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Fuel from plastic waste using the pyrolysis method

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Abstract

This study aims to address the environmental and health hazards posed by plastic waste in Blora Regency, Indonesia, by investigating the conversion of plastic waste into fuel oil using the pyrolysis method. Specifically, it explores the potential of converting Polypropylene (PP) and High-Density Polyethylene (HDPE) waste collected during the Eid holiday, when waste generation surges, into valuable fuel. Waste PP and HDPE plastic were collected and pyrolyzed in a reactor under varying temperatures and time durations. The fastest oil production for PP was achieved at 450°C in 300 minutes, while HDPE reached optimal oil yield at 330°C in 330 minutes. The influence of temperature and time on the volume of oil produced and the overall pyrolysis process was analyzed. The study successfully converted plastic waste into fuel oil through pyrolysis. Temperature and time significantly impacted the oil yield, with higher temperatures generating more oil but shortening the pyrolysis duration. PP and HDPE demonstrated different optimal temperatures for maximizing oil production. Utilizing pyrolysis to convert plastic waste into fuel oil offers a promising solution for managing plastic waste in Blora Regency. This approach not only reduces landfill burden and environmental pollution but also creates a valuable energy resource from a potential hazard. Further research is needed to refine the pyrolysis process for optimal efficiency and explore potential economic and environmental benefits of implementing this technology on a larger scale.

Keyword

Fuel, Plastic waste, Pyrolysis method

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Introduction

Plastic waste poses serious hazards to the environment and human health. The volume of waste in Blora Regency, Central Java, increased significantly during the Eid holiday. On regular days, it averages 20.04 tons/day but surged to 28.183 tons/day, marking an increase of 8.143 tons per day (40.63%) of waste entering the landfill [1]. Its durable and non-biodegradable nature makes it one of the most detrimental environmental pollutants. Improperly managed plastic waste can contaminate oceans, land, and air, negatively impacting wildlife and ecosystem balance.

There is a problem of Blora Regency government is plastic pollution wreaks havoc on the environment. Improperly managed plastic contaminates oceans, soils, and air, disrupting ecosystems and endangering wildlife. In Blora Regency, this translates to clogged waterways, degraded soil fertility, and potential health risks for communities. But in the other hand, conventional waste management strategies struggle to cope with the volume and characteristics of plastic waste. Landfill's overflow, while existing recycling infrastructure often lags behind the ever-growing problem. This leaves Blora Regency facing a double-edged sword: an environmental threat from plastic pollution and an operational burden on waste management systems. Finding sustainable solutions for plastic waste management is crucial for the health and well-being of both the environment and communities in Blora Regency.

However, there is a significant opportunity to change how we perceive and manage plastic waste. Innovations in recycling, reducing the use of single-use plastics, and developing eco-friendly waste management methods offer hope to mitigate the negative impacts of plastic waste. One waste management approach involves converting it into fuel. Considering that plastic raw materials originate from petroleum, plastics can be reprocessed into hydrocarbons as the basic energy source [2].

There are several methods for processing plastic waste based on the 3R principle: Reduce, Reuse, and Recycle. Each of these methods has its own advantages and disadvantages, often depending on the type of plastic, technological availability, and associated environmental aspects. One waste management method applied in this research involves the use of pyrolysis. Pyrolysis is a process of breaking down a material at high temperatures that occurs in the absence of air or with limited air. The decomposition process involves high temperatures and low pressures, reaching up to 800°C and 700 kPa [3]. But in [4] pyrolysis is a heating process (without oxygen) that turns organic materials like wood or plastic into oil and charcoal, at temperatures between 400 and 650 degrees Celsius.

Pyrolysis of plastic waste involves heating organic compounds within the plastic with little or no oxygen. This process breaks down the chemical structure of the material into gas, oil, and residues such as wax and char. Long-chain hydrocarbon compounds found in plastics are expected to be broken down into shorter-chain hydrocarbons that can be used as oil fuel during the pyrolysis process [2]. Continuous pyrolysis technology can also be used to treat the 24% of municipal solid waste in Malaysia that comes from plastic [5]. By utilizing pyrolysis, it is hoped that plastic waste can be reduced and recycled, particularly plastics that are difficult to recycle, thereby adding value and increasing revenue.

This research delves into the potential of pyrolysis for Blora Regency i.e. a) e will investigate the optimal conditions for converting two common plastic types, Polypropylene (PP) and High-Density Polyethylene (HDPE), into fuel, b) we will analyze the influence of temperature and time on the pyrolysis process and oil yield, and c) our findings aim to contribute to the development of efficient and sustainable waste management strategies in Blora Regency and beyond.

The research related to the processing of plastic waste into fuel using the pyrolysis method has been widely conducted. Wajdi et al., in a journal titled Processing of plastic waste into oil fuel by pyrolysis method as an alternative energy [2]. The plastic waste used consisted of Poly Propylene (PP) and High-Density Poly Ethylene (HDPE). The highest yield of pyrolysis oil was obtained at 300°C, with 110 ml produced from PP plastic waste, while 145 ml was obtained from HDPE. The pyrolysis process from PP plastic waste took the shortest time, at 60 minutes, whereas HDPE plastic waste required 30 minutes. The density of the pyrolysis oil from PP was approximately 777,777 kg/m3, closely approaching the density of ethanol fuel and also near to diesel fuel, which is 818,181 kg/m3. Meanwhile, HDPE had a density close to gasoline fuel, approximately 714,285 kg/m3.

The utilization of pyrolysis methods in the treatment of used plastic bottles from drinking water to produce oil fuel was also carried out by Dhaniswara et al. [6]. This research utilized a pyrolysis reactor with temperature variables of 200°C, 250°C, 300°C, 350°C, and 400°C for 30, 60, and 90 minutes. The liquid resulting from pyrolysis was taken for calorimeter analysis, flash point determination, ash content, water content, and composition analysis using GC-MS.

Sugiarto et al. also conducted the production of oil fuel from plastic waste using the pyrolysis process with two types of plastics [7]. The plastics used as raw materials were High Density Polyethylene (HDPE) and Polypropylene (PP). The raw materials introduced into the stainless-steel pyrolysis reactor ranged from 500 grams to 2500 grams for each type of plastic. The heat source used to heat the reactor was biomass pellets made entirely from wood. The pyrolysis oil produced from PP seeds was 72%, whereas the pyrolysis oil from HDPE plastic waste was 31%. The density results of the pyrolysis oil approached the density value of Pertamax fuel. The heating value of the pyrolysis oil approached the heating value of kerosene. The flash point value of the pyrolysis oil falls within the flash point value range of kerosene.

The utilization of Mount Merapi sand as a catalyst to expedite the pyrolysis reaction was carried out by Rahmadanty using Low Density Polyethylene (LDPE) plastic [8]. Mount Merapi sand catalyst was chosen due to its high silica content with the aim of enhancing both the quantity and quality of the oil. For a single pyrolysis process, 540 grams of plastic and 60 grams of catalyst were used at temperatures of 450°C and 500°C. The maximum quantity of oil was produced at the temperature variation of 500°C, amounting to 69.23%. Oil testing results based on parameters such as flash point ranged from 149.67°C to 155.33°C, density values ranged from 0.76 g/cm^3 to 0.77 g/cm^3, and calorific values ranged from 9341.88 cal/g to 9440.19 cal/g. The quality analysis of the resulting oil product indicates that the LDPE pyrolysis oil can be categorized as kerosene and biodiesel according to the Indonesian National Standard (SNI).

Apart from pyrolysis, another method for plastic waste management was conducted by Nindita [9]. This method is Thermal & Catalytic Cracking (Ni-Cr/Zeolite), applied in the production of fuel oil from LDPE and PVC plastic waste. The research aimed to determine the fuel oil characteristics derived from LDPE and PVC plastics when applied to engines, potentially replacing previously used premium or diesel fuels. This study encompassed two stages: the thermal process (thermal cracking) and the addition of a catalyst (catalytic cracking). The primary outcome of the research was an optimal method for manufacturing fuel from LDPE and PVC plastics using a homogeneous catalyst based on modified natural zeolites with Ni and Cr to break down plastic waste.

In 2019, Nisar studied waste polystyrene from a local market. They heated it at different rates and temperatures under nitrogen. They found the best conditions for making fuel oil were 410°C for 70 minutes [10]. And Zhang study about investigated using heat to break down plastic waste in a rotating kiln, aiming to recover liquid oils valuable for chemicals or fuels. They tested different amounts of heat carriers and plastic types, finding that 15% heat carrier yielded the most oil. Mixed plastic waste pyrolysis produced oil with the most gasoline-like hydrocarbons (89.1%). Simulated distillation showed this oil contained 49-84.5% gasoline [11].

What sets the authors research apart from previous researchers is the pyrolysis reactor, a setup consisting of a 28-liter capacity combustion furnace made of stainless steel, a heater, an inner furnace, a condenser to convert gas into liquid, thermosensors to detect reactor temperature, and a trap for liquid products. The heating furnace is made of 5 mm thick stainless-steel plates. The furnace has a diameter of 300 mm and a height of 400 mm. Inside the furnace, there is a material container made of 1 mm thick stainless steel, with a diameter of 29.5 mm and a height of 200 mm. This material container is designed for easy removal and insertion to facilitate residue cleaning processes. The reactor can accommodate 1 kilogram of unshredded plastic waste or 5 kilograms of shredded plastic waste. The furnace lid is cone-shaped with an outlet at the tip to collect gas, directing it entirely towards the condenser. The height of the furnace lid is 170 mm. The furnace outlet is connected to the condenser via a 55 mm long, 7 mm diameter gas pipe.

Methods

Pyrolysis Reactor Specification

The pyrolysis specifications used in this study are presented in Figure 1.

1. Temperature controller: The device that functions to read and control the temperature inside the combustion furnace.
2. Combustion furnaces the device for combustion carried out through the process of heating a nichrome wire

3. Pyrolysis tube and pyrolysis column: The pyrolysis tube is the container used for heating the raw material to be processed. The pyrolysis column is where the zeolite catalyst is placed and acts as a cover for the pyrolysis tube.
4. Steam pipes: The steam pipe functions as the passage for the flow of combustion steam towards th
5. Condenser The device used to condense the pyrolysis vapor through a pipe circulated with a fluid, usually water, causing the vapor to turn into liquid/ plastic oil as it exits the condenser pipe
6. Water pump: The water pump is used to circulate the cooling water to the condenser pipe.
7. Plastic Oil Collector: The tool used to temporarily store the condensed pyrolysis oil.

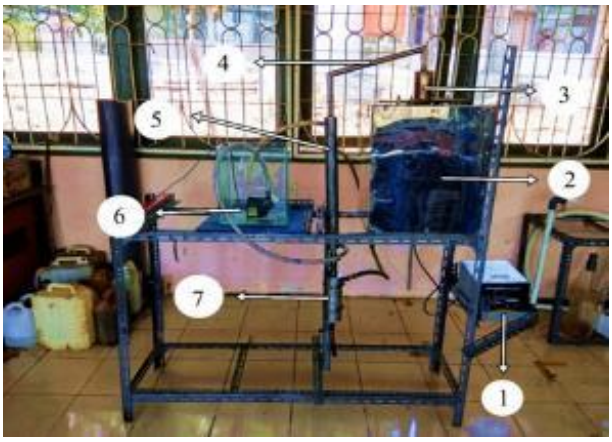


Figure 1. Pyrolysis machine

Process and Workflow

The initial stage is the preparation of pyrolysis material that is plastic from bottles of mineral water. Mineral water packaging bottles are made from different types of plastic. Mineral water bottle caps are generally made from HDPE (High-density Polyethylene) or PP (Polypropylene) plastic. Meanwhile, the bodies of mineral water packaging bottles, which are usually clear or transparent, are made from PET (Polyethylene) plastic. In the initial stage, we sort plastic as raw material for the pyrolysis process, namely from PP type mineral water bottles while the HDPE type comes from used oil bottles. It presented in Figure 2.

The next step is to insert pyrolysis material into the reactor (Figure 3). Then next step is to install the reactor (Figure 4). The next stage is to run a pyrolysis device that works at 500-7000C for 4 hours to be able to produce fuel oil (Figure 5). After approximately 4 hours, 270 ml of oil is produced from 350 grams of plastic. So that in 1 kg of plastic will be produced as much as 771 ml of oil. After approximately 4 hours, 270 ml of oil is produced from 350 grams of plastic. So that in 1 kg of plastic will be produced as much as 771 ml of oil (Figure 6).

Figure 2. Preparation of pyrolysis material

Figure 3. Inserting plastic into the reactor

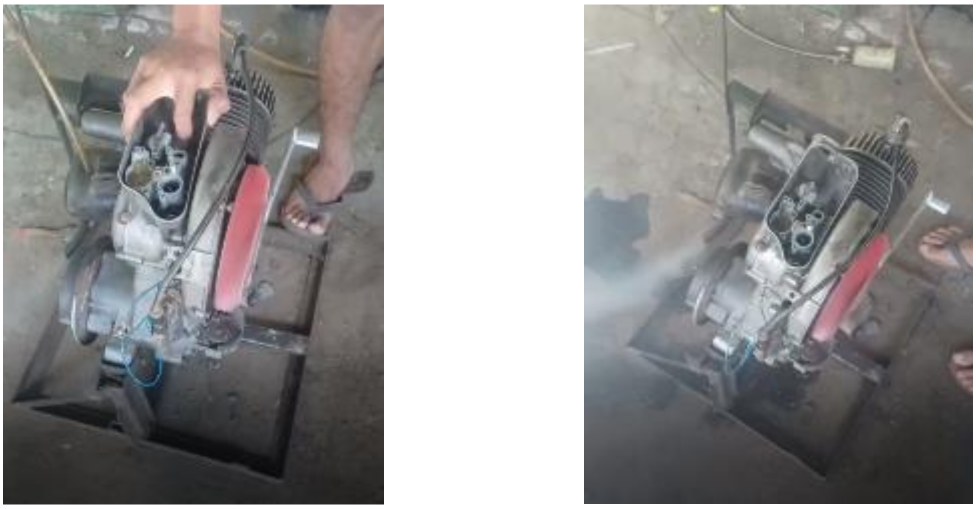
Figure 4. The next stage is the installation of the reactor

Figure 5. Running pyrolysis equipment

Figure 6. Plastic derived from pyrolysis output

Performance testing of plastic oil fuel

To test the capabilities of plastic oil derived from pyrolysis, it was tested on a 4-stroke Vespa brand engine. The initial ignition for PP plastic type was 5 seconds, while for HDPE, it was 7 seconds. This is in line with research [4] which states that co-pyrolysis of lignocellulosic biomass and plastic is efficient to upgrade the quality of bio-oil because plastic facilitates deoxygenation. However, catalysts are required to produce bio-oil that is suitable for potential use as transportation fuel (Figure 7).



(a) (b)

Figure 7. Performance testing of plastic oil fuel (a) PP (b) HDPE

This research in line with [12] that using a 20% blend of waste plastic oil with diesel in an engine test slightly increased efficiency and lowered fuel consumption compared to pure diesel. Emissions were lower at low engine loads but rose with higher loads, similar to diesel.

Result and discussion

Relationship Plastic Type and Volume of Fuel Produced

Relationship plastic type and volume of fuel produced used in this study presented in Figure 8.

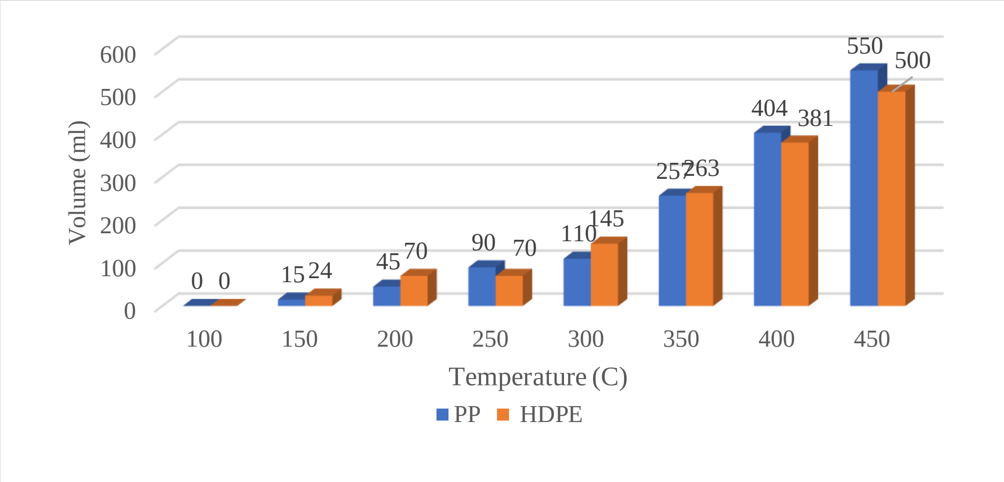


Figure 8. Relationship plastic type and volume of fuel produced

It is known that at a temperature of 1000C, PP and HDPE plastics do not produce oil. This is because plastics do not undergo the melting phase or melting point (Tm) of either PP or HDPE plastics. Where the melting point of PP and HDPE plastics is 1680C and 1380C. This is different from research [13] that polystyrene outperformed polypropylene and polyethylene in liquid oil yield during catalytic pyrolysis, reaching 70% and 60% with TA-NZ and AA-NZ catalysts, respectively. This difference is because research [13] used a catalyst while this research did not.

So that in order to produce oil, the plastic should be heated above its melting point so that it can undergo a decomposition process. Decomposition is a state in which the plastic will easily flow and the structure will undergo decomposition.

As the properties of PP and HDPE plastics are, they are strong, hard semi-flexible, and the waxed surface is still the same as the state after heating. Where the residue is difficult to clean and the surface of the residue is waxy and hollow on HDPE plastic.

Relationship Time and Temperature

Pyrolysis time is the length of time the pyrolysis process takes processing plastic waste into pyrolysis oil. The duration of the pyrolysis process is calculated using a stopwatch from the start of heating the reactor containing plastic waste until. The end of the pyrolysis process is marked by no gas being produced. Relationship time and temperature of pyrolysis process used in this study presented in Figure 9.

The graph shows that the pyrolysis time is getting faster with each increase in temperature. The fastest time for PP plastic is at 450 degrees C with a time of 300 minutes. While the fastest time for HDPE plastic is at 330 minutes. Research of Singh [14] indicated that reaction temperature of 500 C was reported to be an optimum temperature for high oil production with low density and near zerowax whereas several researchers also obtained a high amount of wax at the same temperature with high-density oil at the above said temperature.

Low heating rates (slow pyrolysis) such as 10 and 20 C/min were found to produce oil with lower or no wax formation due to the high residence time of volatiles inside the heating zone for further cracking to produce low range hydrocarbons. Effect of residence time was strong at higher temperature process conditions producing heavier hydrocarbons in gas; and in oil as wax [15].

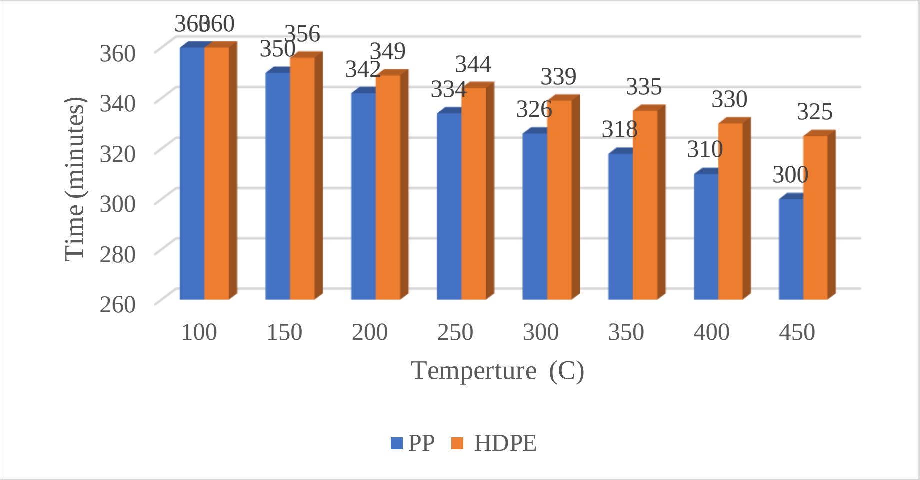


Figure 9. Relationship time and temperature of pyrolysis process

Conclusion

The reactor temperature influences the volume of oil produced and time pyrolysis, because the higher the temperature, the more oil is produced and pyrolysis time will end more quickly.

Pyrolysis can be used as one of the methods for processing plastic waste because 1) Waste Reduction: Pyrolysis converts plastic waste into useful products like oil fuel, reducing the amount of plastic waste ending up in landfills. 2) Alternative Energy Source: The pyrolysis process produces fuel that can be an alternative to fossil fuels like oil or gas, contributing to a more sustainable energy source. 3) Processing Various Plastic Types: Pyrolysis can process various types of plastics, even those difficult to recycle like low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), and polyvinyl chloride (PVC). 4) Flexible Use: Pyrolysis outputs like fuel or oil can be used in various industrial or domestic applications such as heating, engines, or chemical processes. 5) Effective Recycling Contribution: Pyrolysis supports more effective recycling concepts by transforming plastic waste into useful products, promoting the reuse of resources.

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