UTILIZATION OF PP PLASTIC WASTE (POLYPROPYLENE) INTO FUEL OIL THROUGH THE PYROLYSIS PROCESS WITH SAWDUST MIXED WITH USED OIL BRIQUETTES GASIFICATION

Compiled as one of the requirements for completing the undergraduate study program at the Department of Mechanical Engineering, Faculty of Engineering, Universitas Muhammadiyah Surakarta

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Abstract

Polypropylene (PP) plastic waste is a hydrocarbon polymer made from petrochemicals; has a large amount of volatile material (>99% by weight) with a high calorific value and low ash content (0.1% by weight); which may support better product yields from thermal decomposition. The pyrolysis of PP plastic waste can be used as an alternative fuel oil to replace energy from fossil fuels. In this research, the effectiveness of sawdust mixed with gasification of used oil briquettes gasification in the process of plastic waste utilization was tested by Water Boiling Test (WBT). The results show that the effective temperature and effective flame duration of the gasification stove in the PP process is 810.21°C with the duration of 210 minutes calculated from an average of six combustion times. The performance of the water boiling test shows that the kerosene is able to boil water at 6.5 minutes while the pyrolites are able at 5.5 minutes.

Keywords: Plastic, Pyrolysis, sawdust, gasification, briquettes

1.INTRODUCTION

Garbage is one of the problems in the world that until now has not been able to solve the solution. While old waste has not been decomposed, national waste production continues to increase in line with the increasing population of Indonesia. Meanwhile, the use of plastic in everyday life continues to increase. The process of buying and selling in the market requires plastic, food packaging uses plastic. What's interesting is processing plastic waste into an alternative energy source. So far, plastic waste is only burned, used plastic bottles are only sold to collectors to be reprocessed into plastic products. One of the studies on the management and development of plastic waste is to recycle it by means of pyrolysis.

In the world a total of over 100 million tons of plastic is manufactured to meet global plastic demand. This much production and consumption of plastic is a threat to environment as it takes several years to decompose naturally. (Saxena, et al., 2007)

The traditional treatment for plastic waste is recycling, landfilling or burning. Incomplete combustion can produce toxic substances and cause serious health problems. Therefore, a large amount of energy can be generated by converting plastic waste into oil. This can be an alternative energy source to replace fossil fuels. This conversion process is called pyrolysis. (M.Garib Alla, et al., 2014)

Plastic waste recycling has been the focus of many researchers in recent decades. Pyrolysis appears to be a promising technique for converting solid plastic waste (SWP) into more useful materials such as gas fuel and/or fuel oil or into high value feedstock for the chemical industry. The degradation of used plastic materials, by heating in an inert pyrolysis atmosphere, is usually carried out at moderate temperatures between 400-800 °C. The products obtained are volatile hydrocarbon oil and gas with high calorific value which cannot be condensed. (Miteva & Aleksovski, 2016)

The most common plastics used as raw materials for the production of liquid hydrocarbons are high density polyethylene (HDPE), polypropylene (PP) and polystyrene (PS) which produce a mixture of hydrocarbons. High-density polyethylene (HDPE), a thermoplastic polyethylene made from petroleum, is used for the catalytic production of light hydrocarbons, and polystyrene (PS), a synthetic aromatic polymer of styrene is a liquid petrochemical that is converted to hydrocarbons by pyrolysis of microwave-metal interactions. Polypropylene (PP) is a hydrocarbon polymer made from petrochemicals; has a large amount of volatile material (>99% by weight) with a high calorific value and low ash content (<0.1% by weight); which may support better product yields from thermal decomposition. (Pundhir & Gagneja, 2016)

Gasification is a thermochemical process technology that converts solid biomass into a combustible gas. The gasification process using the TLUD (Top Lit Up Draft) method can produce fewer emissions so that it is more environmentally friendly. During the gasification period using the TLUD method on gasification stoves with various designs. This is done to get the best performance from the gasification stove. (Wijianto, et al., 2021) Indonesia is a developing country with agriculture and plantation sectors as the main priority in its development. The agricultural and plantation sectors usually always produce biomass waste. Biomass waste is rarely used optimally. Biomass and waste biomass can be an alternative energy source to replace energy from fossil fuels. (Wijianto, et al., 2020)

1.1 Plastic

The discovery of plastic is an important milestone in improving the quality of human life. Since they were first synthesized in the early 1900s, plastics have replaced materials such as wood, metal, and ceramics in the production of consumer products due to their light weight, durability, resistance to most chemicals, and low manufacturing costs. (Sartorius, 2010)

Plastics can be grouped into two types, namely thermoplastic and thermosetting. Thermoplastic is a plastic material which, when heated to a certain temperature, will melt and can be reshaped into the desired shape. Meanwhile, thermosetting is a plastic which, when made in solid form, cannot be re-melted by heating (UNEP, 2019). Based on the properties of the two groups of plastics above, thermoplastic is the type that allows it to be recycled.

The types of plastic that are most often processed are polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) and polyvinyl chloride (PVC). Types of plastic that can be recycled are coded in the form of a number for easy identification. The plastic code number will be listed on products made of plastic as shown in the following image.

Figure 1. Plastic code number

Important thermal properties data in the plastic recycling process can be seen in the following table:

Table 1. Transition temperature and plastic melting temperature data

Type of Material	Tm (°C)	Tg (°C)	Max Working Temperature (°C)
PP	168	5	80
PE	134	110	82
LDPE	330	115	260
PA	260	50	100
PET	250	70	100
ABS		110	85
PS		90	70
PMMA		100	85
PC		150	246
PVC		90	71

Source: (U.B, 2013)

From the data above, it can be seen that the melting point and transition temperature of plastics vary according to the type of plastic. The table can also be used as a benchmark in the melting of plastic properties to be reprocessed or recycled.

1.2 Pyrolysis Process

The pyrolysis process with this distillation apparatus is also a method that has recently been frequently used in research. According to pyrolysis is the process of heating a substance in the absence of oxygen so that there is a decomposition of the components that make up the coconut shell. Another term for pyrolysis is the disordered decomposition of organic matter caused by heating without contact with outside air. (Irawan & Ridhuan, 2020)

The pyrolysis method is the most promising method. Pyrolysis comes from two words, namely pyro which means heat, and lysis which means decomposition or degradation, so pyrolysis means the decomposition of biomass by heat at a temperature of more than 150 °C. (Wahyudi, et al., 2018)

Several important steps in the plastic pyrolysis process is described in the following image scheme:

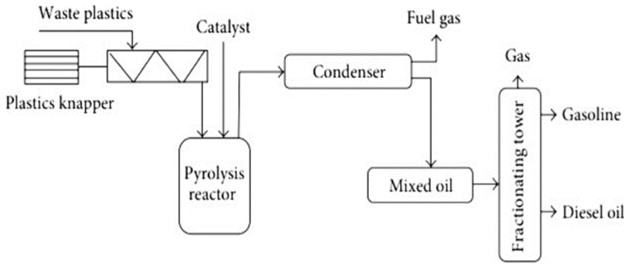

Figure 2. Pyrolysis Process (Isworo, 2018)

From the schematic image, several important steps in the plastic pyrolysis process must be considered are as follows:

1. Heat plastics evenly without excessive temperature variations.
2. Cleaning oxygen from the pyrolysis chamber.
3. Manages carbon charcoal byproducts before turning them into thermal insulators and reduces heat transfer to plastics.
4. Careful condensation and fractionation of pyrolyzed vapors to produce a distillate of good quality and consistency.

1.3 Gasification

Gasification is a thermochemical process to convert solid fuel into gas, where the air required is lower than the air used for the combustion process. This process takes place in a device called a gasifier. (Jenderal , et al., 2018)

Gasification is the process of converting solid fuels (eg biomass, coal) into gaseous products using air / O2 / H2O / CO2, or a mixture thereof with a reactant ratio of between 20-70% of the stoichiometric requirement. The product gas is known as producer gas which consists of flammable gases (CO, H2, and CH4) and non-combustible gases (CO2 and N2). These gases can be used as a source of energy. In addition to these gases, producer gas also contains tar and other contaminants. The gasification process consists of several stages, namely drying, pyrolysis, oxidation, and reduction processes. (Isworo, 2018)

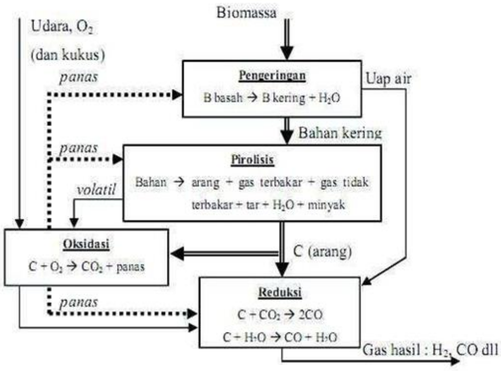

Figure 3. Schematic of the gasification process (Isworo, 2018)

From the working scheme of the gasification process, there are four stages of biomass gasification. The first is drying, a process of evaporation of water vapor that occurs at a temperature of 100 ± 250°C. Pyrolysis, which is the thermal decomposition of solid feed produces combustible gases (H2, CO, CH4, and other hydrocarbons), unburned gases (CO2, H2O), tar, oil, and charcoal. This stage takes place at temperatures between 250-500°C. Oxidation, also known as combustion, is the stage in which the reaction occurs between biomass, charcoal, and pyrolysis products with oxygen from the gasifying medium. This reaction is very exothermic, so the heat it produces can meet the needs of drying, pyrolysis, and reduction processes. Generally, the combustion temperature reaches 1200 °C.ΔH298 = -393.5 kJ/mol. Reduction, which is the stage of an equilibrium reaction between CO2 from the oxidation stage and the charcoal produced by the pyrolysis stage. This reaction is endothermic, with the required heat obtained from the oxidation step, which can occur at temperatures above 800 ± 1000 °C. The reduction reaction that occurs between carbon and carbon dioxide is called the Bouduard reaction.

1.4 Water Boiling Method

Boiling water test is a method that is often used as a parameter to test combustion, such as gasification test or oil quality test. In this study, the boiling water test was used to test the quality of PP plastic waste resulting from pyrolysis by gasification by burning sawdust mixed with used oil briquettes.

In this test, the pyrolysis oil will be tested for boiling water with an oil stove. Where the PP plastic pyrolysis oil will be compared with kerosene using the boiling water test method. Meanwhile, to measure the heat of PP plastic pyrolysis oil must use a bomb calorimeter. Due to limited tools, the researchers approached the calculation of the heating value of the pyrolysis process oil. Meanwhile, the ratio of kerosene has a calorific value of 10,478.95 Cal/gr from the data archive of the Ministry of Energy and Mineral Resources of the Republic of Indonesia. So, the researchers used the data as a theoretical reference.

2.RESEARCH METHODOLOGY

The type of research used in this research is an experimental use of plastic waste into fuel oil by using a distillation process where the combustion process is gasified with sawdust mixed with used oil briquettes. The process stages in this experiment are shown in the flow chart.

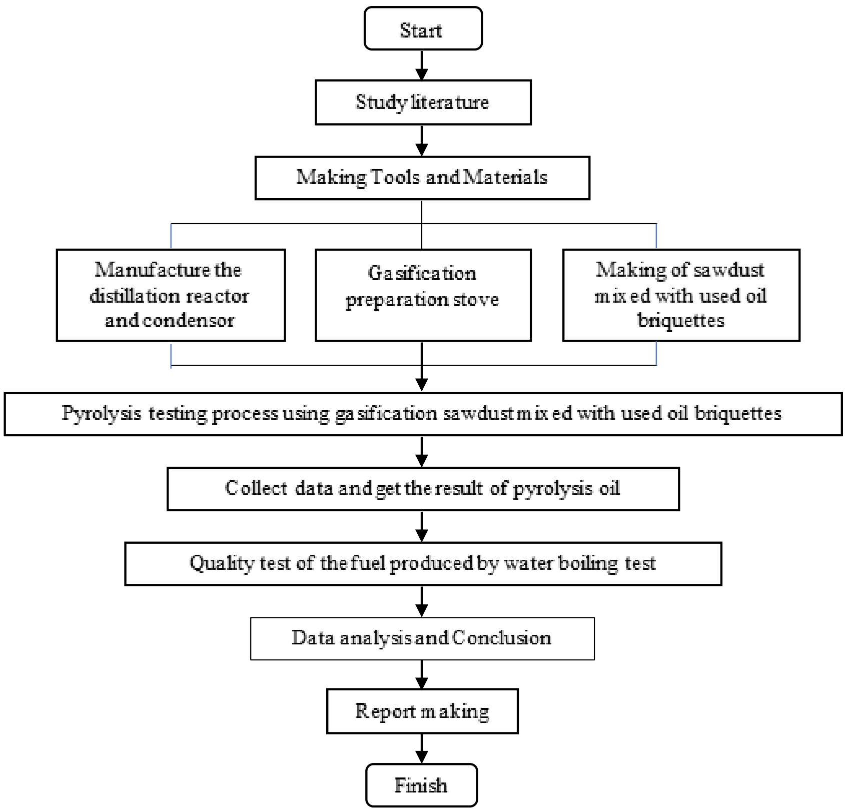

Figure 4. Research flow diagram

2.1 Research installation

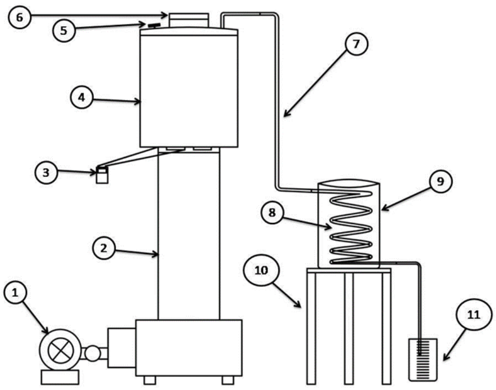

Figure 5. Testing Installation

Information:

1. Blower	7. Steam connection pipe
2. Gasification furnace	8. Copper pipe
3. Thermocouple temperature	9. Condensor
4. Reactor Tubes	10. Condensor chair
5. Thermogauge distilator	11. Measuring cup of fuel oil
6. Shut the reactor	

2.2 Research procedure

In conducting this research, several steps must be taken. The research steps are as follows:

a. Prepare all equipment and materials to be used
b. Assemble all research tools as shown in Figure 5.
c. Entering the chopped plastic waste in the form of PP (Polypropylene) into the waste distillation reactor
d. Fill all coolant in the distiller with water and ice
e. Using the uplift drag method, by turning on the top as a method of burning sawdust mixed with used oil briquettes
f. Entering 900 grams of sawdust mixed with used oil briquettes into the gasification stove reactor
g. Turn on the blower as an air supply

h. Logs all parameters generated in the test

i. If the gasification stove runs out, it is carried out in parallel by providing 2 stoves that are ready to be used as combustion materials until complete.

j. Repeating the test until the plastic waste pyrolysis process is complete.

k. After carrying out all the steps to get fuel oil, then do water boiling test to determine the quality of the oil fuel by comparing it with kerosene.

2.3 Stages of analysis

Analysis of research results was carried out after the research data was obtained and processed. Things that need to be analyzed are the graphs obtained from the gasification test of sawdust mixed with used oil briquettes and the pyrolysis process of plastic waste.

3.RESULT AND DISCUSSION

3.1 Average Combustion Temperature of Sawdust Mixed with Used Oil Briquette Gasification on Six Stoves

Figure 6. shows the average flame temperature per gasification stove for sawdust mixed with used oil briquettes. It can be seen in the graph that the average gasification stove that is lit is not constant. This proves that the flame of the gasification of sawdust mixed with used oil briquettes fluctuates. In the first ignition, the average flame is 816°C, the second ignition is 797.43°C, the third ignition is 829.43°C, the fourth ignition is 837.29°C, the fifth ignition is 736.67°C and the last ignition is 833.14 °C. So, from the six ignitions of the sawdust mixed with used oil briquettes gasification stove, the average temperature for the six ignitions with a duration of 210 minutes is 810.21°C.

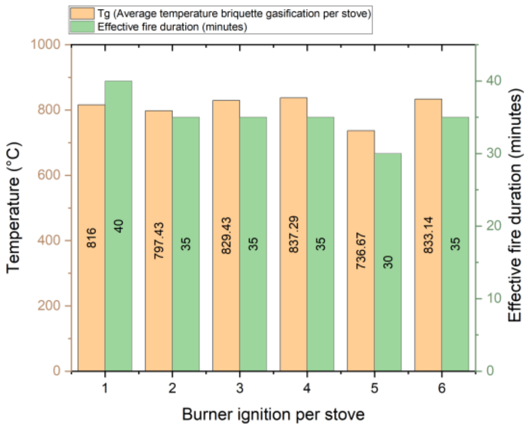

Figure 6. Diagram Average temperature of sawdust mixed with used oil briquettes gasification per stove

3.2 Average Temperature in the Distillation Reactor Section

In the diagram above, it can be seen that during the ignition of the six gasification furnaces with a duration of 210 minutes, the average temperature in the distillation reactor section always increases per ignition of the sawdust mixed with used oil briquettes gasification furnace. At first ignition, the average temperature at the bottom of the reactor is 695.25°C and the reactor chamber is 128.75°C. On the second ignition, the average temperatures at the bottom of the reactor and the reactor chamber were 657.57°C and 176.43°C, respectively. at the third ignition average is 690°C and 172.86°C. On the fourth ignition, the temperatures are 691.86°C and 202.86°C. Then on the fifth ignition 621.83°C and 170.83°C. Finally, on the sixth ignition, it is 707°C and 229.29°C. So that the average temperature at the bottom of the reactor and the reactor chamber sequentially for six times the ignition of the sawdust mixed with used oil briquettes gasification stove is 677.25 °C and 180.17 °C.

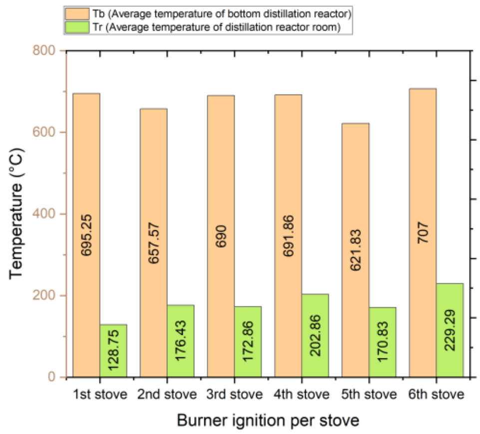

Figure 7. Diagram Comparison of the average temperature in the distillation reactor

3.3 Total Mass of Fuel Produced from the Pyrolysis Process

The researchers found that by pyrolysis of 3000 grams PP plastic waste by burning sawdust mixed with used oil briquettes gasification, the amount of oil obtained was 1.73 liters for 210 minutes of pyrolysis.

Figure 8. Oil resulting from pyrolysis by burning gasification of sawdust mixed with used oil briquettes

Tar or plastic residue is chopped up in the distillation reactor. The measuring instrument recorded tar (leftover) from melted plastic weighing 521 grams. This proves that the results of the existing pyrolysis process will leave melted plastic in the chamber in the distillation reactor.

Figure 9. Tar (residual) Pyrolysis Process measured

So, from the simple calculation above, it can be seen that from 3000 grams of chopped PP type plastic, 39,96% becomes unmeasured residual tar, 42,67% becomes fuel oil and 17,37% becomes tar (residual). Unmeasured tar means that tar (residual) from the distillation reactor cannot be removed because it has stuck to the inside of the reactor tube, so that from this pyrolysis plastic process can be produce oil with a ratio of 1:3.

3.4 Water Boiling Test

The boiling water test is tested using 100 ml of fuel each and will light up until the fuel runs out. The fuel used is kerosene and oil from the pyrolysis of PP plastic waste. The water used is 1 kg. From Figure 10. it can be seen that in the test with kerosene the highest water temperature reached 99°C at 6.5 minutes and was stable for up to 26 minutes. In testing with plastic pyrolysis fuel oil, the highest water temperature was 99°C at 5.5 minutes and stable up to 21 minutes. Then the temperature begins to decrease in proportion to the flame that begins to fall. Ignition with kerosene fuel for 51 minutes 32 seconds while ignition with fuel oil for 38 minutes 30 seconds. During that time, burning kerosene produced 65 grams of water, and 464 grams of pyrolysis oil burned. From these data it can be seen that at the beginning of the ignition of the oil stove, the flame with pyrolysis oil fuel is hotter. The time it takes to boil the water is almost the same. Thus, the combustion of kerosene compared to pyrolysis oil is not much different. Only the resistance and duration of the flame of kerosene is longer than that of pyrolysis oil.

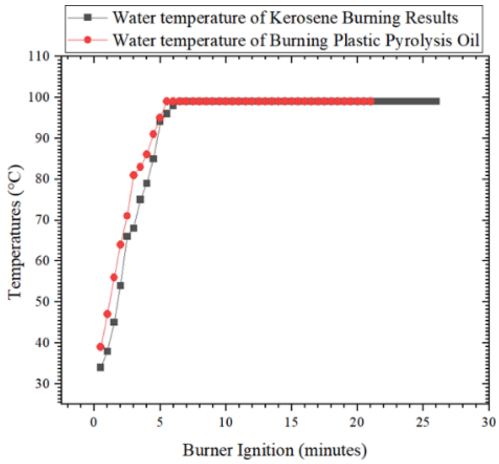

Figure 10. Graph Comparison of Water Boiling Test between Kerosene and Pyrolysis Oil

4.CONCLUSION

Effective temperature and effective flame duration of sawdust mixed with gasification of used oil briquettes in the PP plastic waste pyrolysis process is 810.21°C with a duration of 210 minutes calculated from an average of six combustion times. The average temperature at the bottom of the reactor and the reactor chamber which was carried out for six times of ignition of sawdust mixed with used oil briquette gasification stove was 677.25 °C and 180.17 °C. The mass of the pyrolysis fuel from 3000 grams of shredded PP type plastic is 1280.2 gr and 521 gr residue, in the percentage of 42.67% being fuel oil, 39.96% being unmeasured tar residue, and 17.37% being tar (residual).

The quality of the pyrolysis fuel with the performance of the water boiling test, pyrolysis oil is able to boil water at 5.5 minutes while kerosene is able to boil water at 6.5 minutes. Pyrolysis oil has higher flammability than kerosene. With 100 ml, pyrolysis oil can burn for 38 minutes 30 seconds while kerosene can burn for 51 minutes 32 seconds. The density of pyrolysis oil in this study was 0.74 gr/ml while kerosene was 0.78 gr/ml. The calorific value of pyrolysis oil by approximate calculation is 6913 cal/gr.

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