THE PYROLYSIS OF HIGH-DENSITY POLYETHYLENE (HDPE) AND POLYPROPYLENE (PP) PLASTIC WASTE BLEND

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ABSTRACT: Plastic waste is a growing problem that hurts the environment. The pyrolysis method converts plastic waste into alternative fuels to address this issue. This study aimed to investigate the impact of temperature on the characteristics of pyrolysis oil produced from a combination of High-Density Polyethylene (HDPE) and PolyPropylene (PP) plastic waste. The study focused on the resulting pyrolysis oil's volume, density, viscosity, and calorific value. The study results showed that the highest pyrolysis oil yield was obtained at 450ºC, with a volume of 350 ml. The density of the pyrolysis oil ranged from 670-790 kg/m^3, while the viscosity ranged from 1.611-2.401 cP. The calorific value of the pyrolysis oil ranged from 7393.7584-8946.3759 cal/gr. The results demonstrate that the temperature significantly impacts the characteristics of the resulting pyrolysis oil. The study findings could be useful in optimizing the pyrolysis process to obtain high-quality oil from mixed plastic waste streams, thereby reducing plastic waste and providing an alternative energy source. The study highlights the potential for converting mixed plastic waste into alternative fuels through pyrolysis.

KEY WORDS: Oil, Pyrolysis, HDPE, PP, Plastic waste

1. INTRODUCTION

Plastic garbage has accumulated in landfills, the seas, and other habitats due to the increased consumption of plastic items and inadequate waste management procedures. Polymers are not biodegradable, and their persistence in the environment can have various detrimental effects, including air and water pollution, soil contamination, and harm to marine life [1]. Hence, effective plastic waste management solutions that limit the environmental impact of plastic trash are required.

The new pyrolysis technology can turn plastic waste into lucrative fuels, chemicals, and carbon-based compounds. Pyrolysis is the heat degradation of plastic waste in the absence of oxygen, yielding gas, liquid, and solid compounds [2]. Depending on the intended products and the kind of plastic waste, the process can be conducted at various temperatures and pressures.

Polypropylene (PP) and high-density polyethylene (HDPE) are plastic polymers widely employed in packaging, automobiles, and construction. PP and HDPE are very resistant to breakdown, making recycling and disposal difficult. Pyrolysis of PP and HDPE plastic waste has emerged as a viable technique for transforming these non-biodegradable materials into usable goods [3]. Pyrolysis of PP and HDPE plastic waste generally includes heating the plastic waste without oxygen in a reactor vessel [4]. Depending on the volume and needs of the operation, many types of reactors, including fixed beds, fluidized beds, and rotary kilns, can be utilized.

Temperature and heating rate are crucial pyrolysis factors because they impact product quality and yield. In general, pyrolysis is conducted at temperatures between 300°C and 800°C, with higher temperatures yielding greater liquid product yields [4, 5]. Moreover, the heating rate influences the production and quality of the products, with slower heating rates resulting in greater yields of liquid products and higher quality char.

PP and HDPE plastic waste pyrolysis typically consists of three stages: initiation, propagation, and termination. During the initiation phase, plastic waste is heated to pyrolysis temperature, and polymer chains break into smaller molecules. At the propagation stage, polymer chains continue to degrade, producing gases, liquids, and char [6-8]. The last phase of a chemical reaction comprises cooling the reactor and collecting the products.

The pyrolysis products of PP and HDPE plastic waste depend on the process variables, including temperature, heating rate, and reactor type. The products can be categorized as gas, liquid, or solid.

Current advances in the pyrolysis of waste PP and HDPE plastic include investigating new reactor designs, optimizing process parameters, and creating new product markets [9]. For instance, researchers have examined microwave-assisted pyrolysis, which can shorten processing time and increase product output and quality.

There have also been initiatives to improve the manufacturing conditions for certain goods, such as chemicals and carbon-based substances. For instance, researchers have examined catalysts such as zeolites and metal oxides to enhance the production and quality of liquid products [10, 11].

Mixed plastic waste streams can comprise a variety of polymers with varying qualities and compositions, which can impact the yield and quality of the pyrolysis products. Including impurities, such as metals and chlorine, might further complicate the pyrolysis process and diminish the quality of the products [12].

Reactor design and operating conditions for converting mixed plastic waste streams are important. They must be addressed to improve the economic viability and environmental sustainability of the pyrolysis of PP and HDPE plastic waste. Products obtained with thermal pyrolysis have yet to be optimal, as emphasized in much research work [13, 14]. This study aims to determine the effect of temperature and time on the volume of oil from pyrolysis of HDPE and PP hybrid plastic waste using a low-cost recycler reactor.

2. MATERIALS AND METHOD

In this research, plastic waste obtained from temporary waste collection sites was utilized, which consisted of High-Density Polyethylene (HDPE) and PolyPropylene (PP) with a ratio of 50:50. Prior to the pyrolysis process, the plastic waste underwent cleaning and was subsequently cut into small pieces for easier insertion into the pyrolysis reactor. The reactor wall was subjected to temperatures ranging from 200ºC to 450ºC, with an 80-minute time interval for pyrolysis. Figure 1 depicts the reactor used in this research.

Following the pyrolysis oil production process, the next step involved measuring the volume of the oil and performing characteristic tests on each oil produced. The density of the oil was measured using a Pycnometer; the viscosity was measured using a Falling Ball Viscometer HAAKE, and the calorific value was measured using a Bomb Calorimeter 6400

Automatic Isoperibol Calorimeter from Parr Instrument Company. The calorific value was obtained from varying temperatures.

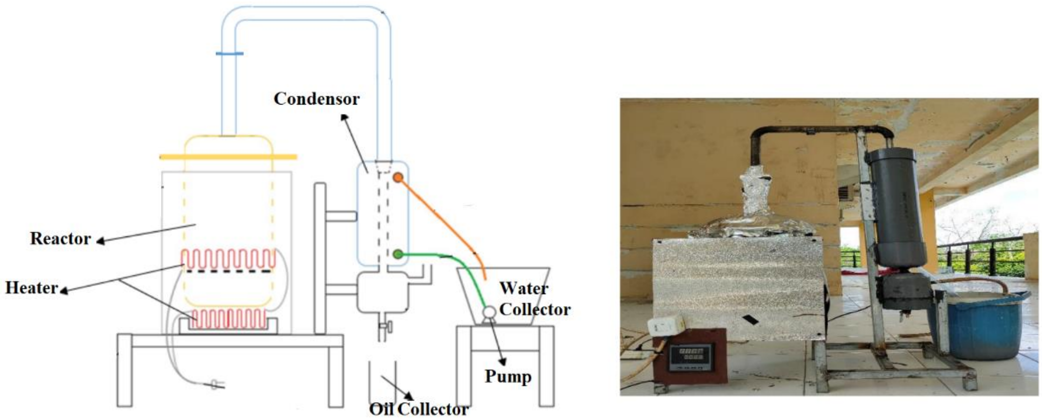

Fig. 1. Pyrolysis reactor

3. RESULTS AND DISCUSSION

The appearance of oil and ash pyrolysis products from the pyrolysis of High-Density Polyethylene (HDPE) and Polypropylene (PP) can be seen in Figure 2. The results showed that the oil obtained from the pyrolysis was a bright brown color and dark brown segmented at the bottom, indicating impurity of high carbon content. The color of the ash obtained from the pyrolysis of HDPE and PP blends was dark gray, indicating the presence of carbon black.

Fig. 2. The appearance of oil and ash pyrolysis products

The effect of temperature on oil products can be seen in Table 1. As temperature increases, the volume of the pyrolysis of HDPE and PP blends also increases; this can be attributed to the fact that as the temperature increases, more thermal energy is supplied to the material, leading to increased thermal decomposition and gasification of the polymer chains. It can also be observed that the rate of increase in volume slows down as the temperature increases. For example, the increase in volume between 250°C and 300°C is much more significant than the increase between 350°C and 400°C; this may be since, at higher temperatures, the polymer chains have already undergone significant decomposition, and there is less material left to decompose. Furthermore, we can see that the pyrolysis of the HDPE and PP blends occurs over a wide temperature range, from 200°C to 450°C, with the most significant increase in volume occurring between 250°C and 300°C; this indicates that the pyrolysis process is complex and involves a variety of reactions occurring over a wide temperature range.

Table 1: Pyrolysis Product on volume and density parameters

Parameter	Temperature (°C)					
	200	250	300	350	400	450
Oil volume (ml)	110	135	245	270	320	350
Density (kg/m^3)	740	762	721	670	761	790

At the lowest temperature of 200°C, the density of the material is 740 kg/m^3, which is relatively low. As the temperature increases, the density of the material also increases, with the highest density observed at 450°C, where it is 790 kg/m^3. Interestingly, the density of the material does not increase monotonically with temperature. For example, we can see that the density at 300°C is lower than at 250°C and 400°C; this could be due to changes in the material's molecular structure during pyrolysis, which can lead to changes in its physical properties. The density of the pyrolysis products can also affect the properties of the resulting byproducts. For example, higher-density materials may be more suitable for specific applications, such as fuel production [15].

The density of the oil obtained from the pyrolysis of HDPE and PP hybrid plastic waste is similar to that of gasoline, which ranges from 700-790 kg/m^3, according to Table 1. This finding is consistent with previous research conducted by Sitepu et al. (2018) [15], who reported a density of 773 kg/m^3 for the oil obtained from the pyrolysis process.

The density values obtained from the pyrolysis process show a decrease at temperatures of 300 ºC and 350 ºC due to the differences in the melting points of HDPE and PP plastic waste. HDPE plastic waste has a higher melting point of 280 ºC than PP plastic waste, which has a melting point of 165 ºC. At temperatures of 200 ºC and 250 ºC, the pyrolysis process has not yet reached the melting point of HDPE plastic waste. Therefore, the resulting oil from pyrolysis at these temperatures is still derived from plastic waste with a melting point of 160 ºC; this is supported by plastic waste charcoal in the reactor after the pyrolysis process at these temperatures. However, at temperatures of 300 ºC and 350 ºC, the HDPE plastic waste starts to decompose as it has exceeded its melting point, resulting in oil from the pyrolysis process with decomposed HDPE plastic waste.

The viscosity values of the oil produced from the pyrolysis of HDPE and PP blends have a relatively high viscosity (Table 2). Viscosity is a measure of a fluid's resistance to flow, and higher values indicate that the fluid is more resistant to flow.

Table 2: Pyrolysis Product on volume and density parameters

Temperature (ºC)	Viscosity (cP)	Calorific (kal/gr)
200	1,775	7393,7584
250	1,868	7521, 6263
300	1,633	7802,4312
350	1,611	8134,6701
400	2,252	8578,7012
450	2,401	8946,3759

At 200°C and 250°C, the viscosity of the oil produced from pyrolysis is relatively low, ranging from 1,775 to 1,868 cP; this is likely since the plastic waste has not yet fully melted and decomposed, resulting in a less viscous oil. As the temperature increases, the viscosity of the oil also increases. At 300°C and 350°C, the viscosity ranges from 1,611 to 1,633 cP, indicating that the plastic waste is beginning to decompose and producing more viscous oil. At higher temperatures of 400°C and 450°C, the viscosity increases significantly to 2,252 and 2,401 cP, respectively. This trend can be explained by the fact that more thermal energy is available at higher temperatures to break the polymer chains and create more minor molecular weight compounds. These smaller compounds may have a lower molecular weight and a lower viscosity. However, as the temperature increases, the smaller compounds can start recombining and form larger and more complex molecules, contributing to higher viscosity.

Another factor that can impact the viscosity of the oil produced from pyrolysis is the presence of different types of plastic waste in the feedstock. As discussed earlier, HDPE and PP have different melting points, which can impact the pyrolysis reaction and the resulting oil properties. The oil produced from HDPE may contribute more to the viscosity at lower temperatures due to its higher molecular weight. In comparison, PP may contribute more to the viscosity at higher temperatures due to its lower melting point and higher reactivity.

The oil's high viscosity can be attributed to the high molecular weight of the polymers present in the plastic waste. HDPE and PP are both high molecular weight polymers, and as they decompose during the pyrolysis process, they can produce complex mixtures of hydrocarbons with varying molecular weights and structures; this can result in a mixture of viscous compounds that contribute to the overall high viscosity of the oil.

The calorific value of the pyrolysis oil increases as the reactor temperature increases; this is because the high temperature of the reactor facilitates the decomposition of the plastic waste and leads to the formation of more volatile compounds in the pyrolysis oil, which have a higher calorific value.

At 200 ºC and 250 ºC, the reactor temperature is relatively low, and the decomposition of plastic waste is incomplete. This results in the formation of pyrolysis oil with a lower calorific value. However, as the reactor temperature increases to 300 ºC and 350 ºC, the decomposition of the plastic waste becomes complete, leading to the formation of pyrolysis oil with a higher calorific value. At 400 ºC and 450 ºC, the reactor temperature is even higher, leading to more complete decomposition of the plastic waste and the formation of more volatile compounds in the pyrolysis oil. This results in the highest calorific values obtained from the pyrolysis process.

Therefore, the reactor temperature is crucial in determining the quality of the pyrolysis oil obtained from the HDPE and PP blends. A higher reactor temperature generally leads to higher-quality pyrolysis oil with a higher calorific value.

4. CONCLUSION

In conclusion, the analysis of the effects of temperature on the yield, density, viscosity, and calorific value of the liquid product from pyrolysis of HDPE and PP blends shows that higher temperatures generally lead to higher yields and higher calorific values, but lower densities and lower viscosities. The results suggest that pyrolysis of HDPE and PP blends can be an effective method for converting plastic waste into valuable liquid fuels and that the process can be optimized by controlling the temperature to achieve the desired properties of the liquid product. Further research is needed to explore the potential of this process for the large-scale production of liquid fuels and other valuable chemicals.

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