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Co-Pyrolysis of Lignite Coal and Rubber Wood Chips to Produce Syngas Based On Feedstock Ratio

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ABSTRACT

Co-Pyrolysis is the process of two or more organic materials undergoing chemical decomposition in the absence of oxygen. The purpose of this research is to determine the effect of syngas products produced from variations in the composition of coal and rubber wood chips and the value of specific energy consumption (SEC). In this research, the composition of raw materials 100;0, 75;25, 50;50, 25;75, 0;100 were carried out. From the research that has been carried out, variations in composition affect the characteristics of the syngas product and the resulting SEC value. From the results of the research, the % yield of syngas increased along with the increase in the composition of rubber wood chips used, the highest % yield of syngas was produced in the composition of 100% rubber wood chips by 46.93%. The optimal CH4 content in syngas is produced in the variation of 25% coal composition: 75% rubber wood chips with CH_4 *content of 63%. In addition, the highest flame height was produced in the composition variation of 100% rubber wood chips, which was 30 cm. The SEC value produced by the most optimal syngas was obtained in the composition of 100% rubber wood chips at 7.879 kWh/kg.*

***Keywords**: Lignite Coal, Rubber Wood Chips , Co-Pyrolysis, Syngas*

1. INTRODUCTION

Indonesia is one of the countries that has the largest natural resources in the form of coal in the world. According to data from the Ministry of Energy and Mineral Resources in 2021, Indonesia has a total coal resource of 143.73 billion tons with coal reserves in Indonesia reaching 38.80 billion tons. [2]. However, most of the coal in Indonesia is low quality (lignite). At present, generally low quality coal is spread quite a lot but has not been utilized optimally.

According to the Central Bureau of Statistics in 2021, the largest rubber plantation in Indonesia comes from the province of South Sumatra, which reaches 898.4 thousand hectares [1]. One of the wastes generated from rubber plantations is rubber wood chips, rubber wood chips is the outer layer of wood that is wasted during the rubber extraction process [9]. This rubber wood chips waste has not been utilized properly by most rubber processing factories, causing a negative impact on the surrounding community. The resulting rubber wood waste needs to be processed so that there is no accumulation and more value for money [8]. Therefore, the waste can be utilized as an alternative energy source of biomass because it has a high calorific value, has a dense structure, high cellulose content and low ash content. In addition, biomass has several advantages, including being a renewable energy source so that it can provide energy sources on an ongoing basis [6].

Co-firing is the simultaneous combustion of two different types of materials. By using Co-firing the emissions from burning a fossil fuel can be reduced. Biomass is known as zero CO_2 emission in other words it does not cause CO_2 accumulation in the atmosphere and biomass also contains less sulfur when compared to coal.

In the process of applying co-firing technology, it consists of co-gasification and co-pyrolysis, so this research uses the co-pyrolysis method. Co-Pyrolysis is the process of thermal decomposition of chemical compounds from a mixture of biomass waste and coal in the absence of oxygen. The pyrolysis process produces three products in the form of liquid (Bio-Oil or tar), solid (char) and syngas. The main components in syngas are CO, CO_2, and CH_4 [4]. In this research, a research will be conducted on Co-Pyrolysis of Coal and Rubber Wood Chips with Variations in Raw Material Composition 100;0, 75;25, 50;50, 25;75, 0;100 to produce more optimal syngas.

2. MATERIAL AND METHODS

2.1 Material

In this research, the raw materials used were lignite coal and rubber wood chips. The total amount of lignite coal and rubber wood chips is 3.75 kg each for 5 runs. Each run uses 1.5 kg of raw material. The series of co-pyrolysis equipment used in this research can be seen in Figure 1.

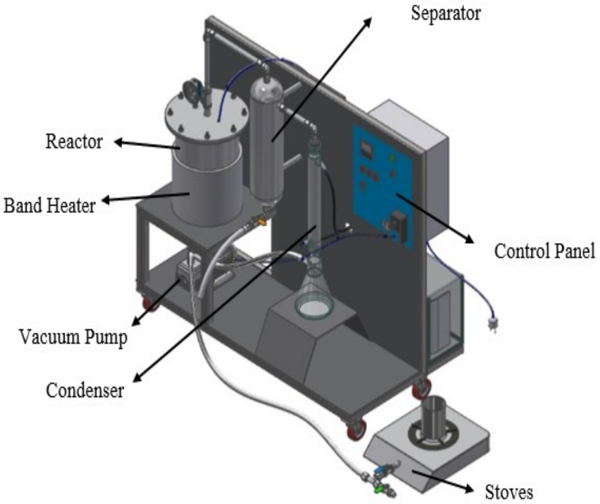

Figure 1. Co-Pyrolysis Prototype Equipment

2.2 Methods

This research was conducted from March to July 2024 at the Energy Engineering Laboratory and product analysis at the Chemical Engineering Laboratory of Sriwijaya State Polytechnic. The equipment used in this research is a set of pyrolysis tools and Multi Gas Detector Analyzer for syngas analysis. The variables used in this research consisted of variations in the composition of raw materials (coal; rubber wood chips) 100;0, 75;25, 50;50, 25;75, 0;100, operating temperature 350^{o}C and operating time for 2 hours.

The research procedure begins with the preparation of raw materials in the form of coal and rubber wood chips, the size of the raw material is reduced to ± 2 cm and then drying is carried out using sunlight for 1-2 days to reduce the water content contained in the raw material. After that, the raw material is further dried using an oven with a temperature of 110^{o}C for one day. After the raw material is ready, calorific value and proximate analysis are carried out to determine the water content, fly ash and fixed carbon of the raw material.

This research produces 3 main products, namely bio-char, bio-oil, syngas and by-products in the form of tar. Taking syngas products is done when the temperature reaches 300 - 350^{o}C by opening the syngas output valve connected to the urine bag as a syngas container before analysis. Syngas analysis using a multi gas detector analyzer. The resulting product yield can be calculated using the following formula:

$$\%\ Bio\text{-}Char = \frac{Bio-char\ mass}{Totally\ mass\ of\ raw\ materials} \times 100\%$$

$$\%\ Bio\text{-}Oil = \frac{Bio-oil\ mass}{Totally\ mass\ of\ raw\ materials} \times 100\%$$

$$\%\ \text{Tar} = \frac{Tar\ mass}{Totally\ mass\ of\ raw\ materials} \times 100\%$$

$$\%\ Syngas = 100\% - \%\ (Bio\text{-}Char + Bio\text{-}oil + \text{Tar})$$

3. RESULT AND DISCUSSIONS

3.1 Effect of Feedstock Ratio on the Yield of Co-pyrolysis Product

In syngas yield, the way to measure or calculate it is different from the yield of bio-oil, bio-char and tar. The measurement method is 100% minus the accumulated yield of bio-char, bio-oil and tar. The yield of syngas is influenced by the yield of bio-char, bio-oil and tar. The higher the yield of bio-char, bio-oil and tar, the lower the yield of syngas produced and vice versa. The following figure 2 shows the yield graph of bio-char, bio-oil, syngas and tar.

Figure 2 shows that the syngas yield increases and the bio-char yield decreases as the composition of rubber wood chips increases, while the bio-oil and tar yields increase and decrease as the raw material composition changes. The highest syngas yield was produced in the composition of 100% rubber wood chips at 46.93%, while the lowest syngas yield was produced in the composition of 100% coal. The yield of syngas produced is influenced by the yield of bio-char and bio-oil as well as by-products in the form of tar. In the co-pyrolysis process, three products are produced, namely bio-char, bio-oil and syngas, the syngas yield increases as the yield of bio-char and bio-oil decreases and vice versa.

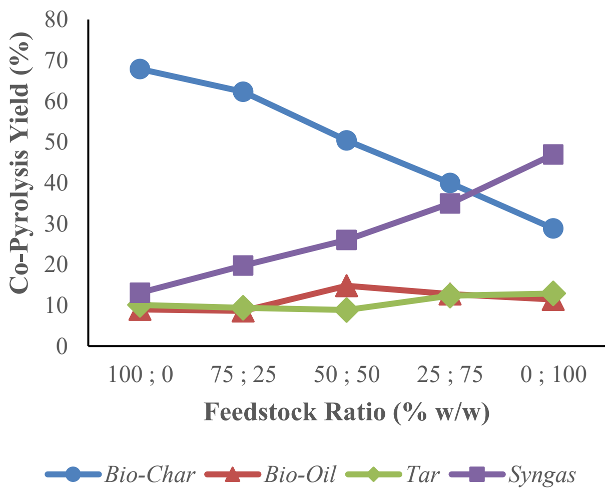

Figure 2. Effect of Feedstock Ratio on the Yield of Co-pyrolysis Products

Figure 2 shows that the syngas yield increases as the composition of rubber wood chips increases. The amount of syngas yield is influenced by the content of volatile matter contained in the raw material, the higher the volatile matter content, the greater the combustible gas produced [5]. This is because the volatile matter content is the components that are easily evaporated and decomposed to form syngas. As the proportion of rubber wood chips increases, more volatile matter will be released and converted into syngas.

In addition, there are several factors that affect the syngas yield in addition to the volatile matter content, namely rubber wood chips have a more reactive structure than coal. The content of cellulose, hemicellulose and ligin in rubber wood chips is easily decomposed at the pyrolysis temperature so that it produces more syngas products compared to coal which has a more stable carbon structure and forms more bio-char products. In addition, at this temperature, rubber wood chips are in the optimal range for decomposition to produce more syngas, while coal at this temperature range has not been fully decomposed so that it produces more bio-char products.

3.2 Effect of Feedstock Ratio on Syngas Flame Height

The height of the syngas flame is influenced by the content of volatile matter contained in the raw material, from the results of the co-pyrolysis research, the height of the syngas flame produced increases along with the increasing composition of rubber wood chips. The following figure 3 shows the graph of the syngas flame height.

Figure 3 shows that the height of the syngas flame produced continues to increase as the composition of rubber wood chips increases. The highest syngas flame height is produced in the composition of 100% rubber wood chips, which is 30 cm, while the lowest syngas flame height is produced in the composition of 100% coal, which is 10 cm.

In Figure 3, it can be seen that there is a significant increase in syngas flame height from 12.25 cm to 25.67 cm at 25% coal composition: 75% rubber wood chips and the maximum height of the syngas flame is produced in the composition of 100% rubber wood chips. From the graph above, it can be analyzed that the more dominant the composition of rubber wood chips, the higher the syngas flame produced. This is caused by several factors including differences in the composition of raw materials where the volatile matter content of rubber wood chips is higher than coal. The higher the volatile matter content in the raw material, the higher the flame produced because volatile matter is an organic compound that is easy to burn and evaporate.

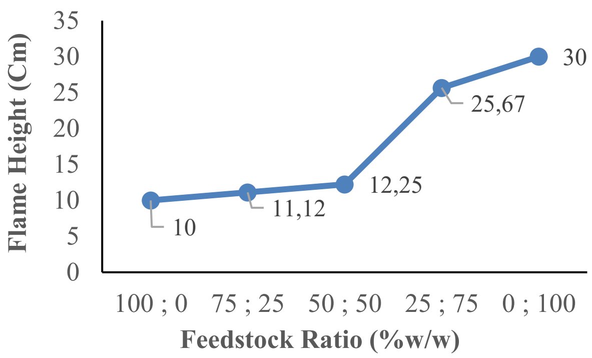

Figure 3. Effect of Feedstock Ratio on Syngas Flame Height

In addition, the air around the flame greatly affects the height of the flame produced, the more air available for combustion, the higher the flame. The air provides the oxygen necessary for the air available for combustion, the higher the flame. The air provides the oxygen necessary for the combustion reaction. A strong airflow will make the flame higher and bright blue in color. A weak airflow will result in a short, red-colored flame. In addition, air velocity also affects the height of the flame, the higher the velocity of the air flowing around the flame, the shorter the flame. High air velocity extinguishes the flame by cooling the fuel and combustion products.

3.3 Effect of Feedstock Ratio on CH_4 Composition of Syngas

Syngas from co-pyrolysis of coal and rubber wood chips was analyzed using Multi Gas Detector Analyzer. In this research, the main discussion of the composition of syngas is the composition of CH_4 contained in the syngas from co-pyrolysis. The composition of CH_4 in the syngas obtained increases and decreases, the following figure 3 below shows the composition of CH_4 produced.

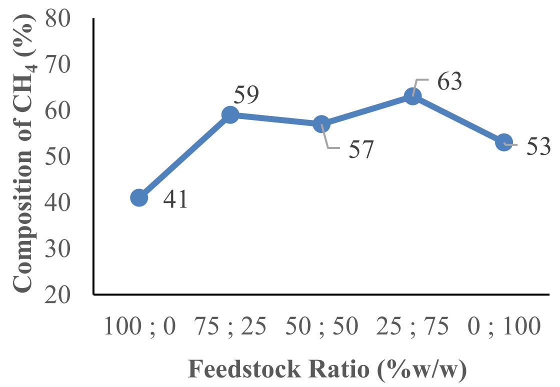

Figure 4. Effect of Feedstock Ratio on CH_4 Composition in Syngas

Figure 4 shows that the CH_4 content contained in syngas produced from the influence of the composition of raw materials has increased and decreased. The highest CH_4 content is produced in the composition of 25% coal: 75 rubber wood chips by 63%, while the lowest CH_4 content was produced in the composition of 100% coal 100% by 41%.

The dominant use of biomass in the co-pyrolysis process has a higher flammable gas (CH_4) compared to coal [3]. The high flammable gas produced in the dominant use of biomass is because biomass has a higher volatile matter content than coal so that the substances contained in biomass are more volatile. This is in accordance with research conducted by [3] which concluded that the use of composition variations with higher biomass compared to coal produced higher syngas.

In Figure 4, the results of syngas analysis are carried out using a multi gas detector where this tool can more dominantly read the main content of CH_4 compared to other syngas components such as CO, CO_2 and H_2, causing the CH_4 produced to be quite high and other syngas components such as CO, CO_2 and H_2 produced very low.

The increase and decrease in CH_4 produced can be caused by several factors including the taking of syngas which is not the same (not constant) due to the influence of variations in the composition of raw materials, taking syngas is carried out in the temperature range of 300 - 350 ºC depending on the color and height of the syngas flame produced. Furthermore, the storage of syngas in the urine bag even though it has been closed tightly there is still a possibility of a little leakage and storage of syngas in time can be up to 0-2 hours before analysis because the multi gas detector analyzer needs to be calibrated first.

3.4 Effect of Feedstock Ratio on Specific Energy Consumption (SEC) Value of Co-pyrolysis Product

Specific Energy Consumption (SEC) is the ratio between the energy consumption used expressed in units (kWh) and the product produced expressed in units (Liters) [10]. SEC is usually used to assess or measure the efficiency of a piece of equipment. In this research using a set of pyrolysis equipment, it is necessary to calculate the SEC value to determine the amount of energy used in producing a pyrolysis product.

The SEC value is obtained based on the amount of energy used in the pyrolysis device which can be measured using a power meter during the pyrolysis process and the resulting product. The graph of the effect of SEC value on the variation of raw material composition can be seen in Figure 5 below.

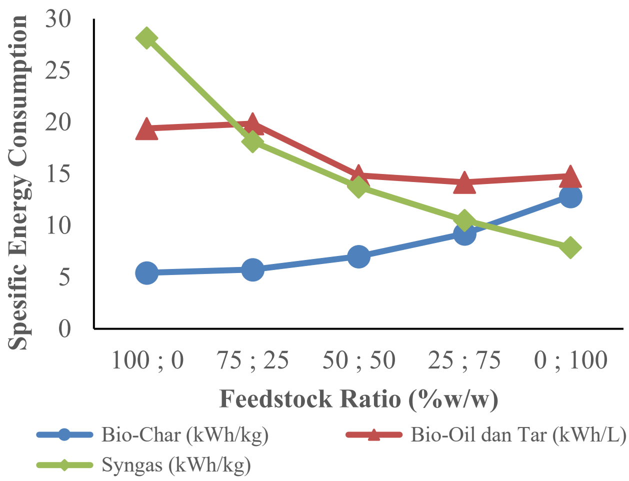

Figure 5. Effect of Feedstock Ratio on Specific Energy Consumption (SEC) Value of Co-pyrolysis Product

In Figure 5, it can be seen that the SEC value of the syngas obtained decreases as the composition of rubber wood chips increases, this is because the dominant composition of rubber wood chips produces more syngas. The lowest SEC value is produced in the composition of 100% rubber wood chips, namely 7.879 kWh/kg, producing a syngas product of 0.704 kg, while the highest SEC value is produced in the composition of 100% coal, namely 28.159 kWh/kg, producing a syngas product of 0.196 kg.

In Figure 5, it can be seen that the SEC value of bio-char obtained increases along with the increase in the composition of rubber wood scat, this is because the dominant composition of rubber wood scat produces less bio-char compared to the composition of 100% coal. The lowest SEC value is produced in the composition of 100% coal, which is 5.424 kWh/kg producing bio-char products of 1.018 kg. while the highest SEC value is produced by the composition of 100% rubber wood scat, which is 12.838 kWh/kg producing bio-char products of 0.432 kg.

In Figure 5, it can be seen that the SEC value of bio-oil and tar (Liquid Product) obtained has increased and decreased. The lowest SEC value is produced in the composition of 25% coal: 75% rubber wood chips which is 14.175 kWh/L produces a liquid product of 0.270 liters while the highest SEC value is produced by the composition of 75% coal: 25% rubber wood chips, which is 19.852 kWh/L, produces a liquid product of 0.289 liters.

In the equation for calculating SEC itself, the amount of product produced is inversely proportional to the SEC value, the smaller the product produced, the greater the resulting SEC value [3]. An energy-efficient process is one with low specific energy, while a wasteful process is one with high specific energy [7]. In Figure 5, it can be seen that the optimal SEC value in the pyrolysis device occurs in the composition of 75% coal: 25% rubber wood chips to produce liquid products (bio-oil and tar), at 100% coal composition to produce bio-char products and at 100% rubber wood chips composition to produce syngas products because in these variations the SEC value is the lowest and produces the highest product.

4. CONCLUSIONS

The % yield of syngas increased along with the increase in the composition of rubber wood chips used, the highest % yield of syngas was produced in the composition of 100% rubber wood chips at 46.93%. The characteristics of syngas are influenced by variations in the composition of raw materials, the optimal CH_4 content in syngas is produced in variations in the composition of 25% coal: 75% rubber wood chips with CH_4 content of 63%. In addition, the highest flame height was produced in the composition variation of 100% rubber wood chips, which was 30 cm.

The most optimal Specific Energy Consumption (SEC) for syngas product was obtained at 100% composition of rubber wood chips at 7.879 kWh/kg, the optimal SEC for liquid product (bio-oil and tar) was obtained at 25% coal composition: 75% rubber wood chips at 14.175 kWh/L while for bio-char products obtained at 100% coal composition at 5.424 kWh/kg.

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