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Syngas Production Through Non Catalytic Gasification of Empty Fruit Bunch and Catalytics Using Natural Bentonite

Atika Rahayu[1], Muhammad Faizal[2*,] David Bahrin[2]
*e-mail: muhammadfaizal@unsri.ac.id

[1]*Master Program of Chemical Engineering, Faculty of Engineering, Sriwijaya University Palembang, Indonesia*
[2]*Department of Chemical Engineering, Faculty of Engineering, Sriwijaya University Palembang, Indonesia*

ABSTRACT

The high increase in production of empty oil palm fruit bunch waste in the palm oil industry has not been utilized optimally. Empty Fruit Bunch (EFB) must be further processed with the aim of reducing pollution and increasing use value. The aim of this research is to compare syngas products using TKKS waste and using natural bentonite catalysts. Gasification is carried out at temperatures of 450, 500, 550, and 600°C. The addition of a natural bentonite catalyst to the gasification process can increase the composition and volume of the gas. In the gasification process, the higher the reaction temperature, the greater the conversion percentage produced. This is proven in the syngas product produced at a temperature of 600 °C. In non-catalytic EFB gasification, the largest concentrations of H_2 and CO were obtained, namely 21.86%vol and 11.93%vol. With the addition of natural bentonite, the concentrations of H_2 and CO increased by 27.18%vol and 14.21%vol. Gasification efficiency is seen from the optimum H_2/CO ratio value of 1.91, CG/NCG value of 5.81, CCE value of 77.07, and CGE value of 62.67. The calorific value in terms of the optimum HHV and LHV values is 11.40 MJ/Nm^3 and 10.26 MJ/Nm^3 using a bentonite catalyst. EFB catalytic gasification using a natural bentonite catalyst is better for producing high-quality synthetic gas products for the production of good environmental fuel.

Keywords: EFB, gasification, natural bentonite, energy

INTRODUCTION

Biomass is an alternative energy source that is often found in Indonesia. Indonesia has a potential of 32,654 MW of energy from biomass but its utilization is still not optimal. Biomass from the palm oil industry is one type of biomass that has not been utilized optimally.

Empty Fruit Bunch (EFB) contains *volatile matter* which is higher than the waste produced from oil palm plants, namely shells and mesocarp fiber, and has a calorific value of 19.45 MJ/Kg (Pino *et al*., 2020). Biomass with a high volatile matter content is suitable for conversion into synthesis gas and has the potential to produce high-gas products in the gasification process (Mufid, 2019). Gasification is the process of converting carbonaceous raw materials into energy in the form of combustible synthesis gas (H_2, CO_2, CH_4) with limited air, namely between 20% and 40% stoichiomeric air (Soria-Verdugo *et al.*, 2019). Synthesis gas from conversion biomass through good gasification has high H_2 and CO content with low CO_2 content (Hossain, 2018).

The reactions in the gasification process are as follows:

Water Gas Reaction
$$C + H_2O \rightarrow H_2 + CO \quad (1)$$
Boudouard Reaction
$$CO_2 + C \rightarrow 2CO \quad (2)$$
Shift Conversion
$$CO + H_2O \rightarrow CO_2 + H_2 \quad (3)$$

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Methanation

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

The gasifier's operating temperature has an impact on how well biomass is converted throughout the gasification process. High-temperature efficiency will help with tar and carbon conversion, but it will cost a lot of money and consume a lot of energy (Chen et al., 2021). In the meantime, it will result in issues with fuel conversion at low temperatures (Xie et al., 2019). Therefore, a catalyst must be added to retain high efficiency at low temperatures and reduce the amount of byproducts that are produced.

A catalyst is a material that helps to react to the tar again by lowering the operating temperature and accelerating the reaction rate (Mandal et al., 2019). The composition and volume of the gas can be increased during the gasification process by adding a catalyst in the form of bentonite (Dou, 2016). The advantages of using bentonite in gasification are its abundant availability in Indonesia and its cheap price. Also, as researched by Rabie *et al* (2018) and Ro *et al* (2019), bentonite contains SiO_2 and Al_2O_3 which can increase gas yield and conduct heat well.

MATERIALS AND METHODS

Material

The primary raw material for this study was empty oil palm fruit bunch trash, which was also combined with a catalyst and gasification medium (air and oxygen). Waste derived from empty bunches of palm oil acquired from a palm oil factory in Ogan Ilir Regency, South Sumatra. The catalyst used is natural bentonite.

Research Procedure

1. A hopper is used to introduce 2 kg of empty fruit bunch trash into the gasifier without the need for a catalyst. The valve is then closed.
2. The reactor is heated to a temperature of 450°C. The EFB gasification operating temperature is set at 450, 500, and 550,600^{o}C.
3. The reactor's bottom is where the gasification medium is introduced and uses water to cool the condenser.
4. The condensation process is carried out in a condenser using cooling water when the biomass temperature is raised to (450-600°C).
5. To provide the creation of H_2, steam is injected during the gasification process.
6. After obtaining maximum gas production from temperature, then the gasification process is repeated at that temperature using a natural bentonite catalyst.
7. The gas resulting from gasification is collected in a gas sampling bag for analysis.

RESULTS AND DISCUSSION

Characteristics of Empty Fruit Bunch

The use of empty fruit bunch waste as fuel can be seen from the findings of the preliminary and final analyses to ascertain the properties of the raw material before it is utilized in the gasification procedure. A prior study (Apriyanti, 2022) examined the proximal and final composition of empty fruit bunches about their utilization as an energy source. Quantitative measurements of the EFB's ash, fixed carbon, volatile matter, and water content are included in the proximate analysis. To characterize the energy content, this technique attempts to offer a ratio of combustible components (volatile matter and fixed carbon) to non-combustible substances (water vapor and ash). The levels of carbon, hydrogen, oxygen, nitrogen, and sulfur are included in the

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final analysis. which are useful in determining the amount of air needed for combustion.

The maximum volatile matter percentage of the empty fruit bunch, 54.13%, was determined by proximate analysis, which results in the material's potential to evaporate into product gas during gasification. The fixed carbon content of an empty fruit bunch is 21.63%, whereas the water and ash contents are 8.93% and 15.31%, respectively. The High Heating Value (HHV) that results is higher because of the high ratio of combustible to non-combustible components caused by the high quantity of volatile matter and fixed carbon. High fixed carbon and volatile matter biomass may be converted to synthesis gas and may yield a large number of gas products throughout the gasification process (Mufid, 2019). Conversely, the presence of ash can lower the High Heating Value (HHV), which in turn lowers the gas's heating value. The Gross Calorific Value or High Heating Value (HHV) obtained from EFB is 3937 Kcal/Kg or the equivalent of 16.47 MJ/kg.

The sulfur content produced is classified as very low, namely 0.06%, which will release small amounts of SO_2/SO_X, causing fewer gas emissions to the environment. The nitrogen content of 0.16% is also relatively low, causing less gas to be released, which is directly proportional to the low NO_X and SO_X formation. Because of this, empty fruit bunches are the ideal raw material for gasification that is favorable to the environment.

Effect of Temperature on Syngas Production Volume Resulting from EFB Gasification (Non Catalytic)

This study examined the syngas generated as a consequence of EFB gasification to assess the gas's quality based on its volume composition. Synthesis gas consists of four main components, namely H_2, CH_4, CO, and CO_2. As seen in Figure 1, there is an increase in synthesis gas as the temperature of the gasification process rises to between 450 and 600 °C. H_2 and CO are two of the most desired synthesis gases. As the temperature rises, the reactions of cracking and reforming cause the chemical equilibrium to change to an endothermic state. This encourages the synthesis of more intense products, which raises the concentrations of H_2 and CO. At 600 °C, the highest quantities of H_2 and CO were measured, at 21.86% vol and 11.93% vol, respectively. An increase in reaction temperature drives the hydrocarbon production process and raises the amounts of H_2 and CO (Anyaoha *et al.*, 2020). The low temperature of the gasification process then decreases slightly as the temperature increases, so that the methanation reaction is limited in forming CH_4 which tends to decrease at higher temperatures (Mardani*et al.*,2021). As more carbon is converted to CO during the Boudouard reaction process, the concentration of CO_2 continues to fall as a result of CO_2 consumption. Temperature-dependent volume composition of syngas produced by EFB gasification without a catalyst is shown in Figure 1.

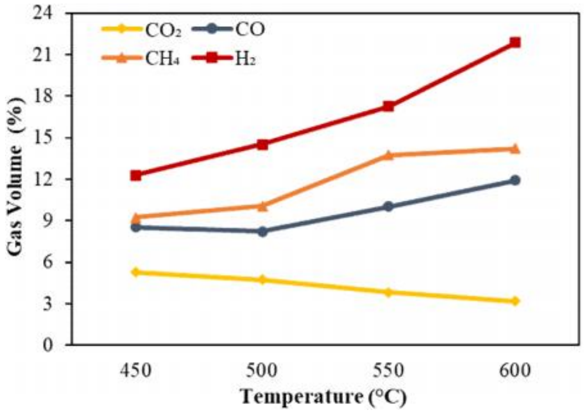

Figure 1. Temperature's impact on the amount of syngas produced by non-catalytic gasification.

The Effect of Natural Bentonite on the Volume of Syngas Results from EFB Gasification

Figure 2 displays the volume composition of syngas produced by EFB gasification with a bentonite catalyst depending on temperature changes.

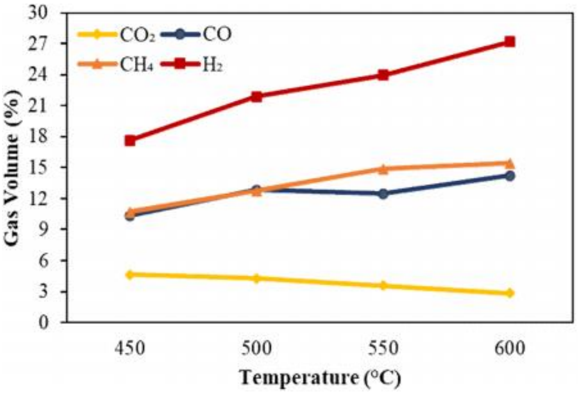

Figure 2. Impact of Bentonite Catalyst Addition on Syngas Volume Outcomes of Catalytic Gasification

The concentrations of H_2 and CO have increased in the 450–600°C temperature range as a result of the application of bentonite. Aside from that, CO_2 levels dropped as well. This is because bentonite's Si and Al concentration accelerates the pace at which complicated chemicals in EFB react to produce gas with fewer molecules. The inclusion of bentonite acid sites Al_2O_3 and SiO_2 alters the catalytic activity route of bentonite to hydrocarbon cracking (Kar *et al*., 2019). Deeper catalytic cracking is enhanced by the acid moiety of bentonite (Han *et al*., 2019).

Empty Fruit Bunch (EFB) Gasification Efficiency

Determining gasification efficiency, can be viewed through the H_2/CO ratio, combustible gas ratio (CG/NCG), Cold Gas Efficiency (CGE), and Carbon Conversion Efficiency (CCE). The utilization of syngas products in different industrial processes is determined by the H_2/CO ratio. The EFB gasification efficiency has been ascertained by both catalytic and non-catalytic EFB gasification, as seen in Figure 3-6.

Based on research, it can be observed that in non-catalytic gasification, the H_2/CO ratio is not yet stable because it decreases at a temperature of 550°C to 1.72 and increases again at a temperature of 600°C of 1.83. It can be observed that as the gasification temperature increases, the H_2/CO ratio increases. This demonstrates that at higher temperatures, the rate at which H_2 concentration increases more quickly than CO concentration results in a drop in CO concentration.

The maximum H_2/CO ratio in EFB gasification was achieved using a bentonite catalyst of 1.92 at 550°C. When employing a bentonite catalyst, the H_2/CO ratio tends to stabilize as the temperature rises. The H_2/CO ratio is a criterion for applying syngas products in several industrial processes, such as the synthesis of alcohol and aldehyde (which has an H_2/CO ratio of around 1.0) and the creation of various fuels, ammonia, and methanol (which has an H_2/CO ratio of about 2.0). This demonstrates that the use of bentonite catalyst in EFB gasification is feasible for fuel production.

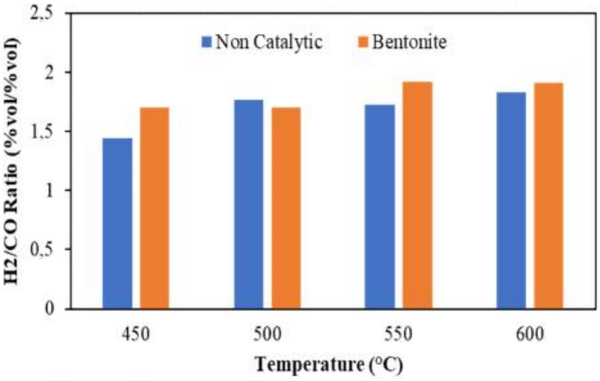

Figure 3. Temperature's Influence on Syngas Gasification's H_2/CO Ratio for Catalytic and Non Catalytic Bentonite

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Determination of efficiency can then be seen in the combustible-to-non-combustible gas ratio (CG/NCG), a measure of the syngas products' quality. The ratio of the percent (%) volume of combustible gas (H_2, CO, and CH_4) to non-combustible gas (CO_2, N_2, and O_2) may be used to compute the CG/NCG ratio based on the findings of the gas composition study. The temperature and syngas quality have a direct correlation with the CG/NCG ratio. As the temperature of gasification rises, the quality increases with a larger CG/NCG ratio. It has been demonstrated that the maximum ratio in bentonite catalytic gasification was 5.81. Figure 4 shows how temperature affects the CG/NCG ratio of syngas produced by EFB gasification.

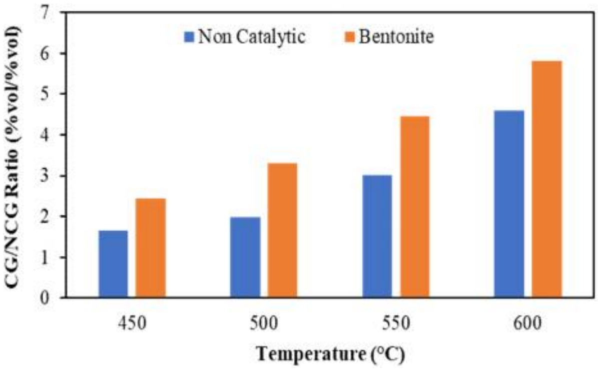

Figure 4. Temperature's Impact on the CG/NCG Ratio of Catalytic and Non-Catalytic Bentonite in Syngas Gasification

The feasibility of the gasification process can be seen from the Carbon Conversion Efficiency (CCE), which shows the fuel conversion process. When the gasification temperature and catalytic process increase, in general, the CCE value increases as in Figure 5. The steam reforming formation reaction, which in turn will increase the CCE. The temperature of the gasification reaction supports endothermic reactions like the Boudouard reaction and the Water Gas Reaction (WGS), which subsequently consume the residual carbon and raise the CCE value. In EFB gasification, the highest CCE value was 77.07 using a bentonite catalyst at a temperature of 600°C. However, in non-catalytic EFB gasification, the influence of higher temperatures can reduce carbon conversion. Observations show that the CCE value dropped to 54.63 at 500°C. This is because more H_2 is produced than CO and CO_2, which is the basis for calculating carbon conversion.

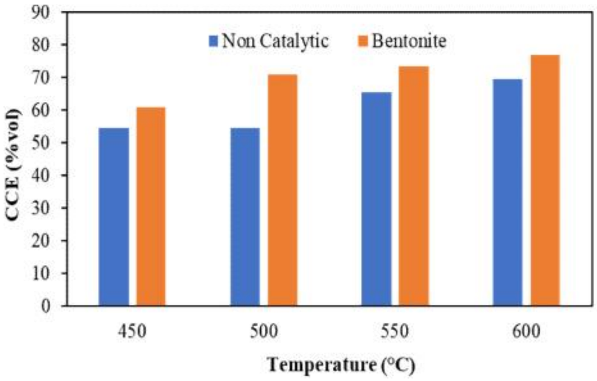

Figure 5. Temperature's Impact on Syngas Gasification Non-Catalytic Gasification Efficiency (CCE) and Catalytic Bentonite

Cold Gas Efficiency (CGE) is the ratio of synthesis gas energy to raw material energy. CGE rises in EFB gasification in proportion to catalyst usage and gasification temperature increases. The application of natural bentonite further demonstrates how the use of a catalyst dramatically raises the cold gas efficiency (CGE) value. As the catalyst ratio rises, so does the overall quantity of carbon (CGE). There appears to be a correlation between the rise in CGE and both an increase in CO_2 and an increase in H_2. CGE is also influenced by the fixed carbon concentration and volatile matter (Su et al., 2020).

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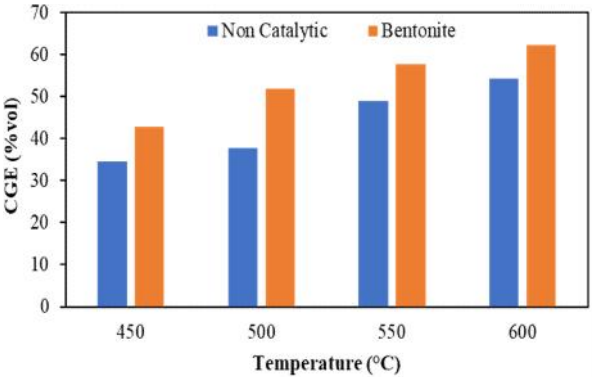

Figure 6. Temperature's Impact on Gasification Efficiency (GGE) of Non Catalytic and Catalytic Bentonite EFB Gasification

Calorific Value of EFB Syngas Gasification

The high heating value (HHV) and low heating value (LHV) can be used to determine the heating value of gasification syngas products. According to the ideal HHV and LHV values, the heating value is 11.40 MJ/Nm^3 and 10.26 MJ/Nm^3, respectively using a bentonite catalyst which is shown in Figure 7-8.

The heating value is increased by tar cracking and hydrocarbon reformation processes. The reactivity of the water gas reaction may be increased by the reaction temperature, which can speed up the generation of CO and H_2. The heating value of the synthesis gas will rise in tandem with an increase in the reaction temperature. Some of the elements that affect the quality of the gas generated include the gasification agents, process parameters, and chemical characteristics of the raw materials. The calorific value of the syngas product increases with an increase in H_2 and CO concentration to increase at higher gasification temperatures (Ismail *et al*., 2020). The concentration of combustible gases, namely CO, H_2, and CH_4, significantly influences the HHV and LHV values. Because of the increasing composition of these three gases, the application of catalysts raises the heating value.

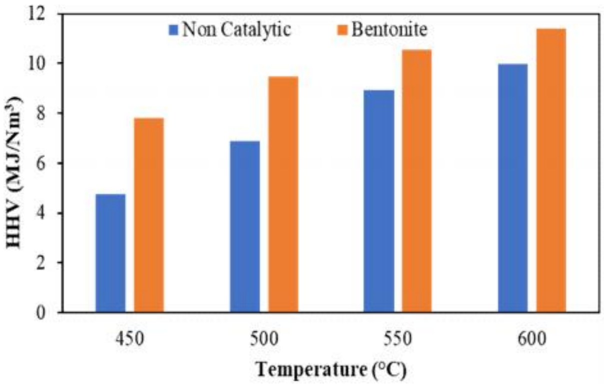

Figure 7. Temperature's Impact on the Non Catalytic HHV Value and Catalytic Bentonite

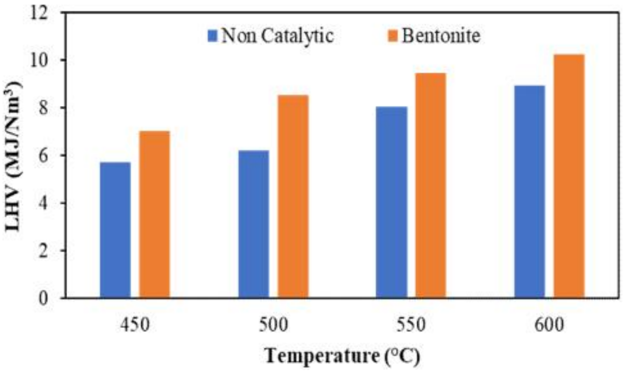

Figure 8. Temperature's Impact on the Non Catalytic LHV Value and Catalytic Bentonite

CONCLUSION

When a catalyst is added, Empty Fruit Bunch (EFB) can make syngas more efficiently. The composition and volume of the gas can be increased during the gasification process by adding a natural bentonite catalyst. When compared to non-catalytic gasification, the optimal process condition for generating syngas in EFB gasification is 600°C utilizing a bentonite catalyst. The ideal H_2/CO ratio value of 1.91, CG/NCG value of 5.81, CCE value of 77.07, and CGE value of 62.67 all demonstrate gasification efficiency. The calorific value according to the ideal HHV and

LHV value is 11.40 MJ/Nm^3 and 10.26 MJ/Nm^3 using bentonite catalyst. EFB catalytic gasification can produce quality synthetic gas products for the production of good environmental fuel.

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