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Water Scrubber and Zeolite Catalyst for Clean Syngas Production on Biomass Gasification of Bagasse in a Downdraft System

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Abstract

Biomass gasification is one solution that can overcome Indonesia's energy crisis. Indonesia is an agricultural country that has a lot of sources of biomass. This work was focused on clean syngas production with purifying process through a water scrubber and zeolite catalyst as a filter. The syngas was produced from bagasse gasification as solid waste from a sugar factory. The weight of bagasse feedstock was studied on 1000 g, 1500 g, 2000 g, 2500 g, and 3000 g. The influence of burning time and syngas composition were also studied on syngas production. The experiment result showed that the burning time of syngas is related to the amount of bagasse; the higher the bagasse, the longer the burning time. The syngas composition from the gasification process was investigated, and it was found that CO, CH_4, and H_2 were percentages of 9.294%, 1.348%, and 2.773%, respectively. The water scrubber and zeolite catalyst can affect the cleanness of the syngas.

INTRODUCTION

Biomass is one type of renewable energy that is attracting the attention of today's society due to the availability of abundant raw material, low pollution, low sulfur, and low carbon dioxide. Biomass from agriculture waste is large in Indonesia as bagasse which becomes an advantage to develop as renewable energy. According to The Ministry of Agriculture, sugarcane production was 33 million tons annually. It is assumed that the bagasse percentage is about 30-40%, so the sugar factory in Indonesia can produce bagasse of about 9.90-11.22 million tons per year (Anukam et al., 2016). The properties of bagasse consist of 55-60% fiber, 20-35% pith, and 10-15% soil (Bridgwater, 2013). The chemical properties of bagasse included 46-47% cellulose, 24-26% pentose, 20-21% lignin, and 10-15% other elements. Bagasse has a heating value of 7.600 KJ/Kg with a water content of 50%. Bagasse has a fiber length of 1.7-2 mm and an average diameter of 20 micrometers. It also contained lignocellulose and was suitable for gasification feedstock.

Bagasse is one of the biomasses that can be used as a material in syngas production. The physical properties of sugarcane bagasse were reported by previous research (Kumar et al., 2010) in Table 1.

Bagasse is biomass that can be converted into energy through gasification, pyrolysis, torrefaction, and combustion (Oasmaa & Peacocke, 2010). The energy can be gas or fuel for turbine, engine, synthesis, and boiler (Herman et al., 2016). Most bagasse has been utilized for energy production. A previous study shows that fuel production from sugarcane bagasse is through torrefaction. Torrefaction is the slow heating of biomass in an inert or oxygen-deficit environment in the temperature range of 200–300 °C. The process was conducted in a downdraft system and pyrolysis with a circulating fluidized bed reactor

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Table 1. The physical properties of bagasse

Component	**Values**
Bulk density	80.49 kg/m^3
Porosity	38.50%
Heating value (ASTM D240)	18.728 kJ/kg
Proximate analysis (Shimadzu TGA50):	
• Volatile matter content	59.20 %wt
• Fixed carbon content	10.45 %wt
• Ash content	20.63 %wt
• Moisture content	9.72 %wt
Elemental analysis (Parking Elmer PE2400)	
• C	45.85%
• H	6.63%
• N	0.34%
• O	47.18%

(Bridgwater & Peacocke, 2000). The gasification process converts the solid or liquid component to a gas product used as biomass or power generator fuel (Patel et al., 2011). Those processes consist of heterogenous reactions that arise along direct combustion. It affected syngas production is converted rapidly (Blasi, 2000). The gasification process is initially followed by the drying process of bagasse feedstocks (Statistik, 2017). Dried bagasse is then directly burned into the furnace. The combustion process occurs in the presence of surrounding air. Finally, the final products contain fuel from pyrolysis and gaseous from gasification processes (Pertanian et al., 2012). The syngas product from the combustion of biomass commonly consists of methane, carbon dioxide, carbon monoxide, hydrogen, and water vapor.

The residue is formed as a co-product of the combustion reaction. The primer content of residues such as tar, ammonia, sulphite, and hydrogen chloride. Syngas can be applied as energy production from generated heat of combustion. Therefore, in its use, good syngas requires a low residue content like nitrogen and tar and has a high hydrogen content. According to a previous study (Blasi, 2000), biomass gasification was converted into gas fuel because of oxidation partial (less oxygen) from biomass at 800-900 °C. The gasification result included fewer hydrogen, carbon monoxide, methane, carbon dioxide, water vapor, and other hydrocarbons (Statistik, 2017). The syngas from the gasification process had a heating value of around 1000-1200 $kCal/Nm^3$ but more efficiency for burning and less carbon emission. Every kilogram of biomass with a water content of ± 10% contains around 2.3 m^3 gas fuel, and the gasification efficiency is about 60-70%.

The gasification unit is classified into three parts based on the flow direction. Firstly, updraft gasification with the flow direction of solids and exhaust gases in the opposite direction. This type is suitable for charcoal or biomass, which is difficult to convert into a gas (Erlich & Fransson, 2011). The second is downdraft gasification, in which the flow direction between solids and exhaust gases is one way. This type is not suitable for materials with high water content. However, this type provides cleaner syngas and simplifies the process (Chum & Overend, 2001). The third is cross-draft gasification, in which the flow direction between solids and exhaust gases crosses each other. Downdraft gasifier ensures that syngas contains only a few particulates and tar (Ahmed & Gupta, 2012).

The focus of the gasification process is the production of syngas without the presence of tar as residue or unwanted gas. Hence, producing clean syngas is possible by using a catalyst as a filter or adsorbent. As reported in previous studies that dolomite, nickel, and olivine have the potential to improve syngas quality (de Diego et al., 2016). In addition, tar content reduction can be achieved by filtration using tire char (Maryudi et al., 2018) or a hot wax filter catalyst (Treedet & Suntivarakorn, 2017). The increase in syngas production can also be carried out using metal catalysts (McKendry, 2002). Based on several previous studies, there has been no improvement in the production and quality of syngas, and no one uses a water scrubber and zeolite catalyst filter to improve syngas quality. The

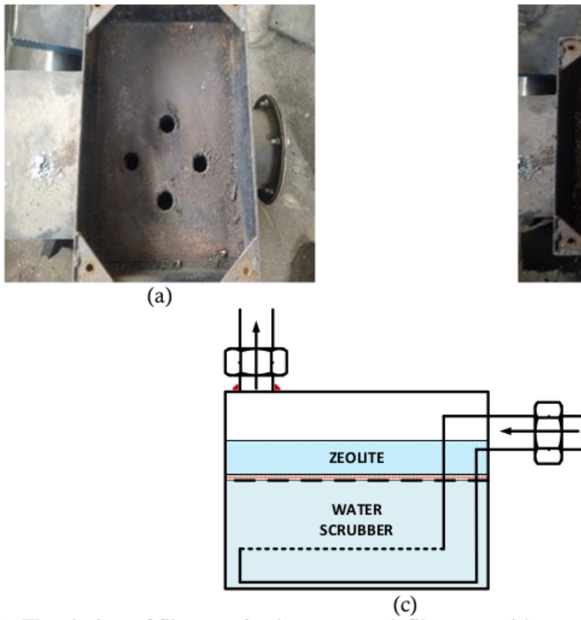

Figure 1. The design of filter gas in the system, a) filter gas without zeolite catalyst, b) Filter gas with zeolite catalyst, c) Design of filter.

exhaust gas flowed through the water scrubber to remove tar content as a by-product of syngas production. The syngas is also purified in the zeolite catalyst filter. This research focuses on producing syngas with a zeolite catalyst filter and water scrubber. GCMS then characterizes the clean syngas.

MATERIALS AND METHODS

Materials

The materials used in the research are bagasse as biomass material, wood charcoal, and zeolite catalyst as a filter (Surface area= 48,266 m^2/g, Pore diameter= 35,933 Å). The bagasse was obtained from the Sugar Factory of Madukismo, Yogyakarta, Indonesia. A drying process is required for bagasse to reduce water content. Then, a size reduction process was applied to the bagasse to reduce its size to 2-4 cm. The combustion process was initiated by wood charcoal in the gasifier unit. The filter consists of a zeolite catalyst to clean the impurities of the output syngas.

Methods

The research equipment incorporated a downdraft gasifier, water scrubber, zeolite filter, and blower. The oxidation process between bagasse and oxygen was conducted in a gasification reactor. The blower supported the gas flowrate. The gasifier can quickly burn the bagasse up to 15 kg/hr. The specification of the gasifier is 170 cm in height and 50 cm in inner diameter. The scrubber contained about two liters of water to purify the syngas from tars. In addition, the purification process is also carried out in a filter containing a zeolite catalyst. Syngas entered the filter through four connected holes and then was contacted with a zeolite catalyst. In the upper of the holes, there is a zeolite catalyst as a filter. A blower sucked the syngas flow with gas indicators to observe the gasification system. Clean syngas was characterized using a GCMS analyzer. The design of the filter gas is shown in Figure 1.

The research involved three primary steps that run in gasification unit shown in Figure 2: preparation of bagasse, gasification process, and characterization of syngas. Firstly, bagasse was prepared through a drying process under sunlight to minimize the water content by up to 25%. Blazing charcoal is also prepared and followed by thermocouple and gas indicator installation. Secondly, the gasification process was conducted with the variation of bagasse feedstock. The weight of bagasse used in the research is 1000 g, 1500 g, 2000 g, 2500 g, and 3000 g. The required oxygen for the gasification process was supplied by sucking the

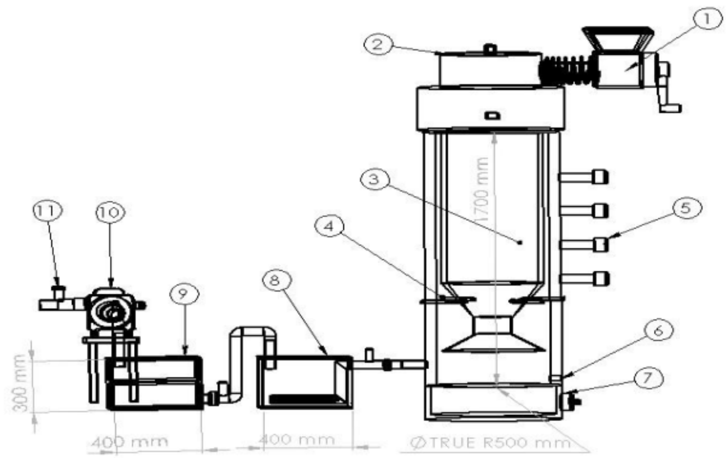

Figure 2. Equipment of gasification. (1) Screw feeder; (2) Cover reactor; (3) Reactor gasification; (4) Supply oxygen; (5) Thermocouple; (6) Shaker; (7) Output wood-charcoal; (8) Filter gas; (9) Water scrubber; (10) Blower; (11) Gas indicator.

surrounding air using a blower into the gasifier. A thermocouple along the gasification process monitored the actual temperature.

Thirdly, the syngas sample as the product of the gasification process was taken using a vacuum tube during the gasification process. The sample was taken in triplicates in different positions. The composition of syngas was then characterized by GCMS analysis to get the amount of CO, CH_4, and H_2. The final step of the gasification process is combustion experiments on syngas products. The exit of clean syngas is ignited using flame matches, and the ignition time is recorded. Residual or ash as a co-product of the combustion was then weighed.

RESULTS AND DISCUSSION

The Effect of Bagasse Weight on Syngas Production

Burning bagasse in the gasification reactor can produce gas and tar. When the gas can burn using the fire, it is shown that syngas come out of the gasification reactor. The effect of bagasse weight on syngas production was conducted in the experiment. The influence of bagasse weight on syngas production can be seen in Figure 3.

Based on the results, the sequentially produced syngas was 679 g, 1209 g, 1404 g, 1763 g, and 2038 g on the bagasse weight of 1000 g to 3000 g (it can be 0.679 kg/kg – 0.806 kg/kg). It found that the amount of syngas production increased with the amount of bagasse because cellulose content in the bagasse is proportional to the conversion of syngas production. That result has the same as previous research that did the gasification of tamarind (A. Aktawan et al., 2019), sengon sawdust (Maryudi et al., 2020), oil palm shell (Aktawan, et al., 2020), and coconut wood sawdust (Aktawan, et al., 2020). Based on our experiment, syngas production has half amount than in previous research (Belgiorno et al., 2003). They experimented with gasification from wood, EFB, and bagasse with syngas of about 1.6 m^3/kg – 1.8 m^3/kg (if it converts using syngas density 0.95 kg/m^3, it becomes 1.52 kg/m^3 – 1.71 kg/m^3). It could be due to different equipment that used our research's water scrubber and filter gas.

The Effect of Bagasse Weight on Syngas Ignition Time

The experiment has conducted to study the ignition time when the syngas comes out of the gasification reactor. The weight of the bagasse used in the experiment was 1000-3000 g. The influence of bagasse weight on syngas ignition time can be seen in Figure 4. It was found that the sequentially burning time on syngas production was 1560 s, 2640 s, 3240 s, 5400 s, dan 9780 s. Based on the results, the syngas ignition time is increased with the weigher of used bagasse. The longer syngas ignition time indicates that more syngas is produced from the gasification process. According to previous research (Belgiorno et al., 2003), (Peng et al., 2017), the downdraft gasification was used for

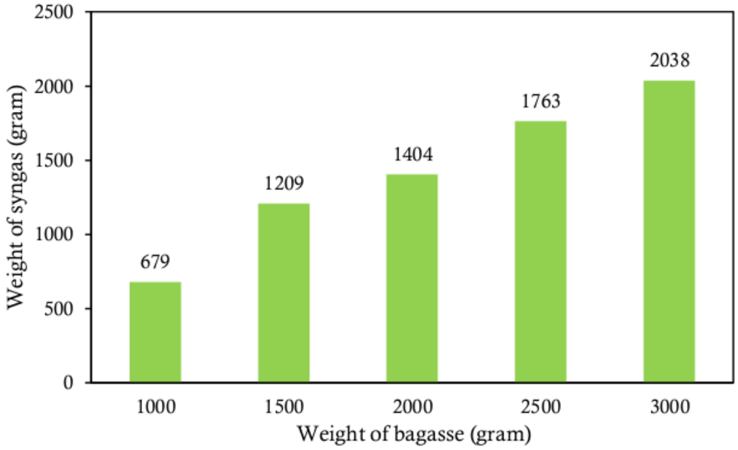

Figure 3. The correlation of bagasse weight on syngas production.

around 5-7 minutes to know the burning time of syngas production. In contrast, our experiment took longer to know the burning time because it takes time to reach steady combustion during batch gasification. Figure 4 is shown the effect of bagasse weight on the ignition time of syngas product.

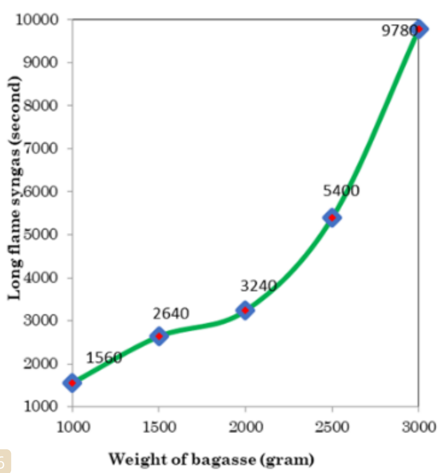

Figure 4. The effect of bagasse weight on syngas ignition time.

The Effect of Purifying Processes on Syngas Compositions

The syngas that was produced through the combustion process in the gasification reactor was then purified using a water scrubber and filtration with a zeolite catalyst. The purifying processes, such as methane, hydrogen, and carbon monoxide, were required to enhance the syngas composition. Residue or tar is undesirable present in the syngas product. Consequently, the water scrubber was installed to catch the tar content on the syngas. The composition of clean syngas in recent and previous studies can be seen in Figure 5. The most important component of syngas product is CO, H_2, CH_4, and CO_2 (Patel et al., 2011). The results of the clean syngas component have the same as previous research, and there are CO, H_2, and CH_4. The value of each component is 9.294% of CO, 1.348% of CH_4, and 2.773% of H_2. The highest content in syngas was carbon monoxide. Boudouard and steam-carbon reaction influenced the massive production of carbon monoxide. Boudouard reaction can occur if there is a reaction between carbon content in bagasse and carbon dioxide from the air. Those reactions produce carbon monoxide along the gasification process. The Boudouard reaction shows in Eq. (1) (Yan et al., 2010).

$$C + CO_2 \rightleftarrows 2CO \quad (1)$$

The second reaction is a steam-carbon reaction identical to the Boudouard reaction. As the name of the reaction, the steam-carbon reaction is a reaction between carbon and water vapor. Water vapor can be supplied from the water content in the biomass. The reaction produces not only carbon monoxide but also hydrogen is formed. The steam-carbon reaction shows in Eq. (2) (McKendry, 2002).

$$C + H_2O \rightleftarrows CO + H_2 \quad (2)$$

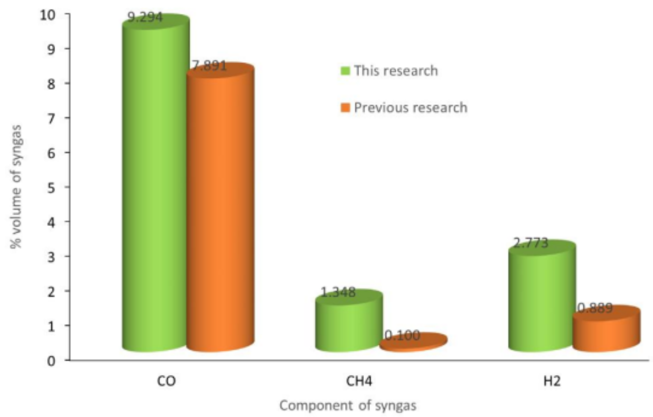

Figure 5. The composition of syngas compared to the previous study.

Another reaction between carbon monoxide and water vapor can occur, namely the water-gas shift reaction. The water-gas shift reaction shows in Eq. (3) (Yan et al., 2010).

$$CO + H_2O \rightleftarrows CO_2 + H_2 \quad (3)$$

Based on the results, there is no carbon dioxide formed. It can indicate that the water-gas shift reaction tends to the left-hand side. Consequently, more carbon monoxide was produced without the presence of carbon dioxide. Additionally, methane can be formed by reacting the carbon content in bagasse with hydrogen. The hydrogen can be supplied by steam-carbon reaction or from the airflow. Carbon content in bagasse was used in Boudouard and steam-carbon reaction. The residual carbon content in bagasse was then reacted with hydrogen to produce methane. The reaction between carbon and hydrogen shows in Eq. 4 (Yan et al., 2010).

$$C + 2H_2 \rightleftarrows CH_4 \quad (4)$$

The comparison of syngas content in the recent study and previous research can be seen in Figure 5.

Based on Figure 5, when we compare the syngas properties, the percentage of each component, such as CO 9.294%, CH_4 1.348%, and H_2 2.773% is higher than in the previous research (Innocenzi et al., 2017). It occurs because there is no water scrubber and zeolite catalyst filter installed. In the water scrubber, most tar contents were reduced through vapor cracking. The hot gas flow through the water was affected the water can evaporate slightly. Along the process, the tar content caught in the water and became condensate. The installed filter before the water scrubber aims to absorb unwanted gas like nitrogen and water vapor. It is due to the presence of nitrogen and water vapor that can reduce the heat combustion of syngas.

The Condition of The Zeolite Catalyst in The Filter Gas

Tar as the secondary product is mainly a problem in the gasification process and reduces the syngas yield TAR has a high viscosity, black color, difficult to remove, and has high molecular weight. TAR can also reduce the tool performance because TAR will be condensed below the dew point temperature, which causes blockages in the pipe. Hence, the system in this experiment used the zeolite catalyst installed in the inside filter gas. Figure 1 shows the design of filter gas. The filter section consists of four holes for gas removal and direct contact with the zeolite catalyst as a filter which is installed above the four holes. After the gas passes through the system, the zeolite catalyst as a filter changes the conditions, as shown in Figure 6. The blue color of zeolite is before running in the system, while the black-brown color in the zeolite means after running in the system. This condition is a sign that the filter gas has worked well. As discussed before, besides absorbing unwanted gas,

(a) (b)

Figure 6. The zeolite catalyst in the system (a) before running (b) after running

the presence of zeolite aims to accelerate the reaction of tar reduction. The reduction of tar and unwanted gas is indicated by the color change of the zeolite catalyst from blue to black-brown.

CONCLUSION

The amount of bagasse has influenced the syngas production and the syngas burning time that the amount of syngas production increased and the longer syngas burning time. The use of a water scrubber and zeolite catalysts as a filter has improved the syngas concentration. The clean syngas consists of CO of 9.294%, CH_4 of 1.348%, and H_2 of 2.773%. The changing color of zeolite which turns from blue into black-brown means the syngas is clean from the impurities.

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