaction, water-gas shift reaction, and methaneation of CO. It is an important process for forming compounds. Compounds are useful in producing combustible gases such as hydrogen and carbon monixide. This process takes place in the temperature range of 400°C to 900 °C [6]. According to the literature, the following chemical reactions occur in this zone:

- *Bourdouar reaction* : $C + CO_2 = 2CO$ [5]
- *Steam-carbon reaction* : $CO + H_2O = CO_2 + H_2$ [5]
- *Water-gas shift reaction* : $C + H_2O = H_2 + CO$ [5]
- *CO methanation* : $C + 2H_2 = CH_4$ [5]

It can be said that in this reduction process combustible gases such as CO, CH_4 and H_2 compounds begin to form. So this section is called a gas producer. Bamboo is one of the plants that is often used for fuel which has the following characteristics seen in Table 1.

Table 1 Characteristics Bamboo [6]

Characteristics	Percentage %
Moisture Content	2,87
Ash Content	6,65
Volatile Matter	14,64
Carbon	78,71

Source: Hastuti et al, 2015

One of the most popular products from processed bamboo is activated carbon. Bamboo activated carbon has many advantages including high hardness and easy handling. The constituent components of bamboo can be see in Table 2. Which is known by using ultimate analysis.

Table 2. Component of Bamboo [6]

Component	Percentage %
C	45,7
H	4,3
O	49,7
N	0,3

Source: Hastuti et al, 2015

There are several chemical components contained in bamboo which can be see in Table 3.

Table 3. Chemical Component of Bamboo [6]

Component	Percentage %
Hemi Selulosa	21,05
Lignin	19,56
Selulosa	43,14

Source: Hastuti et al, 2015

Bamboo charcoal can be formed into briquettes or pellets through a compression process. The conversion of bamboo into charcoal occurs through the process of pyrolysis (heating). During the pyrolysis process, non-carbon elements such as hydrogen (H) and oxygen (O) are lost, leaving as much carbon (C) in the material as possible, this event is called carbonization.

Charcoal produces a large amount of residual carbon and increases ash content but not as much as carbon. Other important changes are the removal of moisture and the reduction of volatile components. Bamboo charcoal has a lot of carbon content so it has good potential to be used as a fuel or feedstock in the gasification process.

2. MATERIAL AND METHODS

The materials and methods used in this study are as follows:

2.1. Materials and Tools

The materials used in this study are one experiment using 5 kg of bamboo charcoal, 3 kg of zeolite and also using glass wool.

The components of the gasifier can be seen in Figure 2.1.

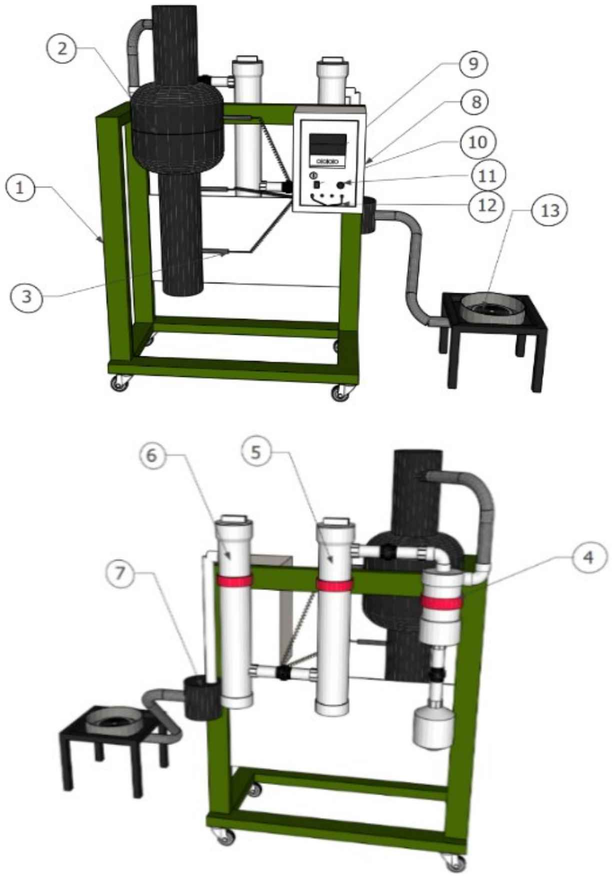

Figure 1. Gasification Equipment

Description :

1. Tool Frame
2. Reactor
3. Termokopel
4. Cyclon
5. Filter Tank I
6. Filter Tank II
7. Blower
8. Control Panel
9. Temperature Set
10. On/Off Switch
11. Blower Speed
12. Temperature
13. Stove

2.3 Methods

The parameters observed in this study were the effect of combustion air velocity on the production of syngas produced in the updraft gasification system. The variables reviewed consist of fixed variables, independent variables and dependent variables.

In this experiment, the fixed variable is the mass of raw material is 5 kg, the independent variable is the combustion air flow rate of 2 m/s, 3 m/s, 4 m/s, 5 m/s, and 6 m/s while the dependent variable is syngas temperature, syngas velocity and also syngas LHV.

The data collection process is carried out in the following ways The first data collection process puts 5 kg of raw material into the gasification reactor then the top of the reactor makes sure the lid is closed again, turns on the blower with maximum capacity, burns with a flame igniter on the input air to start the combustion process. Adjust the blower speed according to the desired parameters, wait 10 minutes until the raw material becomes coals, ignited on the stove so that the flame is obtained. Open the syngas output valve and the syngas is collected using a urine bag to take a sample then the valve is closed again. When the fire on the stove has died, then turn off the blower, close the reactor inlet air valve, ensure the reactor temperature is the same as room temperature.

In this updraft gasification system experiment, raw material analysis was carried out, namely calorific value analysis, syngas analysis, proximate analysis at Polytechnic of Sriwijaya State and also ultimate analysis at PT Geoservice Palembang.

3. RESULTS AND DISCUSSIONS

This study was conducted using an updraft gasification system with 5 kg of bamboo charcoal as raw material for each run. This study aims to analyze the effect of combustion air flow rate on syngas production, syngas calorific value, and thermal efficiency. Variations in the combustion air flow rate in this study are 2 m/s, 3 m/s, 4 m/s, 5 m/s, and 6 m/s. The following research results and analysis of the gasification process can be seen in Figure 3 until Figure 7.

3.1. Effect of Combustion Air Flow Rate on Product

Syngas composition in Figure 3. and Figure 4**.** shows that the reactor combustion air flow rate affects the composition of the syngas produced. The resulting syngas composition consists of CO, CO_2, CH_4, and H_2. At a combustion air flow rate of 2 m/s will produce the least syngas composition of 18% CH4, 0,20% CO, 0,27% CO_2, and 0,10% H_2. While the combustion air flow rate of 6 m/s produces the most syngas composition, namely with a composition of 22% CH_4, 0.17% CO, 0,26% CO_2, and 0.12% H_2.

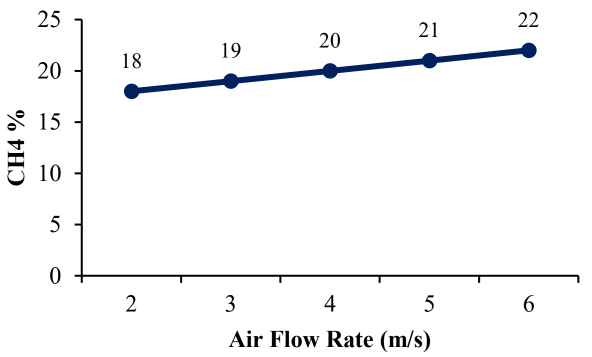

Figure 3. Effect of Combustion Air Flow Rate on CH_4 Content

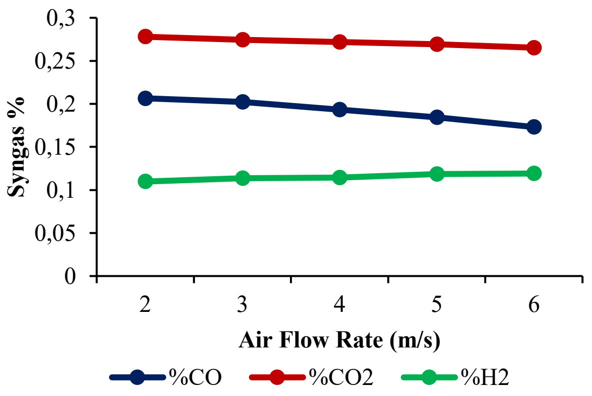

Figure 4. Effect of Combustion Air Flow Rate on CO, CO_2, dan H_2

The gasification process is an endothermic reaction so it can be concluded that the increase in flow rate affects the increase in syngas composition. The results obtained in this study are in line with research [7]. That increasing the combustion air flow rate causes an increase in endothermic reactions, namely boudouard reaction and water gas reaction where at high combustion air flow rates the resulting syngas is high because carbon tends to react with carbon dioxide and water vapor. This reaction results in increased H_2 and decreased CO_2. At high combustion air velocities the carbon consumption is high thus increasing the methanion reaction to form CH_4. Carbon will react with hydrogen to form methane.

CO gas is a combustible gas because it has a high enthalpy so that it can burn with oxygen, but CO gas is also a gas that results from incomplete combustion. CO_2 gas decreases with each increase in the combustion air flow rate variation and CO_2 gets higher at low combustion air flow rates. Based on Figure 4. the content of CO and CO_2 in syngas has decreased due to the adsorption process by the use of filters, because CO and CO_2 gases have a heavier mass than other gases so they are absorbed in the filter.

In addition, the heating value and moisture contained in bamboo charcoal also affect the composition of the syngas produced. Raw materials with high heating values prove that more solids can be converted to form syngas. Low moisture with high gasification combustion air velocity can increase H_2O production so that the reaction of H_2 and CH_4 formation increases [8]. Selection of bamboo charcoal raw materials because bamboo after the furnace has a low moisture content and high calorific value.and high calorific value

The connection between combustion air flow rate and syngas production aims to determine the optimal combustion air flow rate for improving syngas quality and producing the optimal heating value of syngas. Combustion air flow rate can improve carbon conversion and syngas quality.

3.2. Effect of Combustion Air Flow Rate on Calorific Value (LHV) *Syngas*

The results of the calculation of the calorific value in Figure 5. show that the calorific value of syngas increases as the gasification combustion air flow rate increases. Based on the heating value obtained at a combustion air flow rate of 6 m / s, the highest heating value was 7925.32 kJ / kg. Whereas the lowest combustion air flow rate of 2 m / s produced the lowest heating value as well at 6494.90 kJ / kg. The heating value (LHV) of syngas was obtained in this study by transferring the composition of the fuel (CH_4, CO, and H_2) with the Heating Value of each component.

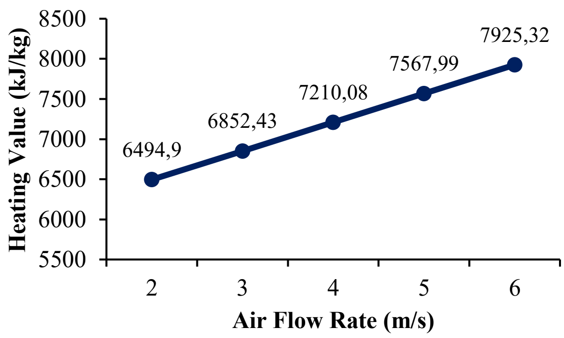

Figure 5. Effect of Combustion Air Flow Rate on Syngas LHV

Based on Figure 5. it can be concluded that the higher the combustion air flow rate in the gasifier, the higher the heating value (LHV) of the syngas produced. The LHV is influenced by the value of the syngas composition in the combustible gas, namely the content of CH_4, CO, and H_2. The greater the volume of syngas produced, the greater the LHV of syngas [9]. The results in this study are the same as research [10] that improving the quality of syngas will increase the LHV value of syngas.

3.3. Effect of Combustion Air Flow Rate on Thermal Efficiency

The results of the calculation of thermal efficiency in Figure 6. increased consistently along with the increase in combustion air flow rate ranging from 2 m/s to 6 m/s. The highest thermal efficiency is at 6 m/s combustion air flow rate with a thermal efficiency value of 28,67% while the lowest thermal efficiency is 23,50% at 2 m/s combustion air flow rate. Based on the value of thermal efficiency obtained, the higher the combustion air flow rate, the higher the thermal efficiency obtained. Thermal efficiency is obtained by the calorific value (LHV) of syngas divided by the calorific value (LHV) of raw materials.

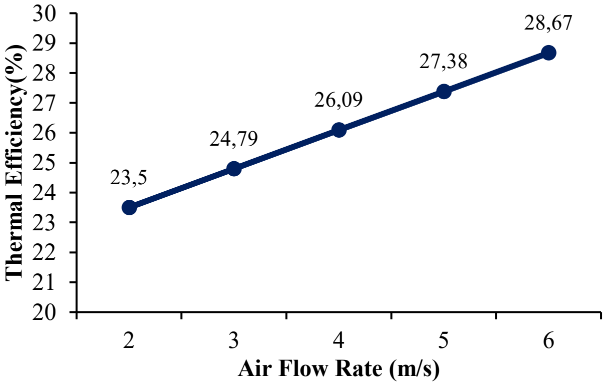

Figure 6. Effect of Combustion Air Flow Rate on Thermal Efficiency

High thermal efficiency is influenced by the heating value of the syngas produced. The better synas produced then the calorific value of syngas will also be higher. Conversely, the lower causes low thermal efficiency obtained. Variation of combustion air flow rate affects the heating value of syngas produced.

The connection between combustion air flow rate and thermal efficiency aims to find out what the optimal combustion air flow rate is to produce optimum thermal efficiency. The heigher the combustion air flow rate in the gasifier, the higher the thermal efficiency. Conversely, the lower the combustion air flow rate of the gasifier, the lower the thermal efficiency.

3.4. Effect of Combustion Air Flow Rate on Duration of Boiling Water

Based on Figure 7. variations in the combustion air flow rate affect the length of the flame produced in the gasification process. Based on the length of the flame obtained, it can be concluded that the higher the combustion air flow rate, the greater the fire produced. Indicates that at a high combustion air flow rate of 6 m / s will produce a large flame so that the time to boil 1 liter of water is faster for 5,05 minutes, while at a low combustion air flow rate of 2 m / s produces a small flame so that the time to boil 1 liter of water for 8 minutes.

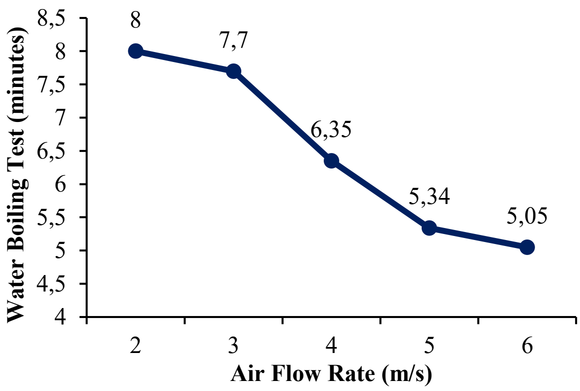

Figure 7. Effect of Combustion Air Flow Rate on Duration of Boiling Water

The flame length is faster at low combustion air flow rates. The length of the flame is calculated when the combustion air flow rate has reached the varied, because the high combustion air flow rate the reactions that occur in the gasification process and the combustion reaction reactions will increase. This increase causes the fuel to burn faster and produce combustible gas so that if the combustible gas has formed, the fire will ignite. The surrounding air also affects the length of the flame so that the flame will die when exposed to wind from the surrounding environment.

4. CONCLUSIONS

Based on the research and testing that has been done, it can be concluded that variations in the combustion air flow rate affect the production of syngas produced. The higher the gasification combustion air flow rate used will increase the syngas content. This is caused by endothermic reactions that are faster at high combustion air velocities. The highest syngas composition at a combustion air flow rate of 6 m / s with a composition of CH_4 22%, CO 0,17%, CO_2 0,26%, and H_2 0,12% the lowest syngas composition is CH_4 18%, CO 0,20%, CO_2 0,27%, and H_2 0,10%.

The heating value produced is influenced by the composition of the syngas. The higher the CH4 and H2 values produced, the higher the heating value of the syngas produced. The highest heating value is produced at a combustion air flow rate of 6 m/s amounting to 7925.32 kJ/kg and the lowest heating value is produced at an air velocity of 2 m/s amounting to 6494.90 kJ/kg. The highest thermal efficiency is shown at 6 m/s combustion air flow rate of 28.67% and the lowest at 2 m/s combustion air flow rate of 23.50%. This means that the gasification combustion air flow rate affects thermal efficiency.

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