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Pyrolyzer Modification for Making Coconut Shell Charcoal with Isolation from a Mixture of Clay, Sand, and Rice Straw

Tegar Trikora Adi[1] *, Rita Youfa[1], Dedy Rahmad[1], Khairul Akli[1]

[1] Renewable Energy Bioprocess Engineering Technology Study Program, Department of Chemical Engineering, ATI Padang Polytechnic
Jl. Bungo Pasang, Tabing, Padang, Indonesia-25171

*Corresponding author: koraadi200@gmail.com
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Abstract

Currently, many charcoal makers use drums as pyrolyzers, this is because the oxygen (O_2) entering the combustion chamber is controlled, the oxygen level entering the combustion chamber must be low so that the shell does not burn out. The aim of this research is to calculate the heat loss rate of the pyrolyzer for making coconut shell charcoal and to analyze the effect of a mixture of clay, sand and rice straw insulator on the charcoal yield and quality of the charcoal produced. This research focuses on reviewing pyrolyzer modifications based on aspects of mixed variations of clay, sand and rice straw insulating materials in dealing with heat loss. Testing of furnace performance is carried out using comparisons of several parameters or components including temperature, time and insulator material. The final stage of the research is to draw conclusions and draw conclusions based on the results of material variations and the factors that influence them. The research results show that the best insulator is the TP3 pyrolyzer with an insulator mixed with clay, sand and rice straw in a ratio of 2:1:0.3 with a heat loss of 7,378.992 W and ΔT of 195°C. The addition of rice straw to a mixture of clay and sand insulators provides significant benefits in increasing ΔT and reducing heat loss. The addition of rice straw to a mixture of clay and sand insulators has a significant impact on the carbonization process of coconut shell charcoal. Even though the charcoal yield decreases with the addition of rice straw to the insulator, the quality of the charcoal produced increases, especially in terms of fixed carbon content with the best insulator being the TP3 pyrolyzer with a carbon content value of 78.54%.

Keywords: Alternative Energy, Modification, Charcoal, Proximate, Insulation.

1. Introduction

Renewable energy is energy whose sources are available in nature in large quantities because they are part of natural processes or the sources can be produced in a relatively short time [1]. One alternative energy source is biomass. Biomass energy is an energy source that comes from renewable natural resources, making it possible to use it as an alternative fuel [2]. Indonesia has great potential for coconut production. Coconut plants are widespread both in yards and plantations in almost all regions of Indonesia. Indonesia has coconut plantations covering an area of 3,417,951 hectares. The average coconut production is 3 million tons per year and the coconut shell waste produced is around 360 thousand tons per year [3]. Shell waste has the potential as an alternative biomass energy.

Coconut shell solid waste has the potential to be developed into a useful and economically valuable product because it contains quite high levels of organic material, namely 36.51% lignin, 33.61% cellulose and 19.27% hemicellulose [4]. The method which is thought to be very effective and efficient in handling coconut shell solid waste is to apply the pyrolysis method [5], from [6] the pyrolysis process requires an equipment system consisting of a pyrolyzer, heater, smoke distribution pipe, condenser, and liquid smoke product container. The pyrolysis method is a process of chemical decomposition of organic materials through a heating process without oxygen, where the raw material will undergo a breakdown of the chemical structure into gas. In general, the pyrolysis process begins at

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a temperature of 200ºC and remains at a temperature of around 250-300ºC [7]. This pyrolysis method is also known as carbonization and has been developed in several developed countries, especially to deal with the problem of plastic waste [8]. However, waste handling using this method in Indonesia is still less than optimal, even though the waste degradation process using this method can take place in a relatively short time. One of the advantages of the pyrolysis method in processing coconut shell solid waste is that it produces products in the form of liquid smoke, activated charcoal and methane gas. The heat energy produced in the pyrolysis process encourages oxidation so that complex carbon molecules partially decompose into charcoal. Pyrolysis for charcoal formation occurs at temperatures of 150–300ºC. Charcoal formation is usually called primary pyrolysis. Charcoal can undergo further changes into carbon monoxide, hydrogen gas and hydrocarbon gases. This event is referred to as secondary pyrolysis [9]. According to [10], generally the pyrolysis process takes place at temperatures above 300ºC within 4-7 hours.

Currently, many charcoal makers use drums as pyrolyzers, this is because the oxygen (O_2) entering the combustion chamber is controlled, because the oxygen level entering the combustion chamber must be low so that the shell does not burn out. Using a drum as a combustion chamber makes it easy for the heat in the combustion chamber to escape because the nature of the drum (metal) easily conducts heat. To find out whether the pyrolyzer is working well or not, you need to calculate the charcoal yield and the carbon value produced. The higher the yield of charcoal and carbon produced, the better the performance of the pyrolyzer. Factors that influence the charcoal yield and carbon value are operating temperature, heating rate, pyrolysis process time, presence of oxygen, water content, material particle size and pressure [11].

This study builds upon the pyrolyzer design developed in [12], which was initially introduced to address excessive smoke emissions commonly reported by agricultural communities during traditional coconut shell combustion. The original design incorporated materials with good thermal conductivity, such as sheet steel, profile steel pipes, and iron drums, aiming to produce coconut shell charcoal with minimal smoke as a more environmentally friendly briquette raw material. However, subsequent research by [13] on the heat transfer performance of the pyrolyzer revealed significant heat loss through the reactor walls. Their findings recommended future modifications to the pyrolyzer's wall structure to reduce thermal losses. In response to this, the current study presents a modified version of the pyrolyzer with additional wall insulation using a natural mixture of clay, sand, and rice straw. This modification is intended to improve thermal efficiency, reduce external heat loss, and increase charcoal yield, thereby addressing the limitations identified in previous studies.

From research [14] regarding the analysis of differences in insulator materials (Glass wool, Clay and Cement) on the effectiveness of the coal gasification process, using three different insulator materials including glass wool, clay and cement. The analysis results show that the clay insulator has the lowest temperature of 228ºC. The lowest air speed in glass wool insulators is 2.56 m/s. The highest temperature comes from cement insulators at 649ºC. Sand has high thermal conductivity, allowing it to transfer heat efficiently. It is commonly used in construction as part of concrete or mortar, not as a primary thermal insulator, but rather as a stabilizing solid for structural strength. In contrast, rice straw is a fibrous and lightweight organic material often used as a binding agent in clay mixtures. Its inclusion helps strengthen the mixture and prevent cracking, while also providing thermal and acoustic insulation in construction applications. On the other hand, the use of these materials is in an effort to utilize natural materials that are environmentally friendly and cost minimal. Furthermore, rice straw is waste that is not utilized in West Sumatra, so its use can reduce waste to the environment. These materials, when mixed, can complement each other in terms of their respective thermal conductivities. Therefore, for this research, the insulator material chosen as a heat insulation medium was a mixture of clay, sand and rice straw. To further perfect the tool that has been designed by [12]. By modifying the pyrolyzer, making coconut shell charcoal with minimal smoke is affected by the insulator of a mixture of clay, sand and rice straw.

2. Experimental Method

This research will be conducted at the Agro-Industrial Engineering Workshop Unit, the Laboratory of Organization and Work Technology, and the Analytical Chemistry Laboratory of ATI Padang Polytechnic. The ATI Padang Polytechnic campus is located in the Bungo Pasang Sub-district,

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Koto Tangah District, Padang City. This research aims to see the rate of heat loss in the pyrolyzer for making low-smoke coconut shell charcoal based on the influence of insulator treatment. The insulator used is a composition of clay, sand and rice straw.

The combination of the insulator mixture in this study was without insulator (TP) as the initial reference standard for heat loss that occurred, then TP0 or a mixture of clay, sand and rice straw with a ratio of 2:1:0, TP1 insulator, namely a mixture of clay, sand and rice straw with a ratio of 2:1:0.1, TP2 insulator is a mixture of clay, sand and rice straw with a ratio of 2:1:0.2, and TP3 is a mixture of clay, sand and rice straw with a ratio of 2:1:0.3. Research data collection was carried out in the time range 30, 60, 90, 120, 150, to 180 minutes. The combination of treatments carried out aims to see the effect of insulators and mixtures of insulators on heat loss during the pyrolysis process. It is hoped that providing insulators with a certain combination can produce a pyrolysis process with small heat loss and good charcoal quality. The complete research flow diagram can be seen in Figure 1.

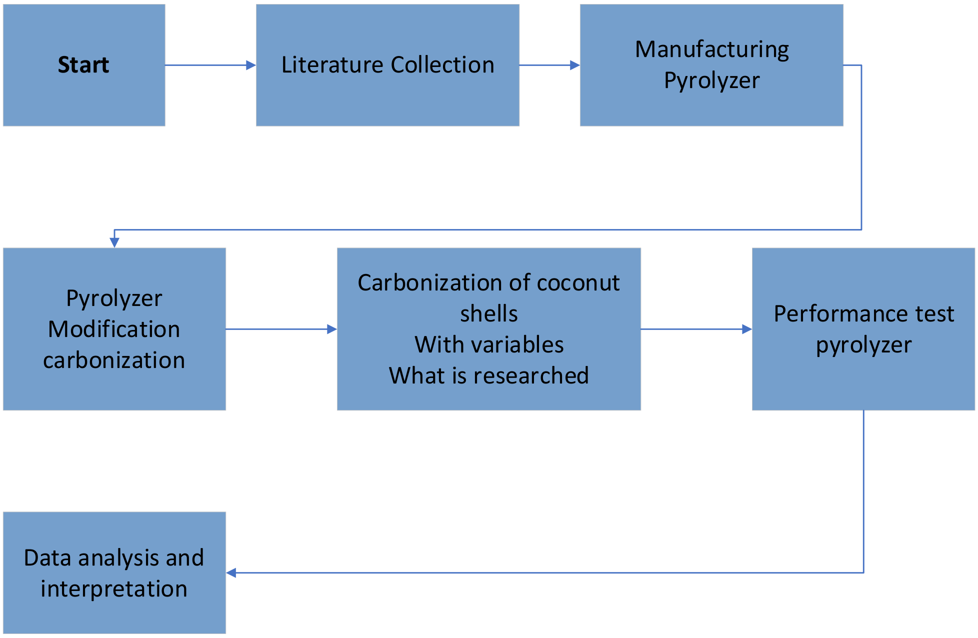

Figure 1. Research Flow Chart

The tool that will be used in this research is a pyrolyzer, as a combustion furnace. Scales, to weigh the weight of coconut shells and charcoal. Furnace, as a sample heating tool with a temperature of 600-900°C which will be analyzed for ash and volatile matter levels. Oven, used as a heating tool for water content analysis with a temperature of 105-107°C. Porcelain cup, sample container to be analyzed. Desiccator, to remove water after oven. Thermogun, thermocouple, and temperature applicator to measure pyrolyzer temperature and environmental temperature. Meanwhile, the materials used are coconut shells, clay, firewood, rice straw and sand.

3. Result and Discussion

This research aims to see the rate of heat loss in the pyrolyzer for making low-smoke coconut shell charcoal based on the influence of insulator treatment. The insulator used is a composition of clay, sand and rice straw. These materials were chosen to be used as insulators because they have low thermal conductivity. On the other hand, the use of these materials is in an effort to utilize natural materials that are environmentally friendly and have minimal costs. Furthermore, rice straw is waste that is not utilized in West Sumatra, so its use can reduce the side effects of waste on the environment. These materials, when mixed, can complement each other in terms of their respective thermal conductivities. The pyrolyzer before modification and after modification is as follows Figure 2.

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A b

Figure 2. a) Pyrolyzer Before Modification (Without Insulation), b) After Modification (Using Isolation)

3.1 The Effect of Adding Insulators on Heat Loss

Heat transfer is a process in which energy in the form of heat moves from one place to another due to temperature differences [15]. There are three main mechanisms of heat transfer: conduction, convection, and radiation. Conduction occurs when heat moves through a solid. This mechanism occurs because particles in a solid vibrate and transfer energy to adjacent particles. Convection is the transfer of heat through a fluid (liquid or gas). Radiation is the transfer of heat through electromagnetic waves, without requiring a medium [16].

Figure 3 shows that heat loss in each treatment has an increasing trend. The longer the time and the higher the temperature, the higher the heat loss. From the graph above we can see that in the TP pyrolyzer treatment, the absence of an insulator used causes the heat loss experienced to be the greatest compared to other treatments that use an insulator.

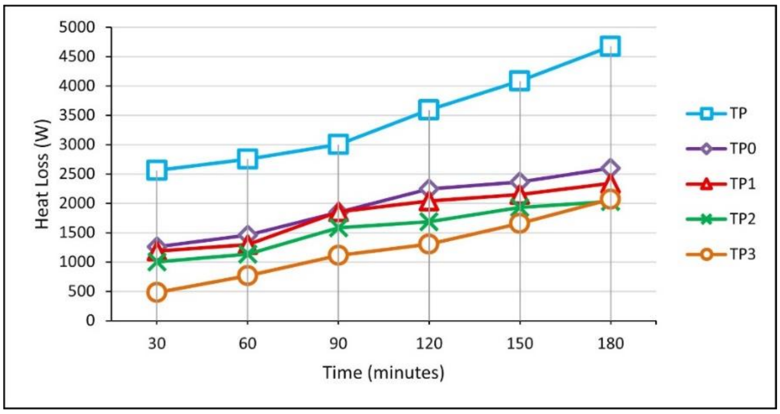

Figure 3. Overall Heat Loss in the Pyrolysis Process

The heat loss in the time interval of 30 minutes to 60 minutes shown by the TP pyrolyzer increased from 2,557.33 W to 2,754.05 W with an increase value of 196.72 W. This shows that in the initial phase, even though the temperature increased, the heat loss that occurred was relatively moderate. Then in the time interval of 60 to 90 minutes the heat loss that occurred was 245.9 W. This increase was greater than in the previous interval which shows that the increase in temperature began to influence the level of heat loss more significantly. Furthermore, at 150 to 180 minutes heat loss increased from 4,081.90 W to 4,672.06 W with an increase of 590.16 W. This shows that without an insulating layer, heat will easily be lost to the surrounding environment [17] stated that insulators are useful as heat absorbers so they can increase equipment efficiency. The absence of an insulator results in the tool's performance efficiency in retaining heat being small as evidenced by the large heat loss value.

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Figure 3 also shows that the pyrolyzer treated with TP0, TP1, TP2, and TP3 has lower heat loss than the pyrolysator without insulator (TP). Treatment at TP0, TP1, and TP2 shows that heat loss over time will be higher as temperature increases. However, the presence of an insulator means that the heat loss that occurs is smaller. When compared with the heat loss of TP0 and TP1, the heat loss of TP2 is smaller. This shows that the addition of straw to the insulator composition is a factor that plays a role in reducing heat loss. The more straw that is added, the better the performance of the insulator will be in terms of the heat loss that occurs.

The best combination of insulator material mixture treatment was obtained in the TP3 insulator. The TP3 treatment is an insulator mixed with clay, sand and rice straw in a ratio of 2:1:0.3. The overall heat coefficient value of TP3 is 13.59 W/m °C. With the lowest total heat loss, namely 7,378.992 W, this indicates that the heat insulator in this treatment is more ideal than the addition of insulators in other treatments. The amount of rice straw and a mixture of clay and sand in TP3 provides optimal thermal insulation, thereby reducing heat loss significantly and increasing the insulator's capabilities.

3.2 Effect of Insulator on ΔT

Figure 4 above shows the difference in temperature ΔT for each pyrolyzer. The TP pyrolyzer has the lowest range compared to other treatments, the ΔT TP value is 121.16 °C, which indicates that there is a small temperature difference between the inside and outside of the system. This shows the amount of heat used in this pyrolyzer. A higher ΔT indicates that there is a temperature difference between the inside and outside of the system, so less heat escapes from the system.

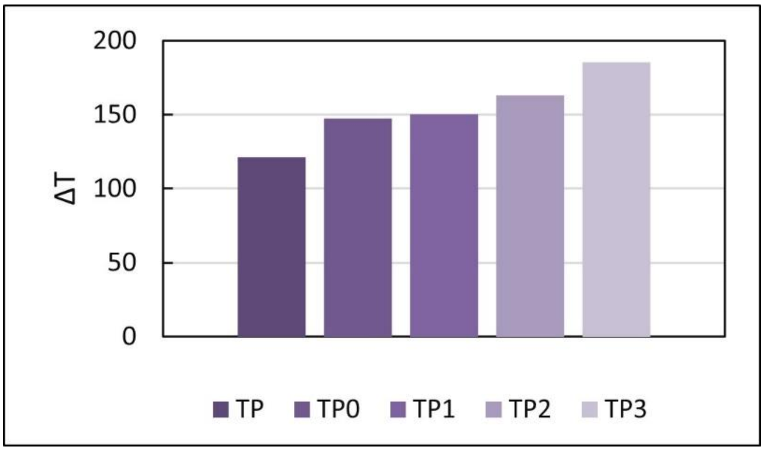

Figure 4. Differences in Temperature ΔT in Each Pyrolyzer

A high temperature difference ΔT indicates that the insulator works well in retaining heat in the system and preventing heat loss to the environment, thereby reducing heat loss as ΔT increases. This identified that an insulator with a mixture of clay, sand and rice straw was able to increase its effectiveness in retaining heat. This is because rice straw helps reduce the thermal conductivity of the mixture, making it more difficult for heat to transfer through the insulator. The use of insulators containing rice straw significantly reduces heat loss, which contributes to higher energy efficiency [18]. This can reduce fuel costs and improve pyrolyzer performance. Rice straw supports sustainability initiatives by reducing waste and utilizing renewable resources in a global effort to reduce the carbon footprint and support a circular economy.

3.3 Yield (%) Charcoal Produced

The graph above (Figure 5) shows the yield (%) of charcoal from the pyrolyzer treatment. TP pyrolyzer or without using an insulator, the yield (%) of charcoal produced is the highest. The resulting yield was 66.8%, which is the ratio of the mass of charcoal formed to the initial mass of raw material without insulator. The high yield of the TP pyrolyzer is due to the imperfect pyrolysis process occurring so that the product mass is greater. The influence of the high yield is likely due to the still high water content, volatile matter content and ash content in the TP pyrolyzer charcoal output, so that the pyrolysis is uneven which allows the carbon to be poor.

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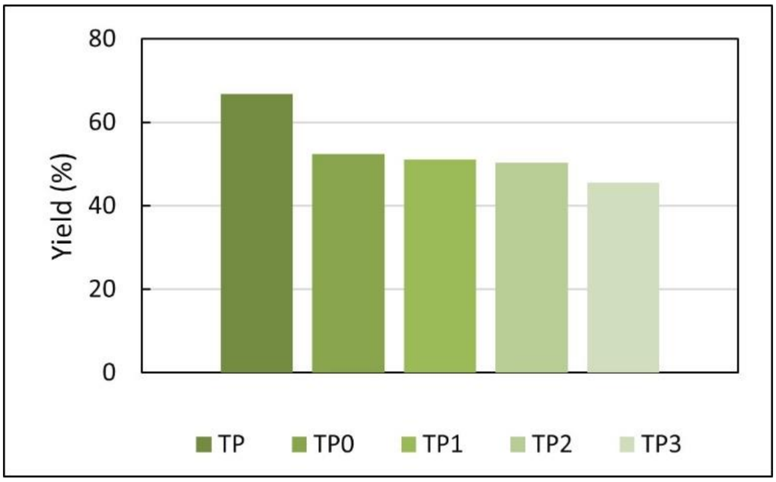

Figure 5. Yield (%) of Coconut Shell Charcoal

A pyrolyzer with an insulator can reduce heat so that the pyrolysis occurs more evenly and in a more controlled manner, which will produce charcoal with more consistent quality [17]. The decrease in yield at TP0, TP1, TP2, and TP3 shows that the pyrolysis process is going better than TP0. This results in some raw materials possibly burning into CO_2 gas or other volatile compounds, rather than charcoal [19].

3.4 Proximate Test of Coconut Shell Charcoal

3.4.1 Water Content and Volatile Matter (%)

Water content is the amount of water contained in a material or object, which is usually expressed as a percentage of the total weight of the material. This water content is important in various fields such as agriculture, food industry, construction, and materials science because it can affect the physical and chemical properties of the material. In theory, the effect of pyrolysis time on water content states that the longer the time, the less water content. The moisture content of charcoal affects the carbon value of charcoal. The smaller the water content, the better the carbon value. Apart from that, from data on the water content of charcoal, we can find out the hygroscopic properties of the charcoal [20].

Volatile matter is a component of a material that can easily evaporate or burn under certain conditions, especially when the material is heated in the absence of oxygen. Volatile matter consists of various organic compounds such as hydrocarbons, water, light gases (such as methane), and other chemical compounds that can evaporate. Flying substances include various components, such as light hydrocarbons, organic compounds, and water contained in the material. The level of volatile matter can be used as a parameter to measure the amount of smoke produced during combustion. The higher the amount of volatile substances in a fuel, the higher the amount of smoke produced [21]. This will make it easier for the charcoal to burn and ignite, so that the combustion rate will be faster [22]. Figure 6 Analysis of water content and volatile matter of coconut shell charcoal is as follows:

The Figure 6a above shows the water content value of pyrolysis charcoal for each insulator treatment. The TP pyrolyzer (without insulator) has a water content of 10.89%, lower than [23], which is 12%. The charcoal produced is quite dry, but the water content is still higher than that using an insulator. The TP0 pyrolyzer has a water content of 8.63%. This shows that the use of an isolator can help reduce the water content by around 2.26% compared to a pyrolyzer without an isolator (TP). TP1 to TP3 (with insulator and rice straw) showed a trend of decreasing water content along with the addition of rice straw. The water content of the TP1 pyrolyzator is 7.6%, the TP2 pyrolyzator is 7.61%, and the TP3 pyrolyzator is the best insulator with the lowest water content compared to other pyrolysator treatments with a water content value of 7.26%. The addition of rice straw in the insulator helps reduce water content significantly.

The Figure 6b above presents the value of the volatile matter content of the pyrolyzer for making charcoal for each insulator composition of a mixture of clay, sand and rice straw. The TP pyrolyzer (without insulator) has a volatile matter content of 16.82%. Higher volatile matter levels indicate that the charcoal may have more volatile compounds, which could result in less stable pyrolysis and more

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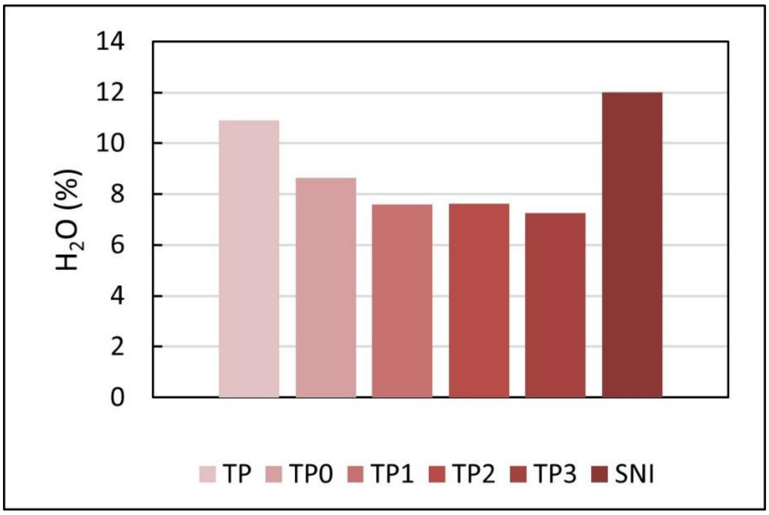
smoke. The TP0 pyrolyzer showed a reduction in volatile matter levels to 14.61%, which means that the use of an insulator without rice straw helped reduce volatile matter levels below SNI standards. Pyrolyzers TP1 to TP3 showed a further decrease, with the best composition value of volatile matter in pyrolyzer TP3 being 13.2%. The addition of rice straw helps reduce volatile matter levels gradually. The addition of rice straw in the insulator contributed to reducing volatile matter levels. The resulting charcoal has lower volatile compounds and tends to produce more stable combustion.



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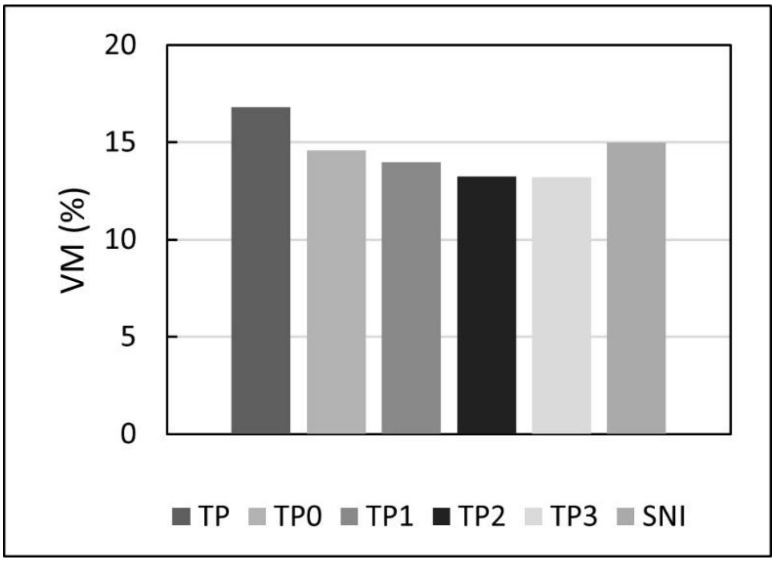

b

Figure 6. a) Graph of Water Content, b) Graph of Volatile Matter Analysis of Coconut Shell Charcoal

3.4.2 Ash and Fixed Carbon Content (%)

Ash is the metal oxides in charcoal which consist of minerals that cannot evaporate during the carbonization process. The ash content greatly influences the quality of the charcoal [24]. High ash content can reduce the carbon value of charcoal [19]. Fixed carbon is the part of solid fuel that remains after removing volatile matter and ash content through the combustion process. Fixed carbon is the main component of fuels such as coal, charcoal and biomass which makes the main contribution to the calorific value and ability of the fuel to produce energy [25].

Figure 7a presents data regarding the value of ash content in the charcoal making pyrolyzer for each variation in insulator composition. TP (without insulator) has an ash content of 4.3%, far below the SNI standard of 2.5%. This shows that this charcoal has little residual mineral residue after pyrolysis. The TP0 pyrolyzer showed a decrease in ash content to 3.6%. Pyrolyzers TP1 to TP3 showed a

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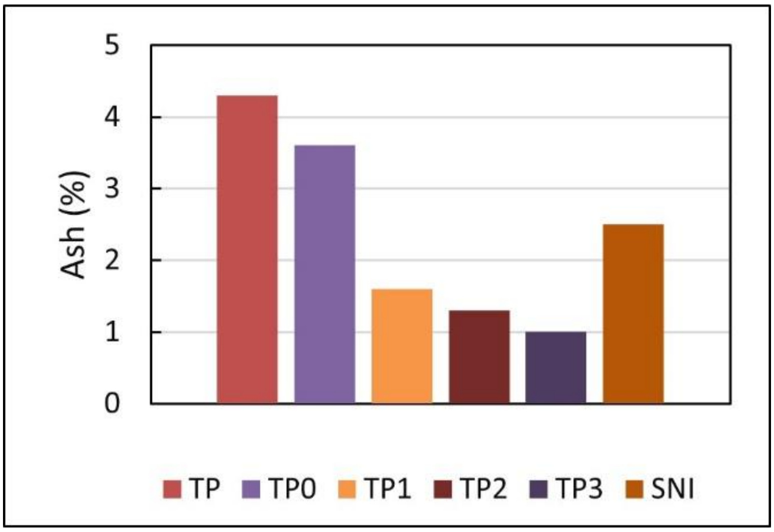
significant reduction in ash content. The TP1 pyrolyzator has an ash content value of 1.6%, the TP2 pyrolyzator has 1.3%, and the TP3 pyrolyzator has the highest ash content value compared to other pyrolyzator treatments, namely 1%. This decrease shows that the more rice straw added, the less ash remains after pyrolysis. This shows that rice straw helps reduce residual non-carbon minerals in charcoal, thereby producing cleaner and more efficient charcoal.



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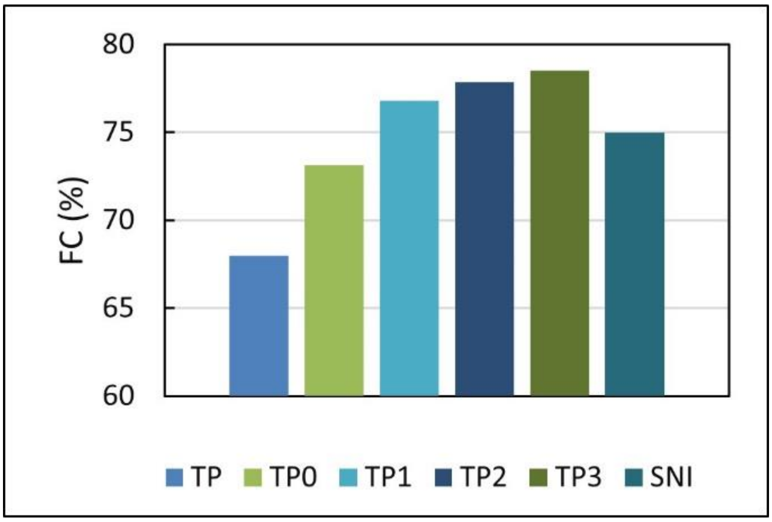

b

Figure 7. a) Ash Content Analysis, b) Fixed Carbon Coconut Shell Charcoal

Figure 7b above presents the fixed carbon value of the pyrolyzer for each insulator composition of a mixture of clay, sand and rice straw. The TP pyrolyzer (without insulator) indigo fixed carbon is 67.98% below the [23] standard, namely 75%. This shows that the charcoal produced has a low carbon value. The decrease in charcoal carbon value is related to the previous test results, namely charcoal moisture content, volatile matter content and charcoal ash content. Increasing the value of water content, volatile matter content and ash content will reduce the carbon value. Another cause is usually due to the high pyrolysis temperature and long pyrolysis time, which causes damage to the carbon plates [24]. The TP0 pyrolyzer shows an increase in fixed carbon to 73.16%, which is close to [23] standards. Pyrolyzers TP1 to TP3 showed further improvement, with TP1 at 76.8%, TP2 at 77.84%, and TP3 with the highest carbon value at 78.53%. The addition of rice straw gradually increases the fixed carbon content above the [23] standard. The addition of rice straw in the insulator increases the fixed carbon value, especially in the TP3 pyrolyzer. This indicates that the straw added is optimal, so that the carbon content produced is high and more energy efficient.

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4. Conclusion

The research results show that the best insulator is the TP3 pyrolyzer with an insulator mixed with clay, sand and rice straw in a ratio of 2:1:0.3 with a heat loss of 7,378.992 W and ΔT of 195 °C. The addition of rice straw to a mixture of clay and sand insulators provides significant benefits in increasing ΔT and reducing heat loss. The higher ΔT indicates that the insulator is more effective in retaining heat, so that heat loss to the environment is reduced. Based on the proximate test analysis that has been carried out, it can be concluded that the addition of rice straw to the clay and sand insulator mixture has a significant impact on the carbonization process of coconut shell charcoal. Even though the charcoal yield decreases with the addition of rice straw to the insulator, the quality of the charcoal produced increases, especially in terms of fixed carbon content with the best insulator being the TP3 pyrolyzer with a carbon content value of 78.54%.

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