Recycling of Plastic Throughout Pyrolysis and Distillation Process to Recover an Alternative Fuel Sources

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Abstract. Pyrolysis process is a process whereby plastic undergo the heating process and transform into another type of product either liquid form or waxy form. The basic purpose of the study was to determine the type of product formed from different type of plastic used. From the product collected in pyrolysis process it will undergo a further distillation process to increase the quality of the product. The methods that was involved in the making of the product is by using pyrolysis process, distillation process whereby a few product are derived. For pyrolysis process, plastic is heated until vaporized and the vapor is collected and condense to collect the product, while for the distillation process the separation process is done to separate the product according to its boiling point. For data collection, every sample is tested by using the Fourier Transform Infrared Spectroscopy (FTIR) and the bomb calorimeter for its calorific value. From three types of plastic used which is polystyrene, polyethylene, and polyethylene tetrathlate the most suitable type of plastic is polystyrene due to its product which is in liquid form. The distillation process will give three end product which is similar to commercial petrol, diesel and high density oil.

1. Introduction
Plastic consumption has increased from a last few decades. Approximately is about 60 million tons annual consumption of plastics in occidental Europe. From the annual capacity, 23 million tons is plastics waste. Packing and packaging is the main product of plastic waste approximately 63 wt% [1]. Agriculture sector is the main user of the plastic materials since they need to cover the vegetables, fruit, some of the farm and etc. Since they need to cover the vegetables, fruit, some of the farm and etc. On the other hand the plastic packaging also need for other industries which is high-volume market and they directly look into the advantages of plastic if compared with the traditional materials. Nowadays the plastic that normally use for packing and packaging is the main contributors to the most visible in the waste stream. A lot of debate and a public criticism on solid materials. It have look into the component and it comparatively short life-cycles and usually are non-degradable. But it have received a great deal of public since the price and maybe their durability is the characteristic that are prefer by the consumer [2]. Basically, the common ways to treat waste plastics is via landfill and incineration. The municipal solid waste is increase year by year and plastic is one of the waste stream.
Normally, the waste plastic that dump into the landfill is not converted to the energy recovery. Incinerator is the solution recovering energy from the plastic waste but this process give an impact to atmosphere since the carbon content in the plastics being mostly converted into CO$_2$ and released. To reduce the plastic fraction of municipal solid waste which is recycling process. But so far the rate below 15%, representing a waste of a resource [3].

In the modern era, pyrolysis may be an attractive ideas. At the same time it will increase the chemical recycling percentage, and to obtain valuable liquid and gas fuels from plastic wastes [4]. Pyrolysis process normally produce three phases such as solid (char), liquid (tar), and gas that it is spontaneously and immiscible. Immiscible means that those phases cannot mixed together after pyrolysis process. Immiscible means that. However, three phases mixture material could be produced by temperature performed [5-9]. Thermal phenomena may include in this process due to degradation process of large molecules may occur caused by temperature, catalyst presence and residence time. However, large molecules degradation occurred with or without the catalyst presence [10]. Degradation of these large molecules depends on a number of different conditions. Basically the temperature, residence time, and the presence of catalysts is the factor that should be considered when dealing with pyrolysis process. And at the same time, the pyrolysis reaction can be carried out with or without the presence of catalyst. Thermal and catalytic pyrolysis reaction according to the setting for the process.

2. Materials
More than hundreds of commercial plastic materials available. Only the reliable and quality material will be user preference. High volume and relatively low price is the factors that will be consider for a thermoplastics commodity. Figure 1 below show the consumption on a global basis according to the plastics and their fractional. Highest consumption plastic types is Low-density polyethylene (LDPE), high-density PE (HDPE), polypropylene (PP) and PVC approximately 61% while the other rest is PVC, PS, EPS, PET and PUR is around 20% and Others is 19% [11].

![Figure 1. World plastic demand by resin type [12].](image)

For the raw materials, the focus is on polystyrene (PS), polyethylene (PE) which include low and high density of polyethylene (LDPE, HDPE), and Polyethylene terephlate (PET). Meanwhile Figure 2 shows the monomer and polymer of certain plastic. For polyethylene its monomer is ethylene which is derived from ethane. Polypropylene is long chain of propylene which is derived from propene.
Figure 2. Representative of plastic monomer and its polymers [13].

Styrene monomer contain of benzene ring and long monomer chain will be called as polystyrene [13].

3. Process Involved

3.1. Pyrolysis process

Common pyrolysis system is shown in Figure 3. It consists of reactor, 2 heat exchanger system which called by first and second heat exchanger, 2 bottles as condenser system and gas storage. They conduct the pyrolysis process at temperature of 500 °C, and various temperature increasing rates between 6 and 14 °C/min [14].

Figure 3. Schematic diagram of pyrolysis process [14].

Figure 3 shows the schematic diagram of pyrolysis. Meanwhile, in this study the similar system was applied. However, it was conducted by different temperature and heating rate in order to eliminating oxidation product which may developed during the pyrolysis process. The process is
started with inserting the plastic according to its type into the combustion chamber. Next the lid of combustion chamber is closed tightly to prevent the vapour from escaping. The condenser is filled with ice and the collection jar is placed beneath it. After completing the setting up procedure, heating process takes place. Turn on the gas and ignite the stove, be very careful in this process because it could cause some serious damage. The process is continued until all the vapour from the plastic is converted into fluid/oil, next repeated the process by using different type of plastic. The product of each type of plastic is collected and recorded the date, time and materials used. Based on the pyrolysis process that we have done, two types of product is in liquid form for polystyrene and waxy form for PE and PET. Both products were stored for analysis and for further process.

3.2. Distillation process
After pyrolysis process was complete, the collected product will be differentiated into liquids form and wax form. In this stage, the oil or product collected cannot be used as fuel to run the diesel or gasoline engine. Thus to make the oil possible to use as alternative fuel sources, some process should be done in order to convert the oil into petrol and diesel. The process is a distillation process. The petrol and diesel can be extracted from the oil collected by separating them according to their boiling point. The distillation process was conducted in the laboratory under controlled environment.

The most important equipment that’s needed in this process is a hot plate, beaker, condenser, and product to be distiller and setting temperature are between 100°C and 300°C. Figure 4 shows the apparatus setup for distillation process.

4. Result and Discussion
For the pyrolysis end product the result is tested by using two different analyzer/machine which are FTIR machine and Bomb Calorie Meter.

4.1. FTIR Result for Pyrolysis of Polystyrene
Figure 5 shows the FTIR result for the pyrolysis process of polystyrene. The red fluctuation line indicate the major group of chemical composition that present in the product, while the blue color graph indicate the exact position of the compound related to their wavenumbers. Theoretically, the first blue graph which has the highest peak around 2900 cm⁻¹ to 3000 cm⁻¹ indicates that the product is hydrocarbon of CH₃ and has asymmetrical stretch. For the blue graph which has the highest peak around 700 cm⁻¹ indicated that there is aromatic group present in the product.
The strong odor that produce within the product is the proved of the aromatic group present in the product.

4.2. FTIR Result for Pyrolysis of Polyethylene

Figure 6 shows the FTIR result for pyrolysis of polyethylene. In general the red line can indicate the composition of the product is aliphatic hydrocarbon, due to lack of fluctuation of the red line at the back of the graph. The blue graph which has highest peak, about 3000 cm\(^{-1}\) shows that the product contained hydrocarbon. To be specified the hydrocarbon is CH\(_3\) with asymmetrical stretch. The blue graph that spike at wavenumbers of 1470 cm\(^{-1}\) indicates the product contain alkanes group which is methyl group and has asymmetrical C-H bending.

The highest peak that aligns with wavenumbers of 700 cm\(^{-1}\) can be categorized as aromatic group. The aromatic group is very small in amount thus produce less odor compared to other product.

4.3. FTIR Result for Pyrolysis of Polyethylene Terephthalate

Figure 7, shows the FTIR result for pyrolysis of polyethylene terephthalate. The highest hydrocarbon peak is at wavenumber of 3000 cm\(^{-1}\). These indicate that the product has CH\(_3\) type of bonding. The fluctuation at the back side of the graph is refer to the aromatic compound that present inside the product, and the highest peak was at wavenumbers of 700 cm\(^{-1}\). Next there was also benzene ring structure that can be detected by the machine which ranges about 1500 cm\(^{-1}\) to 2000 cm\(^{-1}\). High
intensity of the benzene ring will produce a compact structure of the product thus gave the structure the solid waxy formed. These phenomenon cause the product hard to distillate and required higher temperature in order to break the chain reaction. There was lack of light absorption in between the range of 3600 cm$^{-1}$ to 4000 cm$^{-1}$ which indicate that the component is lack of alcohol group inside the product.

![Figure 7. Graph of spectrometer for pyrolysis of polyethylene terephthalate.](image)

From the Pyrolysis process the product collected can be either in liquids form or in waxy formed. The liquids product is derived from the pyrolysis process of polystyrene (PS) while the waxy product is derived from the pyrolysis of polyethylene (PE) or polyethylene terephlate (PET). The Distillate product undergo burning test to determine the soot produce, and duration of combustion. The burning test result is shown in Table 1 and Figure 8 shows the distillation end product.

![Figure 8. Product form distillation process.](image)

| Product          | The temperature required | Viscosity | Color of product         | Soot produce |
|------------------|--------------------------|-----------|--------------------------|--------------|
| Product 1        | 100 °C                   | Low       | Light yellow             | Low          |
| Product 2        | 300 °C                   | Medium    | Light brownish           | High         |
| Bottom product   | More than 500 °C         | High      | Dark brown               | Very high    |
Figure 8 shows the product end product of distillation process form the pyrolysis product. The distillation process is aimed to retrieve thee product which is similar to gasoline, diesel and high density oil.

4.4. Calorific Value for Each End Product
The calorific value for each product that collected was shown in Table 2 below.

| Product                        | Calorific value (MJ/kg) |
|-------------------------------|-------------------------|
| Pyrolysis Product In Liquids Form (PS) | 41.10                  |
| Pyrolysis Product In Wax Form (PE and PET) | 45.50                  |
| Distillate Product At 100 °C   | 41.00                   |
| Distillate Product At 300 °C   | 41.50                   |
| Bottom Product                | 40.60                   |

From this test all the products were confirmed to be fuel base composition. Beside that the product also can be used as fuel source according to their function. The calorific value for the petroleum base product was usually in the range in between 40 MJ/kg to 50 MJ/kg. Due to the product testing, the calorific value was in the range of the commercial petrol and diesel. From the data, this similarity means that the product also can run the vehicle that used the commercial petrol and diesel. The high value of this calorific value also indicated that it stored a lots amount of the energy. It is better because it’s can run the petrol or diesel transportation in much higher duration due to their higher energy stored. In comparison with the commercial petrol and diesel, the product also can run the transportation as good as the commercial product. As for the distillation process, the liquid product from the pyrolysis process can be separated into several products according to its hydrocarbon chain and boiling point. From the distillation process, three more products can be extracted which are petrol, diesel and high viscosity oil. All the product were essential to human daily life, such as powering transportation and also act as an industrial fuel source.

5. Conclusion
Plastic could be recycled into alternative sources through series of process. It could be generate as an alternative fuel such as petrol or diesel, wax or other alternative fuel source. Base on liquids collected it will undergo further process which is a distillation process to extract raw material. While the wax could be instantaneously used in daily life, such as for candle and act as surviving kits when required to start a fire. In comparison with the commercial product, testing is vital in order to test the oil either it could be performed as well as a commercial product. From the FTIR test, the entire product has exactly the same compound as a commercial product while the calorific value of the entire product is in the same range as the calorific value of commercial product. This testing shows that the amount of energy that could be generated by the product as similar with the commercial product.

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