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Pyrolysis of biomass mixture of coconut fiber and rice husk waste with polypropylene plastic

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ABSTRACT

This research aims to evaluate the effect of the composition ratio of oil from coconut fiber waste biomass and rice husks as well as polypropylene (PP) plastic which is not optimally utilized and can be used as an alternative fuel processed through the pyrolysis process. This research was conducted by mixing biomass of coconut fiber and rice husk with PP plastic in the form of refuse-derived fuel (RDF)-3 with compositional variations of 100:0%, 75:25%, 50:50%, 75:25%, and 0:100% for 60 minutes. The pyrolysis product in the form of oil was then distilled to separate the compounds contained in it and produce pure oil. Next, quantity (volume of pyrolysis oil and distilled oil) and quality (yield, density, viscosity, visual, and color) tests were carried out. The results of the study showed that there is an influence of the variation in the composition ratio of the mixture of biomass of coconut fiber and rice husk and PP plastic on its quantity and quality. The highest quantity was obtained from the 100% PP ratio and the best quality was obtained from the 100% PP ratio, which leads to the specifications of solar fuel oil.

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1. INTRODUCTION

All countries in the world are facing the big challenge of energy scarcity. Significant depletion of oil reserves is at the root of this problem. World energy demand continues to increase and has become a global problem in energy use in various sectors, resulting in an energy crisis [1]. Population growth affects energy consumption to meet transportation, industrial, and household needs [2]. The massive consumption of petroleum fuels depletes these energy sources and creates environmental issues due to the increased pollution emissions from burning these fuels [3]. The world's energy demand currently reaches 3×1,020 Joules/year and is predicted to continue to increase to 30 Terra Watts by 2030 [4]. Excessive use of fossil energy sources can lead to the depletion of fossil energy reserves must be immediately offset by the abundant supply of renewable, cheap, and affordable alternative energy for the general public [5].

Experts predict that fossil fuels will soon run out with current consumption patterns. By 2052, oil will be depleted, gas forty years later, coal seventy years later, and by 2090, coal is expected to be exhausted [6]. Reducing reliance on petroleum is possible via the use of renewable energy sources, which are abundant in Indonesia, rather than oil. As a renewable energy source, biomass is one option [2]. Exploring different forms of alternative energy is necessary to keep up with the ever-increasing demand for power. One option is to make use of biomass, which is a byproduct of farming, plantation, or forest operations. As a nation that relies heavily on agriculture for its economy, Indonesia has a wealth of agricultural goods that may be converted into biomass, a sustainable energy source. Even though Indonesia has over 50,000 megawatts (MW) of biomass, only 320 MW of energy has been used, which is equivalent to just approximately 0.64% of the entire biomass [7]. When it comes to sustainable energy, biomass power is unparalleled. This is because of its many benefits, including reduced sulfur, carbon-neutral emissions, and an abundance of it in the form of agricultural waste. As a result, biomass is seen as a promising alternative energy source for the future [8]. Plants, trees, grass, tubers, agricultural leftovers, forest logging residues, manure, and the byproducts of photosynthesis are all examples of organic elements that might be considered biomass [9]. One technique to transform biomass into fuel is by refining it into bio-oil. The process of pyrolysis, which involves heating biomass to a certain temperature and duration without the use of water, is used to accomplish this conversion [10]. Three byproducts may be simultaneously generated by pyrolysis: The process of pyrolysis transforms biomass into gas, bio-oil, and charcoal, which are solid byproducts [11]. Biomass type and operational process factors determine pyrolysis oil output and composition. It is essential to produce refuse-derived fuel (RDF) as direct pyrolysis of biomass yields less than ideal-results [12].

Coconut fiber has great potential among the large biomass that can be utilized in Indonesia. Coconut biomass waste is abundant, especially in coconut-producing regions. With an annual output of 18.3 million tons, Indonesia surpasses all other countries as the world's leading coconut producer, and this figure continues to increase. The utilization of coconut fruit is very diverse, but the utilization and processing of coconut fiber are still limited [13]. Most coconut fiber is only used for handicrafts or burned, burning coconut fiber can cause air pollution and gas emissions in the environment [14]. The natural decomposition process of coconut takes longer than that of fruit and vegetable waste, even though both are organic waste. Not only that, the great potential for alternative biomass energy lies in Indonesia as an agricultural country, abundant but underutilized agricultural waste can be optimized as an alternative biomass energy source [15].

In addition to biomass waste, plastic waste is also a problem due to environmental pollution caused by the accumulation of waste, especially plastic waste from human activities in daily life. The annual plastic demand is around 400 million tons recently, which has generated nearly 9 billion tons cumulative amount of plastic waste in the last 50 years [16]. Proper processing of waste plastics enables their utilization as a source of hydrocarbons, an important feedstock for the chemical and energy industries [17]. Another way to add value to this waste is by pyrolysis to produce renewable energy that is certainly more environmentally friendly [18]. The term "pyrolysis" refers to the chemical breakdown of materials subjected to high temperatures in an environment with little or no oxygen [19]. This process can produce oil as one of the products that can be used as a renewable energy source [20]. The description is the basis for conducting research on the pyrolysis of a mixture of biomass waste of coconut fiber and rice husk with polypropylene (PP) plastic.

2. METHOD

2.1. Research design

The research was conducted in two locations: i) Laboratory of Mechanical Engineering Education Program, Faculty of Teacher Training and Education, Sebelas Maret University Surakarta, as a place for pyrolysis oil production, distillation process, and volume testing, yield value, viscosity, as well as visual and color observation of pyrolysis oil and ii) Chemistry Sub Lab of Integrated Laboratory of Sebelas Maret University as a place to test the density of pyrolysis oil. The method used in this research is the experimental method, and the research sample is the result of testing the quantity and quality of pyrolysis oil from a mixture of coconut fiber and rice husk waste with polypropylene plastic with a variation in the composition ratio of 100:0%, 75:25%, 50:50%, 25:75%, and 0:100%. The data collection methods used are measurement and observation. The research subjects were analyzed using quantitative descriptive analysis techniques.

2.2. Research instruments

Coconut fiber waste and rice husks are plantation and agricultural waste from harvesting. Coconut fiber waste and rice husk are used for the RDF mixture with the size used being 10 mesh. The PP plastic that will be used is chopped into RDF-3 and then dried together with coconut fiber waste and rice husks. In making pyrolysis oil we use pyrolysis equipment consisting of reactor tubes, connecting pipes, and condensers. The reactor tube serves as a place for heating the composition of the material used has a diameter of 260 mm and a height of 488 mm. The connecting pipe connects the reactor with the condenser which has a length of 600 mm, a thickness of 1 mm, and a diameter of 32 mm. The condenser serves as a place to cool the vapor to its dew point. The condenser used has a height of 800 mm with a width of 150 mm. This research uses an oil burner as a heating source equipped with a blower to increase the flame. The digital scales used have a capacity of 10 kg with an accuracy of 0.01 kg, functioning to measure the mass of coconut fiber waste, rice husks, PP plastic, and the mass of pyrolyzed oil liquid. Measurement of temperature in the reactor and condenser water flow using a K-type thermocouple and an Arduino-based flowmeter. A stopwatch was used to calculate the burning time in the pyrolysis process for 60 minutes. Measurement of oil volume using a 100 ml capacity measuring cup with an accuracy of 1 ml. The water pump is used to pump water so that there is circulation in the condenser, the pump used has a capacity of 19 liters/minute and a maximum suction power of 9 m. The capacity of the water tub used is 82 liters with dimensions of 67×47×40 cm. The distillator is used to separate a solution based on its boiling point, the tool used has a distillation flask capacity of 500 ml. The digital thermometer is used to measure the distillation temperature, and has a temperature reading accuracy of -50 °C to 300 °C. Analytical balance has an accuracy of 0.001 grams with a maximum capacity of 310 grams. The volume of the pycnometer bottle used is 20 ml. The measuring pipette has a capacity of 10 ml and is used to put the pyrolysis oil into the pycnometer bottle. Ostwald viscometer is used to measure the viscosity value of the oil. Pipette filler is used to suck the oil on the Ostwald viscometer. The beaker is used as an oil container for visual and color testing. The research procedure can be drawn using a flow chart as shown in Figure 1.

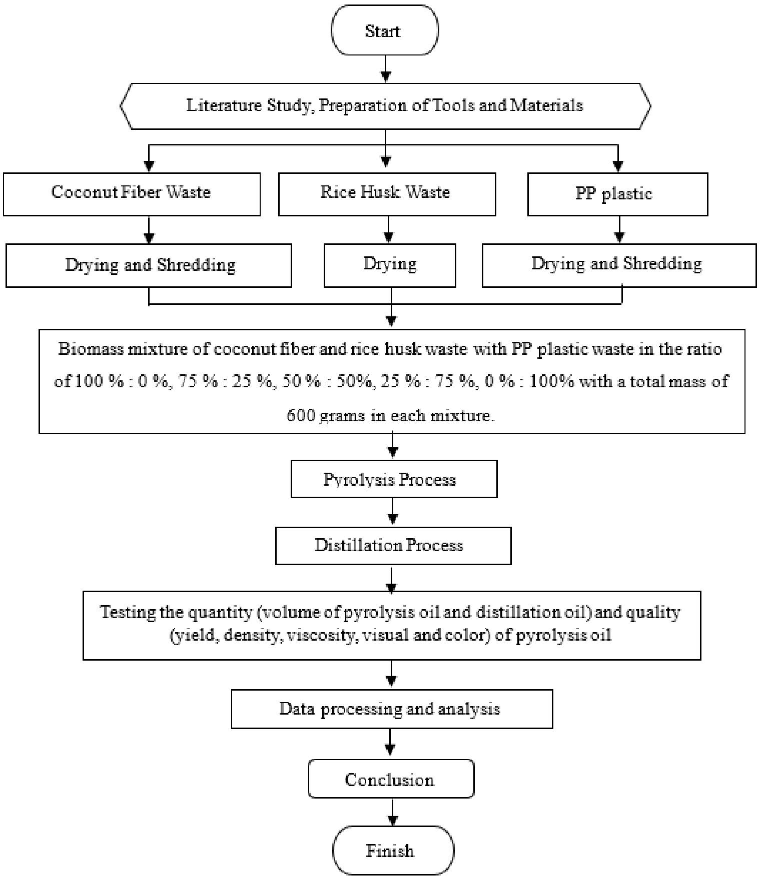

Figure 1. The research procedure

2.3. Data collection techniques

This study aims to collect data on the quantity and quality of pyrolysis oil from a mixture of biomass waste of coconut fiber and rice husk with PP plastic. In this experiment, the total mixture mass is 600 grams with a burning time of 60 minutes. The ratio of biomass to PP plastic mixture was 100:0%, 75:25%, 50:50%, 25:75%, and 0:100%, where the ratio of coconut fiber waste biomass to rice husk waste biomass in each ratio is 50:50%. After the pyrolysis process, the oil was refined and measured for quantity and quality, including yield, density, viscosity, visual appearance, and color. Data were collected three times for each ratio, resulting in a total of 15 samples.

2.4. Data analysis techniques

From collecting data on the results of pyrolysis oil testing, and then analyzing the data using quantitative descriptive analysis methods. The data that has been obtained for the characteristic properties of yield, density, viscosity, visual, and color values will then be compared with the type of fuel oil to determine the results of the values that have been studied. To facilitate data analysis, the data will be made in the form of tables and graphs.

3. RESULT AND DISCUSSION

3.1. Result

Based on the data in Table 1, the quantity (volume) of oil produced through the pyrolysis process with a mixture of coconut fiber biomass and rice husk with PP plastic waste ranges from 266.67 to 616.67 ml. The highest oil yield in the pyrolysis process was obtained from a composition ratio of 100% PP plastic, which was 616.67 ml. The lowest quantity (volume) results obtained from the pyrolysis process were obtained from the composition variation of 100% coconut fiber biomass and rice husk, which was 226.67 ml. The composition ratio influences the quantity (volume) of pyrolyzed oil. The composition ratio of the mixture with more coconut fiber biomass and rice husk compared to PP plastic waste will produce less oil, on the other hand, a mixture with a composition ratio of coconut fiber biomass and rice husk less than PP plastic waste will produce more oil.

Table 1. Pyrolysis oil quantity data

Composition	Ratio (%)				
PP:Biomassa (%)	0:100	25:75	50:50	75:25	100:0
Volume (ml)	226.67	266.67	263.33	366.67	616.67

Based on the data in Table 2, the quantity (volume) of oil produced through the distillation process of a mixture of coconut husk biomass and rice husk with PP plastic waste ranged from 41 to 178 ml. The highest oil yield in the pyrolysis process was obtained from the composition ratio of 0% coconut husk biomass and rice husk with 100% PP plastic waste, which was 178 ml. The least quantity (volume) results obtained from the pyrolysis process were obtained from the composition variation of 75% coconut husk biomass and rice husk with 25% PP plastic waste, which was 41 ml. The composition ratio influences the quantity (volume) of pyrolyzed oil. The composition ratio of the mixture with more coconut fiber biomass and rice husk compared to PP plastic waste will produce less oil, on the other hand, the mixture with less coconut fiber biomass and rice husk composition ratio compared to PP plastic waste will produce more oil.

Table 2. Distilled oil quantity data

Composition	Ratio (%)			
PP:Biomassa (%)	25:75	50:50	75:25	100:0
Volume (ml)	41	79.33	105	178

Based on the data in Table 3, the oil yield produced from the pyrolysis process ranges from 39.72 to 82.38%. The highest pyrolysis oil yield was obtained from the composition ratio of 0% coconut fiber biomass and rice husk mixture with 100% PP plastic waste at 82.38%, while the lowest pyrolysis oil yield was obtained from the composition ratio of 100% coconut fiber biomass and rice husk mixture with 0% PP plastic waste at 39.72%. The composition ratio influences the oil produced through the pyrolysis process of a mixture of coconut fiber biomass and rice husk with PP plastic waste. The composition ratio with a mixture of more PP plastic waste tends to increase the value of the resulting yield, while the composition ratio with a mixture of more coconut fiber biomass and rice husks will tend to decrease the value of oil yield from the pyrolysis process.

Table 3. Pyrolysis oil yield data

Composition	Ratio (%)				
PP:Biomassa (%)	0:100	25:75	50:50	75:25	100:0
Yield (%)	39.72	41	45.28	50.66	82.38

Based on the data in Table 4, the density of oil from the pyrolysis process of a mixture of coconut fiber biomass and rice husk with PP plastic waste ranges from 846.6 to 1158.18 kg/m³. The highest density of oil from the pyrolysis process was produced with a composition ratio of 100% coconut fiber biomass and rice husk mixture of 1158.18 kg/m³, while the lowest density of oil from the pyrolysis process was obtained from a composition ratio of 100% PP plastic waste, which was 846.6 kg/m³. The composition ratio influences the results of the density of oil from the pyrolysis process of a mixture of coconut fiber biomass and rice husks with PP plastic waste. The composition ratio with more coconut fiber biomass and rice husk mixture, the greater the density value, rather than the composition ratio with more PP plastic waste.

Table 4. Pyrolysis oil density data

Composition	Ratio (%)				
PP:Biomassa (%)	0:100	25:75	50:50	75:25	100:0
Density (kg/m³)	1158.18	888.9	867.16	850.33	846.6

Based on the data in Table 5, the oil from the pyrolysis process of a mixture of coconut fiber biomass and rice husk with PP plastic waste has a viscosity ranging from 0.65499 to 1.58696 cP. The highest viscosity of oil from the pyrolysis process is produced with a composition ratio of 100% coconut fiber biomass mixture and rice husk with 0% PP plastic waste, which is 1.58696 cP, while the lowest viscosity of oil from the pyrolysis process is obtained from a composition ratio of 0% coconut fiber biomass mixture and rice husk with 100% PP plastic waste, which is 0.65499 cP. The oil obtained by pyrolysis from a combination of rice husk, coconut fiber biomass, and PP plastic waste may vary in viscosity depending on the composition ratio. As the composition ratio of the combination of coconut fiber biomass and rice husk with PP plastic waste increases, the viscosity value of the pyrolysis oil with varying composition ratios of the three components tends to rise.

Table 5. Pyrolysis oil viscosity data

Composition	Ratio (%)				
PP:Biomassa (%)	0:100	25:75	50:50	75:25	100:0
Viscosity (cP)	1.58696	0.94296	0.91999	0.80869	0.65499

Figures 2-6 show that pyrolysis oil with a composition of 100% coconut fiber biomass and rice husk produces pyrolysis oil with the most concentrated visual and black color. The mixture ratio of coconut fiber biomass and rice husk with PP plastic waste with the composition of 25:75%, 50:50%, 75:25%, and 0:100% produces pyrolysis oil with visual clarity and clear yellow color. Variations in the composition ratio affect the visual and color of the pyrolysis oil, where the addition of PP plastic waste makes the visual color of the oil clearer and clearer yellow.

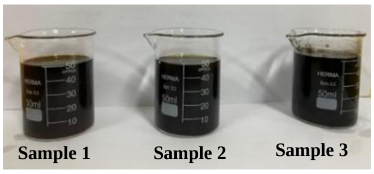

Figure 2. 100% biomass pyrolysis oil

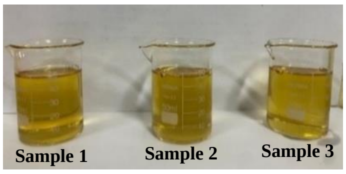

Figure 3. Pyrolysis oil 75% biomass:25% PP

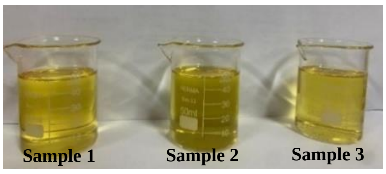

Figure 4. Pyrolysis oil 50% biomass:50% PP

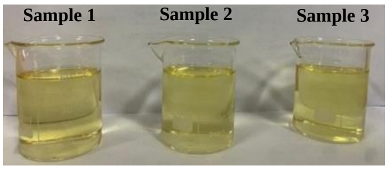

Figure 5. Pyrolysis oil 25% biomass:75% PP

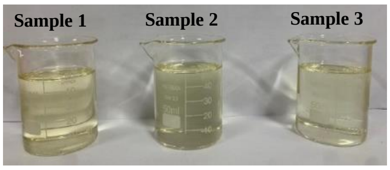

Figure 6. 100% PP pyrolysis oil

3.2. Discussion

Based on Figure 7 the volume of pyrolysis oil mixed with biomass and PP plastic waste was 226.66 to 616.66 ml. Temperature is very influential in the pyrolysis process, where the higher the pyrolysis temperature, the higher the volume of oil produced [5]. This opinion is confirmed by Paris *et al.* [21] high combustion temperatures trigger the thermal decomposition of biomass solids into gases more optimally, producing more liquid smoke and conversely less biochar. This makes it correlates with this study that the pyrolysis oil from the mixture of coconut fiber biomass and rice husk with PP plastic waste using the highest temperature of 523.7 °C will produce more quantity compared to the pyrolysis of palm waste biomass with PP plastic at 316.25 °C.

Based on Figure 8, the quantity (volume) of oil produced through the distillation process of a mixture of coconut fiber biomass and rice husk with PP plastic waste ranges from 41 to 178 ml. The highest oil yield in the pyrolysis process was obtained from the composition ratio of 0% coconut husk biomass and rice husk with 100% PP plastic waste, which was 178 ml. The least quantity (volume) results obtained from the pyrolysis process were obtained from the composition variation of 75% coconut husk biomass and rice husk with 25% PP plastic waste, which was 41 ml. The composition ratio influences the quantity (volume) of pyrolyzed oil. The composition ratio of the mixture with more coconut fiber biomass and rice husk compared to PP plastic waste will produce less oil, otherwise, the mixture with a composition ratio of coconut fiber biomass and rice husk less compared to PP plastic waste will produce more oil.

Based on the data in Figure 9, the pyrolysis yield data obtained ranged from 39.72 to 82.39%. This yield value is higher than the research [22] which was able to produce a yield value of 39.26% from the low-density polyethylene (LDPE) plastic pyrolysis process. According to Supriyanto *et al.* [23], the liquid smoke yield tends to increase as the pyrolysis temperature and time increase until the condition where the production of difficult-to-condense gases increases so that further increases in pyrolysis temperature and time will decrease the liquid smoke yield. This correlates with this study that the oil yield from pyrolysis of a mixture of coconut fiber biomass and rice husks with PP plastic waste with the highest temperature of 523.7 °C produced a yield value of 82.39%. This result is greater than the yield value of the LDPE plastic pyrolysis process with the highest temperature of 500 °C resulting in a yield value of 39.26%. Tu *et al.* [24] stated, that the higher the yield produced, the greater the oil produced. This is also correlated with this study, where the lowest yield value of 39.72% was obtained from a mixture ratio of 100% coconut fiber biomass and rice husk which produced 226.67 ml of oil, while the highest yield value of 82.39% was obtained from a mixture ratio of 100% PP plastic waste with an oil quantity (volume) of 616.66 ml.

Based on the data in Figure 10, the density obtained in this study ranged from 846.6 to 1158.58 kg/m³. The density of pyrolyzed oil tends to be lower when the ratio of PP plastic waste mixture is more than the mixture of coconut fiber biomass and rice husk, on the other hand, the density value will be higher when the composition ratio of the mixture of coconut fiber biomass and rice husk is more than PP plastic waste. The greater the density value states that the material used has many components contained. The number of components contained results in the longer process of atomization of the components that make up the oil during the combustion process [22]. The density of fuel oil certainly has a standard as a benchmark as described by [25], that the specification of gasoline fuel oil is 715 to 770 kg/m³ and diesel fuel is 815 to 880 kg/m³. The density of the results of this study leads to the specification of diesel fuel oil with the composition ratio of mixing PP plastic with biomass waste of coconut husk and rice husk with a ratio of 100:0%, 75:25%, 50:50% produces a density of 846.6 to 867.17 kg/m³. The results of the three ratios lead to the specification of diesel fuel oil. The density of pyrolysis oil from the composition ratio of 75% biomass mixture of coconut fiber waste and rice husk with 25% PP plastic obtained a density value of 888.9 kg/m³. This result almost leads to the standard specifications of diesel fuel, except that the result is higher by 8.9 kg/m³. According to Oasmaa and Czernik [25], the highest density specification of fuel oil is 991 kg/m³, so the mixture of 100% biomass of coconut fiber waste and rice husk does not meet the available specifications.

Based on the data in Figure 11, the viscosity value of oil from pyrolysis of coconut fiber and rice husk waste biomass mixture with PP plastic ranges from 0.65499 to 1.58696 cP. The highest viscosity value was obtained from the composition ratio of 100% coconut fiber and rice husk at 1.58696 cP. The lowest viscosity value was obtained from the composition ratio of 100% PP at 0.65499 cP. The relationship between density and viscosity is linear; a greater density indicates a higher viscosity [26]. The viscosity value is inversely proportional to temperature; a lower temperature results in a higher viscosity and a higher temperature results in a lower viscosity. A substance's viscosity decreases as its temperature rises [27]. According to Arkoudeas *et al.* [28], the result is close to the gasoline specification of 0.652 cP. The result of pyrolysis oil viscosity with a 100% PP plastic ratio has the lowest value of 0.654994 cP [29], suggesting that these results are close to the gasoline specification of 0.652 cP. The results of pyrolysis oil viscosity with the ratio of PP plastic to coconut fiber biomass and rice husk 75:25% and 50:50% has a value of 0.80809 to 0.91999 to 0.94296 cP. According to Christensen *et al.* [29], these results lead to the diesel fuel oil specification of 0.93 cP.

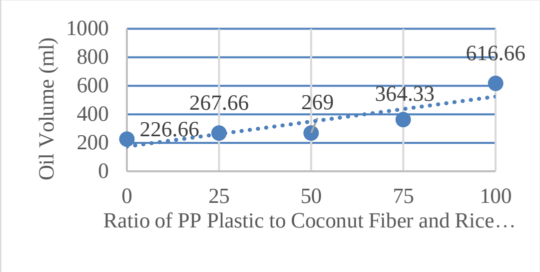

Figure 7. Pyrolysis oil quantity data

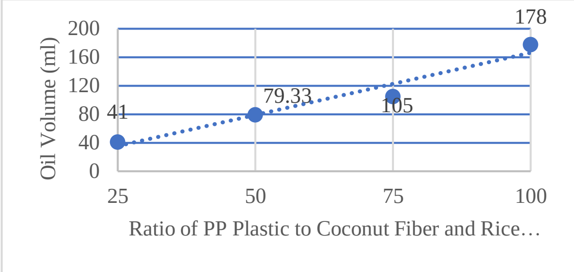

Figure 8. Distilled oil quantity data

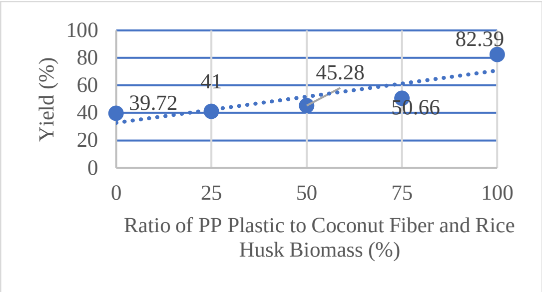

Figure 9. Pyrolysis oil yield data

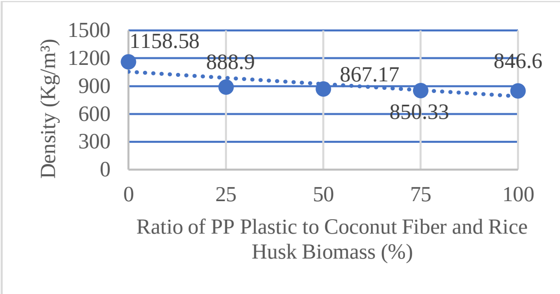

Figure 10. Pyrolysis oil density data

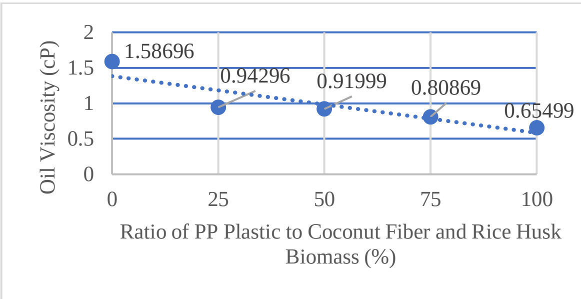

Figure 11. Pyrolysis oil viscosity data

4. CONCLUSION

The production of bio-oil products from waste may be used by the community as a replacement for fossil fuels, which helps to reduce environmental pollution. Quantity (pyrolysis oil and distillation oil volume) and quality (yield, density, viscosity, visual, and color) are affected by the ratio of RDF-3 fluctuation in a biomass combination of coconut fiber waste, rice husk, and PP plastic, according to this study's findings. RDF-3 mixed with 100% PP plastic produces the most quantity of pyrolyzed oil. The results of oil quality testing were obtained in the aspect of the best density value by fuel oil specifications, namely the composition ratio of 100% PP:0% Biomass of 846.6 kg/m³. The highest yield value is obtained from a ratio of 100% PP plastic of 82.39%, then the viscosity value that is directed in the gasoline category is a composition ratio of 100% PP plastic of 0.65499 cP. The last aspect is seen from the best visual and color obtained in the composition of 100% PP plastic with clear visual and clear yellow. The best configuration of 100% PP plastic ratio has the best quantity and quality of pyrolysis oil. Making and testing oil with the pyrolysis method is able to produce oil that is close to the specifications of gasoline fuel oil.

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