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Recycling of Waste Plastic to Produce Alternative Synthetic Fuel Via Pyrolysis Process

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Abstract:
Waste plastic is considered the third after natural gas and crude oil in terms of energy consumption in power plants. Despite the increase in waste plastic around the world, the major challenge for sustainable development is the elimination of environmental pollutants through ecologically friendly alternatives. Unlike incineration, pyrolysis produces no poisonous or environmentally detrimental emissions. In this study, a pyrolysis technique via catalyst was used to transform waste plastic into oil in an effort towards an environmentally beneficial way. The pyrolysis has been conducted in the absence of oxygen and at a temperature of about 350 °C. The system understudy consists of plastic garbage collected from a variety of sources including households, hotels, and markets. The garbage is sorted according to classification family into categories to represent the following polymers; polyethylene terephthalate (PET), high density polyethylene (HDPE), low-density polyethylene (LDPE) and polypropylene (PP). The study showed the successes of using the pyrolysis method to recover fuel oil from the systems understudy. Among the systems, waste PP exhibited a yield value of about 89% followed by LDPE and HDPE with 65% and 53% at 420 °C, respectively. Generally, the produced fuel oil has shown comparable results similar to that of common petroleum products.

Keywords: High-quality fuel, Pyrolysis process, Waste plastic.

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إعادة تدوير النفايات البلاستيكية لإنتاج وقود صناعي بديل بواسطة عملية التحلل الحراري

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الملخص
يأتي استخدام مخلفات البلاستيك في محطات توليد الطاقة ثالثاً بعد الغاز الطبيعي والنفط الخام. فبالرغم من زيادة استهلاك مخلفات البلاستيك فإن التحدي الرئيسي يكمن في إمكانية التخلص من تلوثات البيئة خلال بدائل أخرى. خلافاً للحرق فإن

البيرولايسيس لاينتج غازات او انبعاثات مضرة بالبيئة. في هذه الدراسة تم استخدام البيرولايسيس لتحويل مخلفات البلاستيك لوقود زيتي. لقد تم استخدام هذه الطريقة في غياب الأكسجين وعند درجة حرارة 350مº. هذه الدراسة تمت على مخلفات لأنواع بولي إيثيلين ترفتاليك، بولي إيثيلين مرتفع الكثافة، بولي إيثيلين منخفض الكثافة وبولي بروبلبين. النتائج أعطت وقود من جميع مخلفات البلاستيك المدروسة وكانت نسبة الاسترجاع للوقود مقدارها 89% في حالة بولي بروبلبين. بالإضافة إلى أن الوقود المتحصل عليه أعطى نتائج فيزيائية مشابهة للوقود المتحصل عليه من نواتج تكرير النفط.

الكلمات المفتاحية: النفايات البلاستيك، عملية الانحلال الحراري، وقود عالي الجودة.

Introduction

Plastics are one of the most widely used materials. They are widely utilized in the packaging and manufacturing of a variety of products, including electronics, automobiles, and other consumer goods. In addition, plastics being used as a substitute for wood and metals [1]. In fact, plastics are made from petroleum compounds using some additives such as antioxidants, colorants, and other stabilizers [1]. They are produced in excess of 129 million tons per year around the world, with 77 million tons coming from petroleum [2]. The high durability of plastics makes their disposal a severe environmental issue. Generally, land filling being the most common method of disposal. Despite the increase in waste plastic around the world, the major challenge for sustainable development is the elimination of environmental pollutants through ecologically friendly alternatives. Unlike incineration, pyrolysis produces no poisonous or environmentally detrimental emissions. Pyrolysis is the process of heating and degrading polymeric materials at temperatures between 250 °C and 350 °C in absence of oxygen. The outcome of this process is in the form of a carbonized singlet (strong deposits) and an unpredictably divided mixture that could be separated into condensable hydrocarbon oil and a non-condensable high caloric value gas. According to Scheirs, carbon monoxide, hydrogen, methane, carbon dioxide, water, and hydrocarbons such as ethane, propane, butane, and so on are among the gases formed during the pyrolysis of natural materials [3]. Because temperature and heating rates have such a large impact on the pyrolysis process, they may be manipulated to create desired solid, gaseous, and liquid products. The thermal cracking of polyethylene and polypropylene at high temperatures of 300℃-450℃, as an example, yields an olefin mixture (C_1-C_4) and aromatic compounds like benzene, toluene, and xylene. However, cracking at lower temperatures yields three products: a high-calorific value gas, condensable hydrocarbon oil, and waxes [4]. At low-temperature cracking, a wax product consisting of paraffin and carbonized char is formed in the reactor. After burning, the gaseous fraction can be used to provide the energy required for pyrolysis. Only traces of aromatic compounds may be found in the liquid element, which is mostly made up of linear olefins and paraffin with carbon atoms ranging from C_{11} to C_{14} [5]. The influence of temperature and reactor type on the pyrolysis of waste plastics has been explored by a number of researchers [4][5][6] . After the process of pyrolysis, wax and carbon black were produced. It should be mentioned that liquid fuel created from pyrolysis has similar properties to the generic fuel products such as kerosene, diesel, heavy fuel oil, ... etc. The produced oil fuels contain hydrocarbons with different carbon chain lengths as given in Table 1.

Table 1 Hydrocarbon range of commercial fuels [8]

Fuel	Hydrocarbon range
LPG	C_3 to C_4
Petrol	C_4 to C_{12}
Kerosene	C_{12} to C_{15}
Diesel	C_{12} to C_{22}
Heavy fuel oil	C_{12} to C_{70}

The primary products of pyrolysis can be used directly or by applying some chemical processes, to produce high quality fuel or other chemical products. It is a matter of turning expensive and difficult-to-use solid waste into liquid useful product easy for storage, and transportation. Therefore, the variation of plastic type and operation conditions affect the quality of the pyrolysis products. However, when the same plastic waste is used at the same operation conditions, there will be similarities in the product yield and production distribution. There are also other ways to describe the products such as boiling point range, phase of products at room temperature etc. Several studies have been reported regarding the pyrolysis of waste plastic. Ahmad et al studied the PP pyrolysis and reported a liquid product yield value of 69.82 wt % at 300°C with a total conversion of 98.86% [7]. Sakata et al also reported an 80.1 wt% liquid product yield at 380°C [8]. Fakhrhoseini and Dastanian observed the maximum liquid product yield of approximately 82.12 wt% at a temperature of 500°C, with further temperature rise lowering the liquid product yield [9]. Ballice and Reimert characterized the liquid result of PP pyrolysis by

GC-MS, and key components such as 2-methyl-4-octene, 2-methyl-2-octene, 2,6-dimethyl-2,4-heptadiene, 2,4-dimethyl-1-heptene, and 2-methyl-1-octene were identified [10].

Apart from the temperature and composition of the waste plastic, almost every reaction is influenced by residence time. For batch reactors, residence time is the most important parameter which is referred to the time between when the feedstock materials begin heating and when the reaction is finished. It refers to the contact period of the plastic waste on the heated surface throughout the reactor in continuous processes. Gao et al. showed that longer residence time promotes further conversion of the primary products and providing more heat stable products such as light molecular weight hydrocarbons and non-condensable petroleum gases [11][12][13][14]. Long residence times in batch operations promote carbonization and result in higher levels of tar and char in the products [15]. However, there is a temperature constraint in the process that may influence product dispersion while residence time had no effect on product distribution. Shafferina et al concluded that longer residence time produced higher yield of liquid product when the temperature was less than 685°C and that the influence of residence time was minimal beyond that temperature [16]. The pyrolysis conditions, residence duration, and target products are shown in Table 2.

Table 2 Pyrolysis process and target products [14][13]

Process	Heating rate	Residence time	Temperature (°C)	Target Products
Slow carbonization	Very Low	Days	450 to 600	Charcoal
Slow pyrolysis	10-100 K/min	10 to 60 min	250 to 400	Gas, oil, char
Fast pyrolysis	Up to 1000 K/s	0.5 to 5 s	550 to 650	Gas, oil, char
Flash pyrolysis	Up to 10000 K/s	< 1s	450 to 900	Gas, oil, char

In this study, the pyrolysis process, which is one of the alternative fuel production methods, is addressed by presenting the types of pyrolysis, the types of plastic waste as raw materials, the parameters that affect pyrolysis, and the products obtained from pyrolysis.

Methodology

The steps involved in this study are shown in Figure 1.

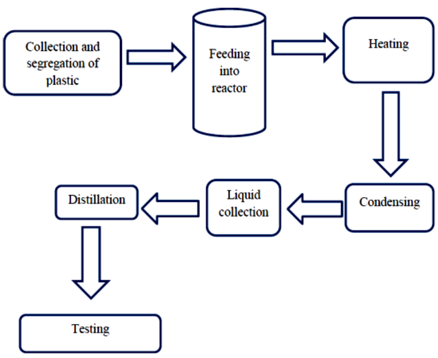

Figure 1: The main steps for pyrolysis process of waste plastics

Plastic garbage is collected from a variety of sources, including households, hotels, and markets, and sorting into several categories. Food containers, milk covers, water bottles, packaging foams, throwaway cups and plates, broken plastic chairs, and shopping bags are among the different sorts of waste plastic. The PET, HDPE, LDPE, PP, and other polymers can be distinguished. After garbage being classified, the plastic is cleaned to eliminate any impurities such as dust and debris and then dried using sunlight to remove any remaining moisture before being chopped into little pieces smaller than 5 cm in length and 1 cm in thickness. The cuttings of waste plastic are then fed into the reactor. The reactor is constructed of mild steel. It should be mentioned that any leakage in the reactor must be avoided at all costs to avoid burning the plastic waste. The reactants (plastic cuttings) and catalyst are fed to the reactor which then heated via a gas heater. The catalyst was prepared by mixing SiO_2 and Al_2O_3 with a ratio of (Si/Al = 1:3). At temperatures of 250°C - 350°C, the plastic trash evaporates. Using a tube condenser, this vapor is condensed and collected in the flask collector. The oil is then distilled to increase its purity as shown in Figure 2. Finally, the oil sample is taken to a laboratory to be tested for qualities characterization. Every test is carried out on various samples.

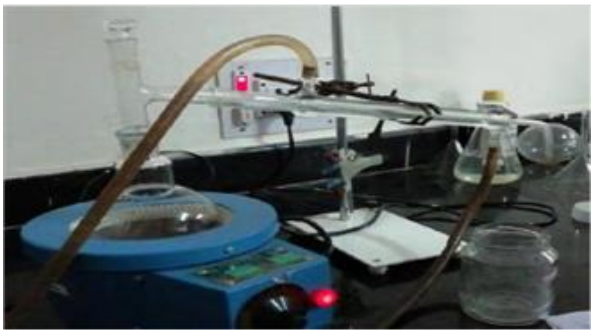

Figure 2: The distillation process of plastic oil.

Results and discussion

The flash point test was conducted for the various samples. The results are shown in Figure 3. These values indicate that LDPE requires the highest temperature to ignite, while PP ignites at the lowest temperature. PET and HDPE have flash points in between. It's important to note that materials with lower flash points pose a higher risk of fire and should be handled with caution.

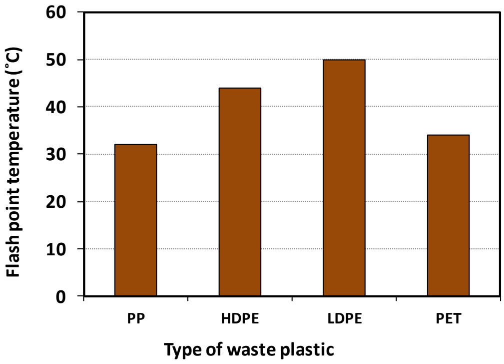

Figure 3: Comparison of flash point for the produced oil.

The density of fuel at different temperatures was measured by a standard 50ml flask using the following equation. The results are shown in Figure 4.

$$Density\ of\ oil\ (\rho) = \frac{weight\ of\ oil}{volume\ of\ oil}$$

The density values give us an idea of the relative weights of the produced oils for a given volume.

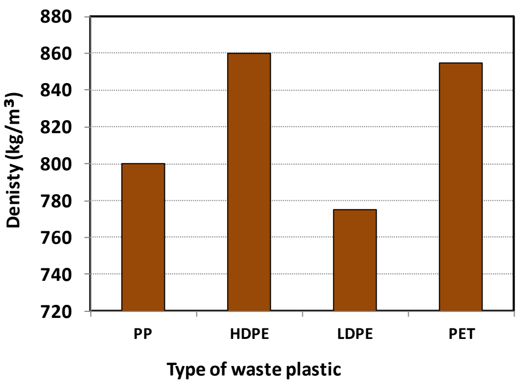

Figure 4: Comparison of densities for the produced oil

Calorific value of fuel is the quantity of heat produced by its combustion at constant pressure and under normal condition. The values have been obtained and the results are shown in Figure 5. The values give us an idea of the relative energy content of these materials. Materials with higher calorific values are more energy-dense and will produce more heat when burned.

Lastly, the pyrolysis product of waste PP has been further characterized to obtain the yield. The yield is calculated from the following equation

$$P = r \cdot t$$

Where;
P = Production of Pyrolysis Process.
r = The amount of volume produced per unit of time (rate of reaction).
t = The time of process.

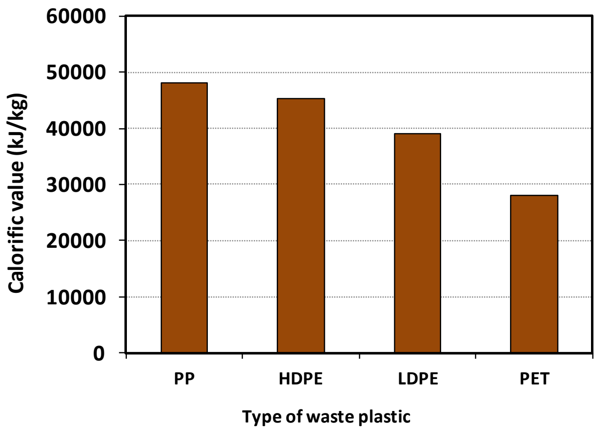

Figure 5: Comparison of calorific value for the produced oil.

Since good results have been obtained from PP pyrolysis system, therefore in-detail study is conducted using this system. The effect of varying temperatures on the PP product yield with and without a catalyst is depicted in Figure 6. The thermal decomposition started at around 190°C. As the temperature elevated from 190°C, the yield of liquid gradually increased in both cases. For example, the maximum yield of 89.34 w % in the presence of a catalyst is obtained at 360°C. On the other hand, the maximum liquid yield of 68.38 w % in the absence of catalyst is shifted to much higher temperature of about 410°C. This is attributed to a need for cracking of hydrocarbons at a higher temperature to overcome the activation energy. Therefore, the optimum temperature for the catalytic pyrolysis system in the present study is chosen to be 360°C.
Additionally, it can be postulated that the yield of the pyrolysis product is directly correlated with the reaction time. This suggests that the time given for the process to complete will determine the maximum yield for successful pyrolysis. The calculations for the yield using the PP pyrolysis are depicted in Figure 7.

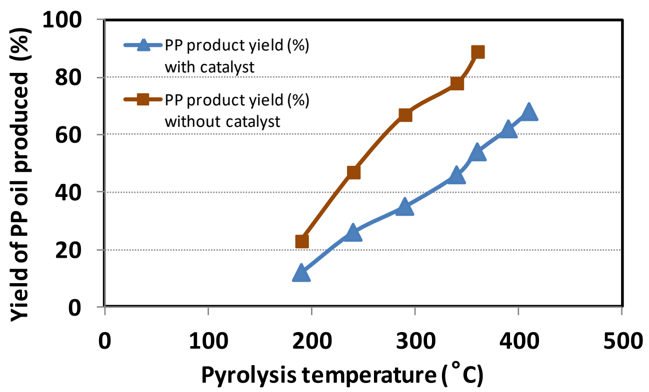

Figure 6: The effect of pyrolysis temperature on PP liquid product with and without catalyst.

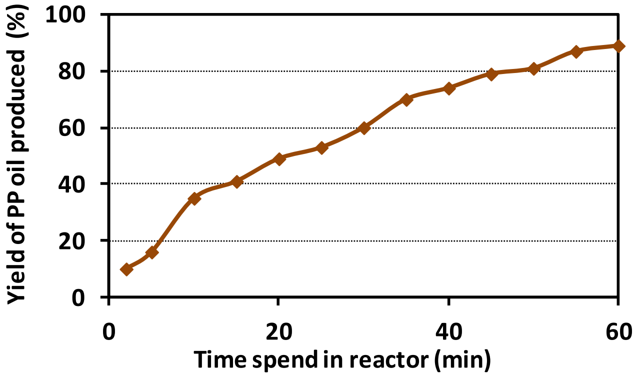

Figure 7: The yield of produced oil from waste PP against time spent in the reactor.

Conclusion

Conversion of waste plastic, via pyrolysis, into fuel has been achieved. The system understudy was garbage and waste materials made from various polymers including PET, HDPE, LDPE, and PP. The obtained results exhibit promising values. The flash point ranges from 30 to 50˚C whereas, densities were in the range of 775 to 860 kg/m3. On the other hand, the calorific values of the pyrolysis oils were in the range of 28000 to 48000 kJ/kg. These values confirm the success of using such materials as alternatives to traditional fuel. Furthermore, the detailed study of the PP pyrolysis showed the possibility of achieving a yield of 89 %. The study also concluded that the kind of plastic utilized affects the final product characterization. Hence, could conclude that pyrolysis of plastic into fuel can solve both the problem of plastic waste management as well as a shortage of fossil fuel.

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