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Conversion of Used Tires into Liquid Fuel using Thermal Cracking Method in Terms of Temperature on the Product Characteristics

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ABSTRACT
According to data from the Ministry of Industry of the Republic of Indonesia, in 2022, natural rubber consumption in Indonesia was dominated by the tire industry at 14,219 tons while synthetic rubber consumption reached 15,430 tons. Then South Sumatra Province is the first largest in natural rubber production, reaching 991,000 tons.One way that can be done to handle used tires is to use the Thermal Cracking method. Thermal cracking is the breaking or splitting of long-chain hydrocarbon molecules into shorter ones so that they can be utilized as alternative fuels. The method used in this research is the experimental method using Thermal and Catalytic Cracking tools and data collection is carried out directly with temperatures of 250°C, 300°C, 350°C, 400°C, 450°C. The highest % rendemen was obtained from the cracking method. The highest % yield was 18.66% at temperature of 400°C. The resulting liquid product will be analyzed such as density, viscosity, calorific value, flash point and GC-MS test. The amount of rendemen and calorific value quality test on liquid fuel products are used as parameters that determine the success of this research.

Keywords: *Natural Rubber, Rendemen, Thermal Cracking, Temperature, Used Tires*

1. INTRODUCTION

The amount of used tire waste from motor vehicles is very abundant and continues to gow every year. Indonesia is the second largest producer of natural rubber in the world. In 2019 natural rubber production in Indonesia reached 3.8 million tons. One of the provinces in Indonesia that ranks first in natural rubber production is South Sumatra Province reaching 991,000 tons. According to data from the Ministry of Industry of the Republic of Indonesia in 2022, the use of natural rubber for the tire industry in Indonesia amounted to 14,219 tons while the use of synthetic rubber reached 15,430 tons. Tire production has geatly increased due to the increasing production of motorized vehicles such as in 2019, the total number of motorized vehicles in Indonesia increased by 143.75 units or an increase of 4.39% from 137.7 million units in 2018. As the production of motorized vehicles increases, used tires disposed of in landfills are also increasing. So far, the handling of used tires is only burning in the open and stockpiling. This causes the problem of pollutant gases from burning used tires that can pollute the environment [1].

Tires are made from raw materials such as natural rubber and synthetic rubber containing styrene, isoprene and butadiene polymers. Natural rubber has much better mechanical properties, namely higher erosion resistance compared to synthetic rubber, but natural rubber is not strong against heat and ozone. While synthetic rubber has good properties against hot weather and is more resistant to ozone, therefore both rubbers are used in the tire manufacturing process. Natural rubber in Indonesia comes mostly from the sap of the Hevea Brasiliensis rubber tree, while synthetic rubber is most widely used in the manufacture of motor vehicle tires [2]. Tires are also one of several types of synthetic polymers that are very difficult to recycle, so the processing of used tires must be done properly so as not to cause pollution to the surrounding environment. In addition to rubber, tires also consist of various materials such as carbon black, steel wire, nylon, polyester yarn, oil, chemicals such as resins, cobalt salt, sulfur, accelerators and softeners. Of these various materials, the largest amount of carbon from the tire composition is between 67 - 76% of the entire tire composition.

One of the ways that can be done to handle used tires is by using the thermal cracking method. Thermal cracking is the breaking or splitting of long-chain hydrocarbon molecules into shorter ones so that they can be utilized as alternative fuels. Temperature in the thermal cracking process can vary in the range of 250 - 450°C. Temperature in this process can also determine the level of decomposition of used tire material, the results of thermal cracking and residence time in the reactor. Products produced in the conversion of used tires into liquid fuels are char, gas and the main product in the form of syncrude oil, these three products are highly dependent on various operating condition factors such as heating rate, presence or absence of catalysts used and temperature. Temperature differences in the production process can affect the time required in the thermal cracking process [3].

Saputra conducted research on the utilization of used tire pyrolysis into alternative fuels. The process in this study produced more oil pyrolysis process at 350°C temperature than at 250°C - 300°C temperature [4]. Pyrolysis products produced at temperatures 250°C, 300°C and 350°C were 74 ml, 98 ml and 126 ml, respectively. Based on the description above, the author aims to conduct research to develop and analyze the effect of temperature on the production of liquid fuels and their characteristics with raw materials for used tires through the thermal cracking process.

2. MATERIAL AND METHODS

2.1 Tools and Materials

The tools used in thermal cracking research, namely one thermal and catalytic cracking unit consisting of band heater components, catalyst reactors, thermocouples, catalyst reactors, separators, condensers, erlenmeyers, control panels, vacuum pumps, gas stove and can be seen in Figure 1. The material used in this thermal cracking research is 10 kg of used tires.

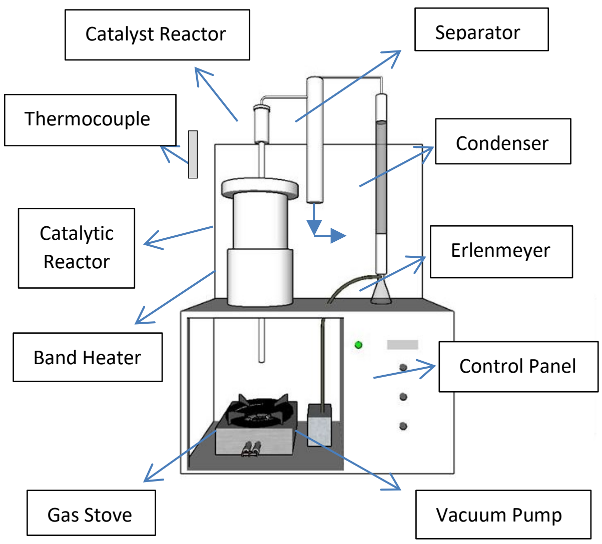

Figure 1. Thermal and Catalytic Cracking Unit

2.2 Methods

Size Reduction of Raw Material

Used tires before reduced the size must washed moreover first to get rid of the dirt in the the outer tire is missing. Then, the tire is split part middle then cut as big as not enough over 3 cm x 3 cm.

Cracking Process

The utilization of tires permitted a reduction in the quantity entered, reaching a minimum of 2 kg in the cracking reactor. Activate the heating and temperature regulation system, maintaining a temperature of 250°C as indicated on the control panel. Subsequently, the vacuum pump is activated, and the water is initiated for circulation within the condenser. The gas is then extracted from the reactor and directed towards the condenser.. The cracking process was terminated when no further condensate was observed coming out from the condenser.Furthermore turn off the heater as well pump on the control panel. Repeat procedure on with material standard fixed 2 kg and temperature (300, 350, 400, 450 °C)

Analysis Procedure

Density (ASTM D4052 or ASTM D1298)

Make sure pycnometer has cleaned before start analyze and weigh pycnometer blank then recorded (m_1). Next, fill in pycnometer with sample and recorded (m_2).

Viscosity (ASTM D445)

Measure the diameter of the ball to be used and calculate the volume of the ball. Enter sample product liquid into the viscometer and place the ball on the surface. Count the time it takes the ball to go through a distance of 20 cm after the ball is released.

Flash Point (ASTM D93)

Prepare tool open cup flash point tester moreover first and let cool sample with ice water. Furthermore insert sample into the beaker then turn it on heater. Note the temperature when fire light up colored blue.

Calorific Value (ASTM D240)

Clean up bomb tube and insert sample in the tube, then prepare wire for igniter with method roll it on the stem igniter on the bomb cover. Place cup containing material burn at the end stalk igniter and close the bomb with strong. Next, fill in oxygen to in bomb with pressure 15-20 bar and place the bomb installed in the calorimeter.

Gas Chromatography Mass Spectometry

A sample of the product liquid should be prepared for analysis. The analysis of the product liquid on a GC-MS instrument will facilitate the detection of fractions as well as existing compounds in the product. This analysis is crucial for ensuring the quality of the liquid product used and for elucidating how variations in chemical composition can affect its performance and reliability as a liquid fuel.

3. RESULTS AND DISCUSSIONS

This research is focused on finding out the effect of temperature in the thermal cracking process on the characteristics and percent yield of liquid and gas products produced.

3.1 Effect of Temperature on % Yield of Liquid Product

Based on the research that has been done, the effect of temperature on % yield of liquid products can be seen in Figure 2. In the thermal cracking reaction of used tires at the beginning of the process there will be a breakdown of the polymer chain into compounds with a lower molecular weight where the termination of the C-C and C-O chain bonds in the hydrocarbon chain is because these two bonds have low bond energy, which is 350 kJ/mol compared to other atomic bonds, such as C=C which reaches 837 kJ/mol. So that the breaking of the styrene chain into shorter chains will allow it to occur at a temperature that is not too high.

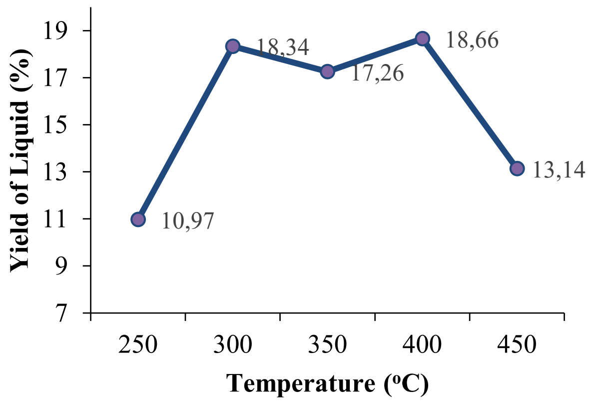

Figure 2. Effect of Temperature on % Yield of Liquid Product

In figure 2. It can be seen that the effect of temperature on % yield tends to increase and decrease, especially at a temperature of 250ºC to 300ºC experiencing a significant increase. The highest % yield was at a temperature of 400ºC which amounted to 18.66%, followed by a temperature of 300ºC of 18.34%. The difference between the two temperatures is 100ºC and based on the research that has been done shows that the percentage yield produced from both temperatures is not much different and from 2 kg of used tire raw materials obtained an average percentage yield of 15.67%. According to theoretical temperature can affect the % yield produced in the thermal cracking process, such as at too low a temperature will make the thermal cracking reaction not take place effectively because the raw material will not be completely split, so that the resulting product has poor quality and produces a low % yield of liquid product. At the optimal temperature, the cracking process takes place efficiently, where the outer used motorcycle tire raw material will be split into lighter fractions, in addition, the % yield of liquid products produced will certainly be maximized.

According to Hasan, the use of coolant water as a cooling medium can also increase condensation efficiency and % yield in the process of thermal cracking of used tires [5]. This happens because radiator water (coolant) has a lower boiling point than used tires and has a geater heat capacity than water, so radiator water can absorb a lot of heat in the thermal cracking process.

Haris said that cracking carried out with temperature is useful for knowing the best and optimal products produced in the thermal cracking process [6]. In this research, temperature was applied and the yield percentage increased and decreased. The amount of raw material used in this research is used tires as much as 2 kg/1 time running process. The first highest percentage increase in liquid product yield was 18.66% at 400ºC and the same % yield was 18.34% at 300ºC. Because the temperature in the thermal cracking process should not be too low and too high, the optimal product in this study is at a temperature of 300ºC

3.2 Effect of Temperature on Density of Liquid Products

Based on the research that has been done, the effect of temperature on the density of liquid products can be seen in Figure 3. The highest density was obtained at a temperature of 250ºC and 450ºC which amounted to 0.847 g/ml, the next temperature is 300ºC density of 0.834 g/ml. At 350°C the density decreased again to 0.832 g/ml and the lowest density at 400°C was 0.828 g/ml. Density which is commonly referred to as density is the mass per volume of a fluid and density is also an indicator of the amount of fluid in the result of a reaction [7].

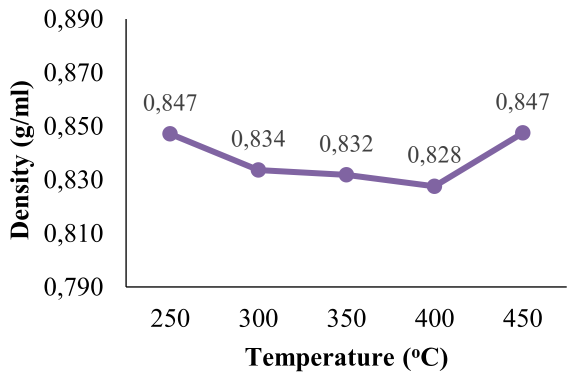

Figure 3. Effect of Temperature on Density of Liquid Products

Higher density in a fuel mean there is more mass per volume unit. Therefore, a fuel with a higher density usually has a geater energy content per volume. Based on Figure 4.3 when compared with the liquid product specification standard, the results obtained in this study are standardized as a liquid product type with solar specification. Solar has a minimum density of 815-870 kg/m^3 or 0.815-0,870 g/ml according to SNI Dirjen Migas No.28.K/10/DJM.T/2016 and the value of the entire liquid product density in this research is included in the standard. According to Endang said the low temperature of the liquid product resulting from the thermal overlap tends to form a candle, so the higher the candle on the product then it will decrease [8]. This causes the mass of the liquid product to decrease.

3.3 Effect of Temperature on Viscosity of Liquid Products

Based on the research that has been done, the effect of temperature on viscosity of liquid products can be seen in Figure 4. The increase and decrease in viscosity occurs where the highest at 250ºC is 2.62 mm^2/s and the lowest at 450ºC is 1.39 cSt. When viewed from the viscosity of diesel fuel, which is 2 - 4.5 cSt, the viscosity of 3 liquid product samples from five samples of this research is in that range and is indicated as diesel fuel.

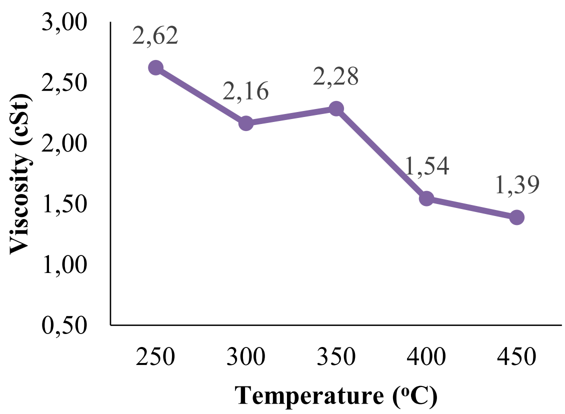

Figure 4. Effect of Temperature on Viscosity of Liquid Products

At 250ºC the viscosity obtained at 2.62 cST, the temperature of 350ºC at 2.28 cSt and the minimum viscosity value against the standardization of solar fuel is at a temperature of 300ºC that is of 2.16 cSt. However, when viewed from the time of movement of the ball fluid falls, the liquid product resulting from cracking has a time of motion of the fluid ball falls tends to be faster or can be said from the physical point of view of the oil liquid product is slightly thicker than the pure fuel marketed.

Viscosity is the measure of the density of a fluid, determined by the interaction between the molecules that make up the fluid. If the liquid product is too fresh, then it will cause leakage of the injection pipe and difficult to burn [9]. When the temperature rises then the viscosity of the liquid fuel will decrease and if the pressure on the liquid fuels increases it can cause the viscosity to increase as well. Besides, the effect of viscosities on liquid fueling is among other things the first, if a fuel with a low viscosity will be more likely to evaporate and burn, the second is that a fuel or a product with a high viscosity is more difficult to mix homogeneously with additives or other materials. Lastly, if too low the viscosity can increase the risk of leakage or spill because the fuel is more easily flowing. On the contrary, too high viscosity can cause problems in handling and filling fuel..

3.4 Effect of temperature on the flash point of liquid products

Based on the research that has been done, the effect of temperature on the ignition flash point of liquid products can be seen in Figure 5. There are two liquid products resulting from thermal filling with temperatures of 350ºC and 450ºC having the highest flash point of 54ºC. Then, at temperatures 250ºC, 300ºC, and 400ºC have the same flash point of 52ºC.

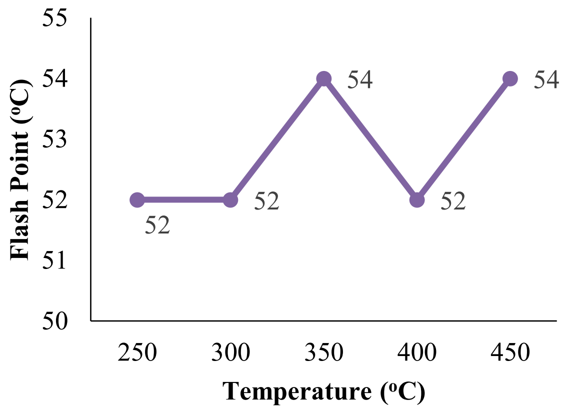

Figure 5. Effect of temperature on flash point of liquid products

Meanwhile, if compared with the standardized range of ignition points of solar fuel category according to the standard, namely, 52ºC – 60ºC, then the five samples of liquid products are all indicated in the solar fuel flash point range. An analysis of the ignition point is used to determine the temperature at which the fire will start and its importance in determining the safety in use as well as storage of liquid products to avoid the occurrence of fire. Wide boiling distances have some influence on the ignition point. The height of the steam pressure has an effect on the decrease of the ignition point and on the contrary, the pressure raises the ignission point.

Liquid products are easily evaporative and flammable so the combustion process does not take long. Liquefied products with a lower ignition point tend to be more easily ignited and more dangerous. Higher ignition points indicate that liquid products are more difficult to ignite and safer to use. Flash points affect the quality of liquid products in combustions efficiency where higher inflammation points tend to become more efficient because they are harder to ignition. The higher the temperature of the thermal filling, the lower the water content in the liquid product so that the fire can hit quickly and the resulting ignition point is smaller [10].

3.5 Effect of Temperature on Calorific Value of Liquid Products

Based on the research that has been done, the effect of temperature on calorific of liquid products can be seen in Figure 6. The lowest calorific values in this research were obtained at 250°C and 450°C, that is 10896 cal/g. If sorted from the highest, then at 400°C the maximum is 10974 cal/g. Next, at 300°C the calorific value is 10952 cal/g and the temperature of 250°C is 10896 cal/g.

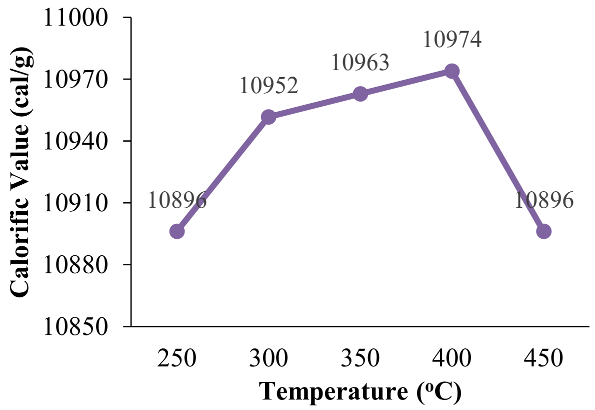

Figure 6. Effect of Temperature on Calorific Value of Liquid Products

Temperature in the process of thermal coating can affect the calorific value generated. If temperature are too low such as below 500°C will produce liquid products with high calorific values as well, gas production is relatively low and also less residue is produced. At temperatures between 500°C and 600°C, the calorific value of the liquid product is slightly lower due to the decrease in the content of heavy compounds, and then the production of gases and residues will increase. Finally, at high temperatures, that is above 600°C, the thermal filling process will produce more gas than the liquid products. High temperatures can accelerate the heat filling reaction rate, but if the temperature is too high, it will result in the degadation of the resulting product.

In a research of thermal collapse without catalyst with the raw material of used tires obtained a variable increase in calorific values starting from 250°C, 300°C, 350°C, 400°C and the calorific value returned to a temperature of 450°C. This is due to the ability of the cracking device that can not work to the maximum and obtain a less good calorific of liquid product. Based on the calory value of liquid products resulting from the thermal cracking study where if compared with the SNI standard is in the range of 10755 – 10900 cal/g, then the sample of the liquid product is indicated as solar fuel. The increase in calorific values can be enhanced by re-purification and calorific value is heavily influenced by the time of the thermal stacking process. The longer the process takes it will affect the calorific value of the tested sample [11]. According to Saparudin said the higher the temperature used in the thermal cracking process, the lower the calorific value of the liquid product produced [12].

3.6 Percent Composition of Liquid Product using Gas Chromatogaphy-Mass Spectrometry Instrument (GCMS)

Based on the analysis of Gas Chromatogaphy-Mass Spectrometry Instrument that have been performed with one the most abundant sample of liquid products sample at 400°C can be seen in Figure 7. In the liquid product tested the most percentage fraction is the solar fraction with the C_{12} - C_{25} chain of 80,41%.

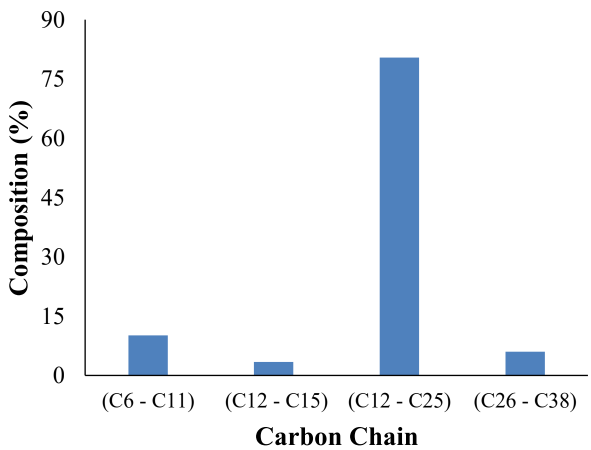

Figure 7. Percent Composition of Liquid Product using Gas Chromatogaphy-Mass Spectrometry

Next, most fraction composition is the C_6 - C_{11} chain which is the gasoline fraction at 10.11%. The lubricant fraction in the C_{26} - C_{38} chain is in third position at 6.04% and finally the kerosene fraction in the C_{12} - C_{15} chain at 3.42%. Based upon the GC-MS instrument results the liquid products at the temperature of 400ºC thermal cracking results are indicated as solar fuel. In table 4.4 there are some components such as Pentadecane (C_{15}), Hexadecane (C_{16}), Heptadecane (C_{17}), Octadecane (C_{18}), Eicosane (C_{20}), Docosane (C_{22}), Tricosane (C_{23}), Tetracosane (C_{24}) these components contribute to the properties of solar fuels, such as energy density, boiling point, and combustion properties. Meanwhile, some other components that have a specific aromatic structure or function goup, such as 4,6,8-Trimethylazulene, 2,2'-Dimethylbiphenyl, and Phenathrene, can affect the oxidative stability and thermal stability of the solar. Hexadecanetrile and Pentadecanoic acid 14-methyl- show a more complex chemical in the solar sample. This analysis is important to ensure the quality of the liquid product used and to understand how the chemical composition can affect its performance and reliability as a liquid fuel.

4. CONCLUSIONS

Temperature in the thermal wrapping process of used tires affect the yield of the liquid product produced. At 400°C the highest liquid yield of 18.66% is obtained and at 450ºC the lowest yield is 13.14%. Average percent Based on the analysis to determine the characteristics of liquid products produced from thermal cracking, a lowest density at 400°C of 0.828 g/ml and a maximum density in 450ºC is 0.847 g/ml. Solar fuels have a range of 0,815 – 0.870 g/ml and all liquid products are indicated solar. Standard solar viscosity specifications are in the range of 2-3 cSt and at temperatures of 250ºC, 300ºC, 350ºC have indicated solar viskosity. Based on the analysis, the lowest flash point of a liquid product is 52°C and the highest is 54°C Where all liquid products are included in the standard flash point for solar (52°C-60°C). The highest calorific value of a liquid product is 10,974 cal/g at a temperature of 400°C. The lowest is 10,896 cal/g at 250ºC and 450ºC. GCMS analysis uses the most liquid product thermal cracking results at 400ºC and obtains carbon chains C_{14} to C_{25} of 80,41%. This liquid product has been indicated in the fraction of solar fuel with carbon chain in the range C_{12} - C_{25}.

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