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RESEARCH PAPER

Determining the Preeminent Plastic Wastes in the Production of Petrol Using Pyrolysis Method and Its Effectiveness as an Alternative Fuel

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Abstract: This study aimed to determine which type of plastic – PET, HDPE, LDPE, PP, PS, and Others, produces most oil yield in terms of time of complete degradation, temperature and amount of plastics using a non-catalytic slow pyrolysis method; it also determined the physical characteristics of the oil yield in terms of its color and appearance; and it also aimed to determine which petroleum produced by different types of plastics are more efficient in terms of (a) production of oil and (b) combustion time. Production of oil and oil yield is presented in milliliters and percentage, respectively. Combustion time is expressed in seconds from the time of ignition to total disappearance of flame having 1ml of oil tested from each produced pyrolytic oil. Experimental-descriptive comparative method was used in determining the type of plastic that yields to most of pyrolytic oil. Based from gathered results, at constant temperature and amount of plastics, PS produced most petroleum at 29.5% oil yield followed by PP with 29%. While PET produced the least petroleum with 0.01% oil yield. Color varies at different types of plastics, given that PET and PP produces light brown color, LDPE produces light yellow while HDPE, PS and Others produces black color. PET, HDPE, PP, PS and Others produced liquefied petroleum while LDPE produces flammable wax product. PS produced most petroleum with 295ml (29.5%), and PET produced least oil with 1ml (0.01%). Combustion time varies at different types of plastics: PS at 145 seconds, PP at 141 seconds, HDPE at 115 seconds, Others at 78 seconds, LDPE at 77 seconds while PET produced non – flammable oil yield. Thus, PS is most efficient as an alternative fuel in terms of production and combustion time. For the betterment of similar study, future researchers are encouraged to test the pyrolytic oil yielded from different types of plastics in engine performance and machineries and the comparative performance to the available commercial fuels.

Keywords: Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS), combustion time, pyrolytic oil.

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INTRODUCTION

Lebreton & Andrady's study shows that the Asian continent is the top generating region of plastic waste. In particular, Southeast Asia is the leading contributing region to plastic waste in Asia. Among the countries of Southeast Asia, the Philippines is in the third spot as the most generating country of the global mismanaged plastic wastes [1].

Plastics are divided into PET or PETE, HDPE, PVC, LDPE, PP, PS, and OTHERS based on their chemical structure and applications, and which Society Plastic Industry (SPI) provides a resin identification code system for each type of plastic.

As the human population increases, the production and consumption of plastics also increase and are relatively unavoidable. With its low costs and ease of manufacture, metric tons of plastics are produced each year for people's demands. The 42% of the global annual production and consumption of resin resulted in the accumulation that leads to an alarming state of plastic waste pollution [2]. Globally, mismanaged plastic wastes can be generated twice by mid-century [1].

On the aspect of fuel consumption, it increases yearly, and the demand for petroleum is highly unpredictable. However, the world is threatened by the depletion of fossil resources and fossil fuel prices [3]. Over the past several decades, the increase in global fossil fuel consumption resulted in environmental problems and air quality deterioration because of pollutants [4].

Therefore, the researchers seek for a solution to minimize the plastic waste pollution in the environment and convert plastic wastes to produce an alternative petroleum that will help the masses to use alternative fuel that is cost-efficient and readily available. This is also a consideration to the United Nations program on Sustainable Development Goals (SDG). SDG 12 aims to ensure sustainable consumption and production patterns which includes the reduction of waste generation through prevention, reduction, recycling and reuse. This research aims to reduce plastic waste materials in the environment and recycle into a valuable alternative petroleum source. Similarly, this research also aims to convert plastic waste materials into a reusable petroleum resources. The researchers used the non – catalytic pyrolysis slow pyrolysis method to produce the alternative petroleum.

Pyrolysis is the thermal degradation of plastic waste at different temperatures (300–900°C) to produce liquid oil in the absence of oxygen [5]. Pyrolysis of waste plastic is an economical method to solve the waste plastic problem and produce quality liquid fuel that can have similar properties to the commercially used petroleum fuels. There is no sulfur in the waste plastic feedstock, giving a sulfur-free product. It benefits traditional fossil fuels like diesel, which can produce SO_2 after burning due to Sulphur content. SO_2 is a pollutant that contributes to severe air pollution, endangering people's health and deteriorating concrete structures.

In this study, the researchers used a non – catalytic slow pyrolysis in each type of plastic to determine the preeminent plastic that will produce a quality petroleum in terms of complete degradation time of each plastic materials, temperature, and amount of plastic. Researchers also aims to analyze and describe the physical characteristics of petroleum produced by each type of plastics in terms of color and appearance. Researchers also aims to determine which petroleum produced by each type of plastics are more efficient in terms of production of oil and combustion time. Meanwhile, researchers also tested each of their combustibility to determine its effectiveness.

MATERIALS AND METHODS

This study utilized an experimental-descriptive comparative design to analyze the difference between the types of plastics in processing them as an alternative fuel and the difference between each produced fuel. An experimental method helped to examine the six types of plastics in petroleum production and their potential as an alternative fuel. Feedstock from every kind of plastic were subjected to the non – catalytic pyrolysis process using an alternative pyrolysis reactor. Descriptive method was used to present the data and evaluation of this research [6]. The descriptive design was used in data analysis that required descriptive interpretation, such as presenting the data for physical properties of the produced liquid fuel, particularly the color and appearance. Furthermore, this study also utilized a comparative design in determining the preeminent plastic waste in petroleum production. Comparative analysis was also used to evaluate which plastic type has the potential to produce more liquid fuel, among other.

Figure 1. Plastic feedstock of different types of plastic materials

This study used the different types of plastics to subject for non – catalytic slow pyrolysis in the production of petroleum in which the researchers will be examining the produced oil for each kind of plastic. The six type of plastics are the PET, HDPE, LDPE, PP, PS, and Others.

Plastic wastes were segregated according to the marked numerical codes in each plastic material. Plastic wastes materials that has no code marks were not included for use. The plastic waste materials of different types – PET, HDPE, LDPE, PP, PS and Others, were washed and cut into desirable sizes, as shown in figure 3. One (1) kilogram of washed and cut plastic wastes from each type of plastic were accumulated for non – catalytic slow pyrolysis at contant temperature of 350.

This study will not use any catalyst to enhance and maximize the oil yield of the different types of plastic materials. The pyrolysis reactor to be used in this research is a modified alternative pyrolysis reactor adapted from Kumar et al. (2015) [33].

Each type of plastic wastes were put in the alternative pyrolysis reactor (Figure 2) and was subjected to heat at exactly 350°C at one (1) hour residence time. However, due to different melting point of each type of plastic, degradation time varied to each type of plastic resulting to non – uniform residence time.

Source of heat is from a conventional burner that is capable of reaching 350°C as measured by a thermometer. The same treatment and process was made to all the types of plastic materials.

After subjecting to non – catalytic pyrolysis reaction at constant temperature, amount of plastic and important consideration of relative melting point, measurement of oil yield from different types of plastics was determined using an Erlenmeyer flask and a dropper for exact measurement. Time of complete degradation was also noted. Complete degradation time was the time that each type of plastic was degraded completely. It was determined by the complete disappearance of smoke and oil production. Degradation time is highly affected by the melting point of each type of plastic materials.

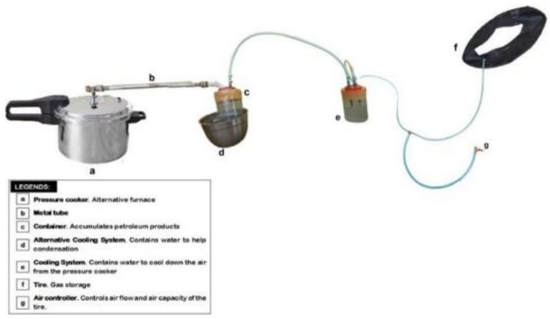

Figure 2. Modified Alternative Pyrolysis Reactor, adapted from Kumar et al. (2015) [33].

Physical characteristics of oil yield from different types of plastics were determined based on observable data and characteristics of each product. Color is determined by the observable and comparable data of oil yield from each type of plastic. Appearance was determined by observable product behavior of petroleum produced of different types of plastic – liquefied or wax – like.

Efficiency of petroleum produced was determined based on two parameters, production of oil and combustion time. Production of oil was determined by using a percentage formula by dividing the oil yield in milliliters into 1000 milliliters and multiplied by 100%. Combustion time of different types of plastic were determined by dropping one milliliter of sample petroleum from each type of plastic into a petri dish with ashes and flaming it. Each petroleum from different types of plastic were tested in separate ashes and petri dish for equal treatment. Combustion time was measured in seconds from the time the flame appeared and ended when the flame completely disappeared.

Determining the production of petroleum will be presented in percentage using the equation:

$$\%Yield = \frac{amount\ of\ oil\ yield}{total\ amount\ of\ feedstock} \times 100$$

In which the amount of oil yield is the dependent variable from the different types of plastics denoted in milliliters, while the amount of feedstock is the independent variable of 1000 milliliters.

RESULTS AND DISCUSSION

Type of plastic that produces most petroleum

Oil yield from different types of plastic materials varies with different parameters to be considered. At constant temperature of 350°C and at one kilogram (1000g) of feedstock each type of plastic, oil yield was determined. The Table 1 below shows the oil yield from different types of plastic materials at constant temperature, amount of feedstock and time of complete degradation with important consideration of the melting point of each type of plastic:

Table 1. Oil yield of different types of plastics and complete degradation.

Types of plastics	Time of Complete Degradation	Oil Yield (%)
PET	18 mins	0.01
HDPE	45 mins, 30 secs	2.5
LDPE	57 mins	25
PP	29 mins, 7 secs	29
PS	31 mins, 47 secs	29.5
Others	mins	5.6

Table 1 presents the percentage of oil yield and complete time of degradation of every types of plastics. The data shows that the polystyrene (PS) has the highest amount of petroleum produced based on time of complete degradation, temperature and amount of plastic. Each types of plastic has a constant temperature of 350 °C and 1000 grams (1 kilo) as amount of feedstock. Time of degradation of different types of plastics was change in consideration of the melting point of each type. Polystyrene produces 29.5 % of oil yield with a melting point of 210-249°C and a complete degradation of 31 minutes and 47 seconds. Similarly, study of Miandad et al. (2016) shows Polystyrene (PS) has the maximum production of liquid oil along with least production of gases and char in comparison to other types of plastic [5]. The data also revealed that Polyethylene terephthalate (PET) has the least amount of oil produced which is 0.01% of oil yield, 260°C of melting point and a complete degradation of 18 minutes whereby comparable to the study of Miandad et al. (2016) that polyethylene terephthalate (PET) has the highest amount of solid and benzoic acid as crystals and gas with no oil [5].

Table 1 also revealed that at constant temperature and amount of plastics and considering the melting point of each type, PS, PP and LDPE produces most pyrolysis oil with 29.5%, 29% and 25%, respectively. Others and HDPE produces low oil yield at 5.6% and 2.5%, respectively. The general oil yield of different types of plastics was less than 30% (<30%) can be attained from slow pyrolysis of plastic materials at 300°C - 600°C (Erdogan, 2020) [7].

Physical characteristics of petroleum produced

The physical characteristics of petroleum were determined in terms of color and appearance based on the product of each type of plastic waste that undergoes non – catalytic slow pyrolysis. The six types of plastic waste are PET, HDPE, LDPE, PP, PS & OTHERS were found out to vary in color and appearance. Color and appearance of petroleum products derived from the pyrolysis of the six types of plastic materials are presented in table 2.

Table 2. Color and appearance of petroleum produced by different types of plastics.

Types of plastics	Color	Appearance
PET	Light brown	Liquefied
HDPE	Black	Liquefied
LDPE	Light yellow	Wax
PP	Light brown	Liquefied
PS	Black	Liquefied
Others	Black	Liquefied

a. Color

The table 2 shows the summary of the color exhibited by the petroleum products from the different types of plastic materials. Similarly, figure 5 shows the actual color variation of the petroleum products of PET, HDPE, LDPE, PP, PS & OTHERS subjected to non – catalytic slow pyrolysis.

The data revealed that the petroleum products produced from the pyrolysis of HDPE, PS, and

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OTHERS are black in color while petroleum products obtained from the pyrolysis of PET and PP were light brown and LDPE produces light yellow petroleum product. The pyrolysis of six different types of plastic waste at a constant temperature of 350°C produces oil yields that vary in color at one kilogram (1000 g) of feedstock.

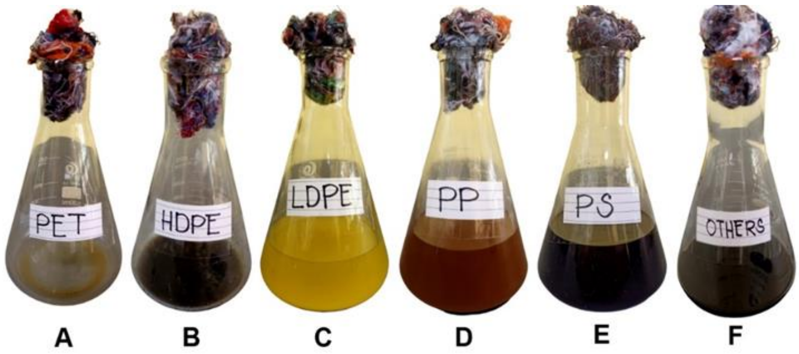

Figure 3. Color characterization of petroleum products of different types of plastic materials (A – PET; B – HDPE; C – LDPE; D – PP; E – PS; F – OTHERS)

In this study, it was discovered that products obtained from the pyrolysis of Polyethylene terephthalate was a light brown color. In contrast, the study of Saker (2011) pyrolysis of PETE resulted in a yellowish color. The present study pyrolyzed High Density Polyethylene (HDPE) and produces black color. On the other hand, the study of Prurapark et al. (2020) HDPE obtained a brown color [8], while in the study of Heydariaraghi et al. (2016) the appearance of the liquid fuel produced from HDPE is light yellowish [9]. The color of petroleum produced in Low Density Polyethylene was a light yellow. In contrast to the study of Erdogan et al. (2020) the pyrolytic oil derived from LDPE are yellow color [7]. While the pyrolysis of Polypropylene produces light brown color. However, according to the study of Erdogan (2020), the obtained product from PP is seen as deep brown [7]. In Polystyrene the color of the product was black which differs from the findings of the study of Heydariaraghi et al. (2016) and Erdogan (2020) that PS obtained dark yellow color. Lastly, the pyrolysis of OTHERS produces also a black color [7,9].

Non – catalytic slow pyrolysis of different plastic materials can result to varying color characteristics. The present study has produced petroleum that are relatively different in terms of color as to compare with existing researches on the color of petroleum products of plastic pyrolysis. The difference in color can be traced on the temperature and catalyst use.

In conclusion, the six types of plastic waste materials exhibited diversity in color and it has no effect on the flammability of the fuel but it is highly dependent on the temperature, catalyst use and time under pyrolysis method.

b. Appearance

The pyrolysis of PET, HDPE, PP, PS and OTHERS under non – catalytic slow pyrolysis method were degraded into liquid oil at the constant pyrolysis temperature of 350°C.

Table 2 presents the summary of the appearance of the petroleum products derived from the pyrolysis of the six types of plastic materials. Data revealed that the pyrolysis of plastic materials in non – catalytic slow pyrolysis method produces two kinds of appearances. Data shows that most of the plastic materials produces liquefied petroleum products. Particularly, PET, HDPE, PP, PS and OTHERS produces liquefied petroleum. However, LDPE produces petroleum in wax state.

In most studies in the pyrolysis of plastic materials, dominant product is a flammable liquid oil from PET, HDPE [10,11,12], PP [5,11,13] and non – catalytic pyrolysis of PP produces 83% oil [14], PS [5,10,13], and an instant increase in oil yield without formation of wax content [12]. Other types of plastics that were studied includes the polylactic acid plastic polymer [11], latex and polymethyl methacrylate (Paraschiv et al., 2015) which yields to pyrolytic oil [15].

On the other hand, the pyrolysis of LDPE produces a petroleum fuel in a wax state instead of liquid oil. This finding is similar to the study of Lee (2012) as cited from Miandad et al. (2016) that pyrolysis of LDPE converts the feedstock into wax instead of liquid oil due to its long carbon chain structure [5,16]. The same result was seen in the study of Miandad et al. (2019) in which the pyrolysis of LDPE produces wax instead of oil [13]. However, a non – catalytic pyrolysis conducted by Sonawane et al. (2017) produced 73.91% oil without wax production [14].

Pyrolysis of plastic materials mostly produces liquid petroleum products while HDPE typically produces petroleum product in wax state. The differences in the characteristics of appearance produced by the different types of plastics can be traced on the chemical composition, temperature and the use of catalyst.

Efficiency of petroleum produced from plastic materials

Efficiency of petroleum produced by the different types of plastics – PET, HDPE, LDPE, PP, PS and Others were tested for its efficiency based on two aspects: production of oil and combustion time.

a. Production of Oil

The petroleum produced by different types of plastics are presented in milliliters and is shown in figure 4.

Figure 4 presented the produced petroleum from different types of plastics in milliliters (ml). The data revealed that PET has the least produced petroleum with 1ml oil yield. HDPE and Others yields to 25ml and 56ml, respectively. LDPE has the third with more petroleum produced with 250ml, followed by PP with 290ml. The data also revealed that the PS produced most petroleum with 295ml. One kilogram from each type of plastics were subjected to non – catalytic pyrolysis method at constant temperature and time considering the melting point of each types. Numerical figures revealed that at one kilogram of feedstock, less than 30% (300ml) can be yielded from slow pyrolysis of plastic materials with solid charcoal as its primary product (Erdogan S., 2020) [7].

The data also revealed that the PET, HDPE and Others are the types of plastics that produces lesser petroleum while LDPE, PP and PS produces more petroleum products.

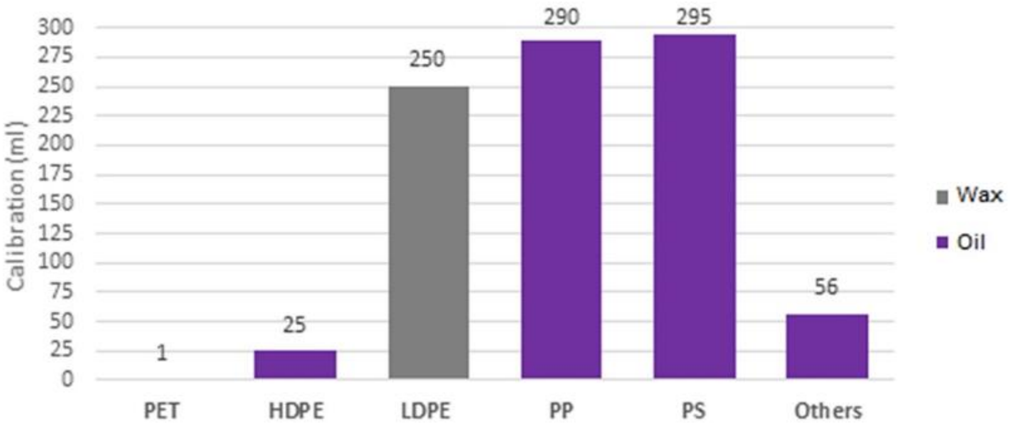

Figure 4. Production of oil of different types of plastics

Studies states that PET is rarely pyrolyzed because of its very low oil yield compare to other types of plastics because PET produces more gases than pyrolytic oil [7,10,17]. Further study of Sogancioglu et. al. (2014) shows that PET can even produce no oil yield [12]. Production of pyrolytic oil from plastics varies with respect to the chemical compositions of plastic compounds that affects the production and quality of liquid oil. Analysis of Erdogan (2020) and Abnisa et al. (2014) states that at high amount of volatile matter, increases the oil yield, while as the ash content is high, the char yield also increases [7,18].

According to analysis on volatile matter content of different types of plastics, LDPE and PS has the highest volatile matter content with 99 – 99.8 followed by Others with 97 – 99.8 and PP with 95 – 99.6. However, PET has the lowest volatile matter content which ranges from 85 – 92 [7,19,20]. The high volatile matter of plastic materials has potential in generating high liquid yield[19]. PET has the lowest amount of volatile matter which supports the low amount of oil yield of the study. PS and LDPE has the highest proximate volatile matter in the plastic content, in which PS produces the most petroleum in the present study while LDPE was third on the most oil yield. Volatile matter content of plastic materials is one of the factors that affects the oil yield of plastic materials.

PET produced the very least oil yield of 1ml. PET produces most gases and very low amount of oil yield (Erdogan, 2020) because PET is reported to yield high amount of carbon monoxide and carbon dioxide since plastic contains high amount of oxygen [7,8]. According to Odejobi, et. al. (2020), the low oil yield of PET can be linked with the chemical composition of PET which is mainly a Terephthalic acid [21]. Degradation of terephthalic acid produces waxy liquid which solidifies at room temperature. Therefore, the low oil yield of PET is caused by the presence of oxygen in the chemical structure which indicates to the high production of gases and with the composition of PET with terephthalic acid.

HDPE produces 25ml of oil yield which is much lower from other studies that can yield to 88% (Sogancioglu, et. al., 2019). Similarly, at 400°C, lesser oil yield and at maximum of 600°C 47% oil is produced [11]. However, several studies on non – catalytic pyrolysis of HDPE produces 73 grams from 100 grams of feedstock [14]. Another con – catalytic pyrolysis of HDPE was investigated by Akubo, et. al. (2017) which produced 70% pyrolytic oil [22].

LDPE produces more oil yield with 250ml. However, the liquid oil from the pyrolysis of LDPE was solidified and formed into flammable wax content. The same result was seen in the study of Miandad et al. (2019) in which the pyrolysis of LDPE produces wax instead of oil [13]. The formation of wax of LDPE can be traced from its chemical structure as LDPE having long carbon chain structure (Lee, 2012). However, several studies of non – catalytic pyrolysis of LDPE can yield to 73 grams from 100 grams of feedstock.

PP produces 290ml oil yield. High oil yield of PP can be traced because it can be easily degraded because of its branching structure [23]. Another reason can be the high proportion of tertiary carbons present in the polypropylene chains – promoting thermal cleavage of C-C bonds (Aguado, et al., 2000) [31]. Study of Ahmad et al. (2014) reported that maximum oil yield from PP is attained between 300 to 350°C and decreases with further increase in temperature [23]. High oil yield at 350°C can also be seen in studies of Ahmad et al. (2014) with 67% oil yield [23]. Another study produced maximum oil yield at 500°C with 82% oil yield [17].

PS has the highest amount of oil yield with 295ml. PS degraded easily because it degrade at a very low temperature [19] because of its cyclic structure [24]. High oil yield and maximum degradation of PS can be tracked on its simple and cyclic structure [25]. In addition, Lee (2012) reported that the degradation of PS occurs both random – chain and end chain scissions which leads to formation of stable benzene rings and therefore enhances further thermal cracking and increasing oil yield [16]. Non – catalytic pyrolysis of PS produces no solid char unlike in the study of Ma et al. (2017) which catalytic pyrolysis of PS has high production of solid char because of the high acidity of the catalyst (zeolite) [32].

b. Combustion Time

The combustion time of different type of plastics was derived in experimental basis. 1ml of petroleum produced from each type of plastic is ignited to flame in the same amount of ash in a petri dish for easy observation. Combustion time is measured from the time of ignition to the time of total disappearance of flame on ash. The result is presented in a table below indicated in seconds, smoke characteristics is also indicated.

Table 3. Combustion time of petroleum produced and smoke characteristics (Smoke characteristics: + - thinnest; ++ - thick; +++ - thickest).

Types of plastics	Combustion time (seconds)	Smoke characteristics
PET	0	-
HDPE	115	+
LDPE	77	+
PP	141	+++
PS	145	+++
Others	78	+++

Table 3 shows the combustion time of the petroleum produced of different types of plastics. The table revealed that at the same amount of petroleum tested, PS is most efficient in terms of its combustion time with 145 seconds IT followed by PP at 141 seconds appearance of flame and HDPE with 115 seconds. On the contrary, LDPE and Others has relatively low combustion time with Others with 78 seconds. The dissolved wax product of LDPE can be ignited giving 77 seconds which is the lowest of all the flammable products of plastic materials. The table also revealed that PET has no data because of producing non – flammable oil.

Table 3 also shows the characteristics of smoke produced from the combustion of pyrolysis oil of different plastics. HDPE and LDPE shows thin and quiet smoke release while PP, PS and Others releases black and very thick smoke. Smoke characteristics is one of the parameters in choosing a commercial petroleum products.

According to Ding et al. (2014) [26] and Sharuddin et al. (2016) [19], Flash point (and boiling point) are the important physical properties of flammable liquids and is important parameters in evaluating the combustion behavior of materials. Flash point is the lowest temperature of liquid (usually petroleum products) to form vapor in the air at sufficient concentration that it can be ignited. Flammable liquids have flash point of less than 37.7°C (100°F) in which liquids with lower flash points ignites easier. Combustible liquids has flash point at or above 37.7°C.

Analysis of Sharuddin et al. (2018) shows that the flash point of HDPE and LDPE, 48°C and 41°C, respectively, are very close to that of flash point of gasoline with 42°C which indicates that the two are comparable in the light petroleum distillate fuel [27]. The flash point of PP 30°C and PS with 26.1°C have very low flash point in comparison to gasoline and diesel which indicates that PP and PS pyrolysis oil can easily vaporized and needs an extra precaution and handling (Sharuddin et al., 2016) because it is relatively flammable [19].

During pyrolysis large molecules of hydrocarbons are broken down into smaller hydrocarbons thru different reactions such as depolymerization, dehydration, decarbonylation, decarboxylation, deoxygenation, oligomerization and aromatization [28]. The quantity of pyrolysis products are influenced by different parameters such as pyrolysis temperature, biomass composition, melting point, and catalyst effect. These parameters plays a major role in optimizing the product yield and composition in any processes [19].

Temperature is one of the most significant operating parameters in pyrolysis because it controls the cracking reactions of the polymer chains of the plastic materials, temperature is an important consideration to ensure maximum oil yield [7,19]. As the temperature increases, the vibration of molecules inside the system will be greater and these molecules will evaporate. Furthermore, temperature requirement depends on the product preference, if liquid product is preferred to attain, lower temperature, 300 - 500°C is recommended (Sharuddin et al., 2016). Similar analysis is seen in the study of Erdogan (2020) which states that maximum oil yield is attained at 550°C however, further increase in temperature can turn liquid products into gases [7].

Biomass is composed of lignin, hemicellulose , cellulose, extractives, and inorganic elements [28]. The amount of pyrolysis products varies depending on the content of biomass constituents as well as the distribution of and relative content of each constituents [29]. Plastic materials are organic polymers and are high – polymer materials made of raw materials consisting of cellulose, starch and sugar contained in plants. Cellulose is a linear – structured polymer consisting of b-1,4 linked glucose units which are decomposed through depolymerization and ring scission – forms different compounds [28]. Cellulose is generally degraded at temperature ranging from 240 – 372°C. Collard et al. (2012) noted that pyrolysis of cellulose biomass produced highest amount of volatiles [30].

Table 3. Degradation time of plastic materials.

Types of plastics	Degradation time
PET	18 mins
HDPE	44 mins, 32 secs
LDPE	6 mins
PP	4 mins, 55 secs
PS	3 mins
Others	12 minutes, 11 seconds

Another important parameter to be considered is the melting point of the plastic materials. Melting point of different types of plastics affects the degradation of plastic materials, thus affecting the oil yield. Degradation time (first appearance of smoke/oil in container) is shown in a table 3.

PET has high melting point of 260°C and PS ranging from 210 - 249°C. Polyethylene plastic polymers (LDPE and HDPE) and PP has relatively low melting point of 130°C and 160°C, respectively. Melting point of the Other types of plastics varies according to the specific type of plastic materials. Table 4 shows that PS, considering having high melting point, has the shortest time to degrade with 3 minutes followed by PP and LDPE. On the contrary, HDPE having the lowest melting point had degraded the longest.

Generally, the lower the melting point, the faster the degradation time of the polymer plastics. However, the data revealed that PS, among others, although having high melting point had degraded easily. This can be traced from its cyclic structure and lightweight properties. In addition, temperature in the present study of 350°C is high enough to easily degrade the lightweight and simple structure of PS. On the other hand, HDPE, having the lowest melting point has the longest degradation time. The longest degradation time of HDPE is because of its thick and heavy materials which resulted in uneasy degradation.

Another important parameter to be considered during pyrolysis is the use of catalysts. Catalysts are used to speed up the chemical reaction. Catalysts helps not only in fast pyrolysis reaction but also in improving the hydrocarbon distribution to obtain the pyrolysis liquid product which is similar to the commercial gasoline and diesel (Erdogan, 2020) [7]. The present study has pyrolyzed pure plastic materials without the use of any catalysts to maximize the oil yield in alternative and inexpensive manner.

CONCLUSION

This research generally sought to determine which type of plastic materials produces most petroleum in terms of complete degradation and at constant temperature and amount of feedstock. It also sought to determine the most efficient plastic materials in terms of production of oil and combustion time. This research used a non – catalytic slow pyrolysis method on the six types of plastic materials – PET, HDPE, LDPE, PP, PS, Others. Data shows that PS produces the most petroleum with 29.5% and PET produces the least petroleum with 0.01%. Different types of plastics produce petroleum products in varying colors and PET, HDPE, PP, PS, and Others produces liquefied petroleum while LDPE produces flammable wax. Data also shows that the non – catalytic slow pyrolysis of plastic materials can yield to less than 30% oil yield. Results also concludes that PS has the longest combustion time with 145 seconds while PET has non – flammable petroleum product. This research concludes that color and appearance have no effect in the combustibility of petroleum products from plastic pyrolysis.

CONFLICT OF INTERESTS

All authors declare to have no conflict of interests

REFERENCES

[1] Lebreton, L., & Andrady, A. (2019). Future scenarios of global plastic waste generation and disposal. *Palgrave Communications*, *5*(1). https://doi.org/10.1057/s41599-018-0212-7

[2] Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, *3*(7). https://doi.org/10.1126/sciadv.1700782

[3] Ryu, H. W., Kim, D. H., Jae, J., Lam, S. S., Park, E. D., & Park, Y. (2020). Recent advances in catalytic co-pyrolysis of biomass and plastic waste for the production of petroleum-like hydrocarbons. *Bioresource Technology, 310,* 123473. https://doi.org/10.1016/j.biortech.2020.123473

[4] Hwang, Y., Farooq, A., Park, S. H., Kim, K. H., Lee, M., Choi, S. C., Kim, M. Y., Park, R., & Park, Y. (2019). NH_3-induced removal of NO_x from a flue gas stream by silent discharge ozone generation in a double reactor system. *Korean Journal of Chemical Engineering, 36,* 1291-1297. https://doi.org/10.1007/s11814-019-0325-8

[5] Miandad, R., Barakat, M., Aburiazaiza, A. S., Rehan, M., Ismail, I., & Nizami, A. (2016). Effect of plastic waste types on pyrolysis liquid oil. *International Biodeterioration & Biodegradation*, *119*, 239–252. https://doi.org/10.1016/j.ibiod.2016.09.017

[6] Karta, I. W., Farmasari, S., & Ocampo, D. M. (2023). Online Assessment of Primary Students' Cognitive, Psychomotor, and Affective Domains: Practices from Urban and Rural Primary Schools in Indonesia. In *SHS Web of Conferences* (Vol. 173, p.01014). EDP Sciences.https://eric.ed.gov/?id=ED629883

[7] Erdogan, S. (2020). Recycling of waste plastics into pyrolytic fuels and their use in IC engines. *Sustainable Mobility*. https://doi.org/10.5772/intechopen.90639

[8] Prurapark, R., Owjaraen, K., Saengphrom, B., Limthongtip, I., & Tongam, N. (2020). Effect of temperature on pyrolysis oil using High-Density polyethylene and polyethylene terephthalate sources from mobile pyrolysis plant. *Frontiers in Energy Research*, *8*. https://doi.org/10.3389/fenrg.2020.541535

[9] Heydariaraghi, M., Ghorbanian, S., Hallajisani, A., & Salehpour, A. (2016). Fuel properties of the oils produced from the pyrolysis of commonly-used polymers: Effect of fractionating column. *Journal of Analytical and Applied Pyrolysis*, *121*, 307–317. https://doi.org/10.1016/j.jaap.2016.08.010

[10] Singh, R., Ruj, B., Sadhukhan, A., & Gupta, P. (2019). Thermal degradation of waste plastics under non-sweeping atmosphere: Part 1: Effect of temperature, product optimization, and degradation mechanism. *Journal of Environmental Management*, *239*, 395–406. https://doi.org/10.1016/j.jenvman.2019.03.067

[11] Saeaung, K., Phusunti, N., Phetwarotai, W., Assabumrungrat, S., & Cheirsilp, B. (2021). Catalytic pyrolysis of petroleum-based and biodegradable plastic waste to obtain high-value chemicals. *Waste Management*, *127*, 101–111. https://doi.org/10.1016/j.wasman.2021.04.024

[12] Sogancioglu, M., Ahmetli, G., & Yel, E. (2017). A comparative study on waste plastics pyrolysis liquid products quantity and energy recovery potential. *Energy Procedia, 118,* 221–226. https://doi.or/10.1016/j.egypro.2017.07.020

[13] Miandad, R., Rehan, M., Barakat, M. A., Aburiazaiza, A. S., Khan, H., Ismail, I. M. I., . . . Nizami, A. S. (2019). Catalytic pyrolysis of plastic waste: Moving toward pyrolysis based biorefineries. *Frontiers in Energy Research*, *7*. https://doi.org/10.3389/fenrg.2019.00027

[14] Sonawane, Y. & Shindikar, M., & Khaladkar, M. (2017). High calorific value fuel from household plastic waste by catalytic pyrolysis, nature environment and pollution technology. *Nature Environment and Pollution Technology*. *16*(3). 879-882. Retrieved on 6 March 2021 from http://www.neptjournal.com/upload-images/NL-61-29-(27)B-3435.pdf

[15] Paraschiv, M., Kuncser, R., Tazerout, M., & Prisecaru, T. (2015). New energy value chain through pyrolysis of hospital plastic waste. *Applied Thermal Engineering*, *87*, 424–433. https://doi.org/10.1016/j.applthermaleng.2015.04.070

[16] Lee, K. H. (2012). Effects of the types of zeolites on catalytic upgrading of pyrolysis wax oil. *Journal of Analytical and Applied Pyrolysis*, *94*, 209–214. https://doi.org/10.1016/j.jaap.2011.12.015

[17] FakhrHoseini, S. M., & Dastanian, M. (2013). Predicting pyrolysis products of PE, PP, and PET using NRTL activity coefficient model. *Journal of Chemistry*, *2013*, 1–5. https://doi.org/10.1155/2013/487676

[18] Abnisa, F., & Wan Daud, W. M. A. (2014). A review on co-pyrolysis of biomass: An optional technique to obtain a high-grade pyrolysis oil. *Energy Conversion and Management*, *87*, 71–85. https://doi.org/10.1016/j.enconman.2014.07.007

[19] Sharuddin, S. D., Abnisa, F., Wan Daud, W. M. A., & Aroua, M. K. (2016). A review on pyrolysis of plastic wastes. *Energy Conversion and Management*, *115*, 308–326. https://doi.org/10.1016/j.enconman.2016.02.037

[20] Zannikos, F., Kalligeros, S., Anastopoulos, G., & Lois, E. (2013). Converting biomass and waste plastic to solid fuel briquettes. *Journal of Renewable Energy*, *2013*, 1–9. https://doi.org/10.1155/2013/360368

[21] Odejobi, O., Oladunni, A., Sonibare, J., & Abegunrin, I. (2020). Oil yield optimization from co-pyrolysis of low-density polyethylene (LDPE), polystyrene (PS) and polyethylene terephthalate (PET) using simplex lattice mixture design. *Fuel*

Communications, *2–5*, 100006. https://doi.org/10.1016/j.jfueco.2020.100006

[22] Akubo, K., Nahil, M. A., & Williams, P. T. (2017). Aromatic fuel oils are produced from the pyrolysis-catalysis of polyethylene plastic with metal-impregnated zeolite catalysts. *Journal of the Energy Institute*, *92*(1), 195–202. https://doi.org/10.1016/j.joei.2017.10.009

[23] Ahmad, I., Khan, M. I., Khan, H., Ishaq, M., Tariq, R., Gul, K., & Ahmad, W. (2014). Pyrolysis study of polypropylene and polyethylene into premium oil products. *International Journal of Green Energy*, *12*(7), 663–671. https://doi.org/10.1080/15435075.2014.880146

[24] Wu, J., Chen, T., Luo, X., Han, D., Wang, Z., & Wu, J. (2014). TG/FTIR analysis on co-pyrolysis behavior of PE, PVC and PS. *Waste Management*, *34*(3), 676–682. https://doi.org/10.1016/j.wasman.2013.12.005

[25] Siddiqui, M. N., & Redhwi, H. H. (2009). Pyrolysis of mixed plastics for the recovery of useful products. *Fuel Processing Technology*, *90*(4), 545–552. https://doi.org/10.1016/j.fuproc.2009.01.003

[26] Ding, C., Zhou, D. C., Zhang, X. H., Ma, X., & Wang, J. (2014). A relationship between flash point and boiling point of the flammable liquids at low pressure. *Applied Mechanics and Materials*, *664*, 210–214. https://doi.org/10.4028/www.scientific.net/amm.664.210

[27] Sharuddin, S. D. A., Abnisa, F., Daud, W. M. A. W., & Aroua, M. K. (2018). Pyrolysis of plastic waste for liquid fuel production as prospective energy resource. *IOP Conference Series: Materials Science and Engineering*, *334*, 012001. https://doi.org/10.1088/1757-899x/334/1/012001

[28] Kabakcı, S. B., & Hacıbektaşoğlu, E. (2017). Catalytic pyrolysis of biomass. *Pyrolysis*. https://doi.org/10.5772/67569

[29] Stefanidis, S. D., Kalogiannis, K. G., Iliopoulou, E. F., Michailof, C. M., Pilavachi, P. A., & Lappas, A. A. (2014). A study of lignocellulosic biomass pyrolysis via the pyrolysis of cellulose, hemicellulose and lignin. *Journal of Analytical and Applied Pyrolysis*, *105*, 143–150. https://doi.org/10.1016/j.jaap.2013.10.013

[30] Collard, F. X., Blin, J., Bensakhria, A., & Valette, J. (2012). Influence of impregnated metal on the pyrolysis conversion of biomass constituents. *Journal of Analytical and Applied Pyrolysis*, *95*, 213–226. https://doi.org/10.1016/j.jaap.2012.02.009

[31] Aguado, J., Serrano, D., Escola, J., Garagorri, E., & Fernández, J. (2000). Catalytic conversion of polyolefins into fuels over zeolite beta. *Polymer Degradation and Stability*, *69*(1), 11–16. https://doi.org/10.1016/s0141-3910(00)00023-9

[32] Ma, C., Yu, J., Wang, B., Song, Z., Xiang, J., Hu, S., ... & Sun, L. (2017). Catalytic pyrolysis of flame retarded high impact polystyrene over various solid acid catalysts. *Fuel Processing Technology*, *155*, 32-41.

[33] Qian, K., Kumar, A., Zhang, H., Bellmer, D., & Huhnke, R. (2015). Recent advances in utilization of biochar. *Renewable and Sustainable Energy Reviews*, *42*, 1055-1064.