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Investigation on Pyrolysis of Plastic Waste to Fuel Oil

R.Saravana Sathiya Prabhahar [1], M.Anandhan[2]

[1, 2] Department of Mechanical Engineering, Mepco Schlenk Engineering College, Sivakasi, India.

Abstract

Growing demand for the energy promotes the research for alternate fuels. Energy can be generated from different sources like solar, wind, biomass, etc. In this work an effort has been made to convert the waste plastics into a useful source of energy. Pyrolysis is one form of thermo chemical conversion in the absence of air. In this work pyrolysis of High Density Poly Ethylene (HDPE) & Polypropylene has been carried out. Waste plastics were collected from nearby sources and were cut into small pieces. It was subjected to thermal decomposition in a laboratory scale pyrolysis set up at a temperature range of 300-500^{o}C and at atmospheric pressure. The volatile matter which comes out of the reactor was condensed to obtain pyrolytic oil. The various properties of the products obtained were then tested and compared with the actual values for petroleum oil. In order to improve the yield of the pyrolytic oil, Nickel nano particles and Nickel oxide nano particles were added as a catalyst along with the plastic wastes. It was found that the yield was improved significantly in the presence of catalyst.

Keywords: Pyrolysis , Catalyst ,Fuel, HDPE

INTRODUCTION

Modern life style promotes the use of plastics in many of the day to day activities. Plastics have now almost become indispensable materials and the demand is continually increasing due to their diverse and attractive applications in household and industries. Due to the abundant use of thermoplastics polymers, a high proportion of waste is generated and this is continuously increasing around the globe. Disposal of these waste plastics pose a very serious environmental challenge because of their huge quantity and also they do not biodegrade for very long time. Plastics are produced from petroleum derivatives and are composed primarily of hydrocarbons but also contain additives such as antioxidants, colorants and other stabilizers. Their destruction by incineration poses serious air pollution problems due to the release of harmful gases such as dioxins and hydrogen chloride, air borne particles and carbon dioxide. So recycling of plastics is one of the best way to handle the waste plastics. There are many forms of recycling which includes primary, secondary, tertiary and quaternary form of recycling. Tertiary recycling returns plastics to their constituent monomers or to their basic hydrocarbon feedstock. The basic idea of tertiary recycling is to break polymer molecules into smaller organic molecules or monomers. The most important and widely used tertiary recycling process is pyrolysis, where plastics are heated in the absence of oxygen. Tertiary recycling of waste plastics may not be considered as a solution for waste plastics disposal rather generating an environmentally acceptable transportation fuel or feed stock for the production of virgin plastics also. Waste plastics are one of the promising sources for fuel production because of their high heat of combustion and their increasing availability in local communities. Waste plastic oil generates less NO_X when compared to diesel oil.

Pyrolysis is one of the thermochemical composition of biomass into a range of useful products in the total absence of oxidizing agents or with a limited supply that does not permit gasification to an appreciable extent.

Plastic is a material consists of a wide range of synthetic or semi-synthetic organic compounds that are malleable and can be molded into solid objects. Plastics are typically organic polymers of high molecular mass, but they often contain other substances. Due to their relatively low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in an enormous and expanding range of products, from paper clips to spaceships.

Plastics are usually classified by their chemical structure of the polymer's backbone and side chains such as acrylics, polyesters, silicones, polyurethanes, and halogenated plastics. They can also be classified by the chemical process used in their synthesis, such as condensation, polyaddition, and cross-linking. Thermoplastics are the plastics that do not undergo chemical change in their composition when heated and can be molded again and again. Thermosets can melt and take shape once; after they have solidified, they stay solid. Polyethylene terephthalate is the most common thermoplastic polymer resin of the polyester family and is used in fibres for clothing, containers for liquids and foods, etc. High-density polyethylene is a polyethylene thermoplastic made from petroleum mostly used in the production of plastic bottles, corrosion-resistant piping, geomembranes and plastic lumber. Polyvinyl Chloride is used for all kinds of pipes and tiles, but is most commonly found in plumbing pipes. Low Density Poly Ethylene is a very healthy plastic that tends to be both durable and flexible widely used in cling-film, sandwich bags, squeezable bottles and plastic grocery bags. Poly propylene is strong and can usually withstand higher temperatures which is used to make lunch boxes, margarine containers, yogurt pots, syrup bottles, prescription bottles. Polystyrene is commonly recycled, but is difficult to do. Items such as disposable coffee cups, plastic food boxes, plastic cutlery and packing foam are made from it.

The main objective of this work is to convert the waste plastics such as High-Density Polyethylene and Polystyrene collected from our domestic environment into plastic oil by pyrolysis.

C.A. Rinaldini et.al. (2016) discussed about “Performance, emission and combustion characteristics of a IDI engine running on waste plastic oil”. They detailed about the experimental campaign carried out on a current production indirect injection, naturally aspirated diesel engine, running on standard Commercial Diesel Oil (CDO) and on a Waste Plastic Oil (WPO) derived from the pyrolysis of plastics. Tests have been carried out at both full and partial load, while in-cylinder pressure traces have been measured in order to analyze the combustion phase.

P. Senthil Kumar et.al., (2016) studied about "Investigation on environmental factors of waste plastics into oil and its emulsion to control the emission in DI diesel engine" In this study, waste plastic oil (WPO) was tested in DI diesel engine to evaluate its performance and emission characteristics. Results showed that oxides of nitrogen (NOx) emission get increased with WPO when compared to diesel oil.

Ana-María Al-Lal et.al.,(2015) studied about the "Desulfurization of pyrolysis fuels obtained from waste: Lube oils, tires and plastics" This study reveals the use of two affordable desulfurization techniques without hydrogen to reduce the sulphur content of these three pyrolysis fuels with moderate success that could make them useful as heating fuels.

Preetham Reddy Churkunti et.al., (2015) published a research article on "Combustion analysis of pyrolysis end of life plastic fuel blended with ultralow sulfur diesel" It reports about the ever increasing energy demand along with fast depleting non-renewable fossil fuels and global climate change has led to a search for alternative energy resources, Waste plastic fuels have gained significant interest since they not only solve disposal problems but also provide an alternative energy resource.

Viswanath K. Kaimal et.al., (2015) revealed about "A detailed investigation of the combustion characteristics of a DI diesel engine fuelled with plastic oil and rice bran methyl ester" They analyzed the performance of diesel engine run on plastic oil which is obtained from the pyrolysis of waste plastic materials and rice bran methyl ester obtained using the methanolysis of rice bran oil.

Houyang Lia, et.al.,(2015) published a research article about **"**Investigation on the co-pyrolysis of waste rubber/plastics blended with a stalk additive" This is a study on experimental investigation of co-pyrolysis of discarded rubber and plastics in a tube furnace, The properties of the pyrolysis oil and solid residue under various blending ratios of rubber and plastics were investigated.

Chiara Santella et.al.,(2012) reported the "Thermal and catalytic pyrolysis of a mixture of plastics from small waste electrical and electronic equipment (WEEE)" This study deals with the thermal and catalytic pyrolysis of a synthetic mixture containing real waste plastics, representative of polymers contained in small waste electronic components.

Mohammad Nahid Siddiqui et.al.,(2009)" detailed about "Pyrolysis of mixed plastics for the recovery of useful products" They analyzed the Thermal and catalytic pyrolysis of polystyrene (PS) with low-density polyethylene (LDPE), high-densitypolyethylene (HDPE), polypropylene (PP), poly-ethylene terephthalate (PET) plastics were carried out in a 25 cm^3 stainless steel micro reactor at around 430–440 °C under 5.5–6.0 MPa of N_2 gas pressure for 1 h. The results obtained from this study have shown usefulness and feasibility of the pyrolysis process of the mixed plastics as an alternative approach to feedstock recycling.

MATERIALS AND METHODS

Material

The raw material chosen for the current work is waste plastics which has high calorific value of 3580.41 kcal/kg. Since it is readily available everywhere and has not been researched yet, this material has been chosen. High density polyethylene waste (Fig. 2.1.1) is obtained from an industry located at Sulakkarai, industrial estate Virudhunagar, Tamilandu. Polypropylene (Fig. 2.1.2) is obtained from nearby plastic industry, Virudhunagar District who are the principal manufacturers of water bottles which is used in our day to day life.

Figure 2.1.1 HDPE Granules

Figure 2.1.2 Polypropylene

TGA Analysis:

Thermo gravimetric Analysis (TGA) can be used to evaluate the thermal stability of a material. In a desired temperature range, if a species is thermally stable, there will be no observed mass change. Negligible mass loss corresponds to little or no slope in the TGA trace. TGA also gives the upper use temperature of a material. Beyond this temperature the material will begin to degrade. In this work, TGA was performed for the virgin HDPE shown in fig 2.2.1. From the TGA curve, the virgin HDPE degradation started at 300°C and was completed at 468°C for a heating rate of 293 K/min in nitrogen atmosphere. The degradation temperature at which weight loss of 50% takes place was about 450°C for virgin HDPE. The temperature range for waste HDPE was 390°C to 490°C, and maximum weight loss occurred at temperature 468°C. TGA Curve of Polypropylene is shown in fig 2.2.2. From the TGA

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curve, waste poly propylene degradation started at 125°C and was completed at 560°C for a heating rate of 293 K/min in nitrogen atmosphere. The degradation temperature at which weight loss of 50% takes place was about 400°C for Polypropylene. The temperature range for waste polypropylene was 200°C to 590°C, and maximum weight loss occurred at temperature 560°C.

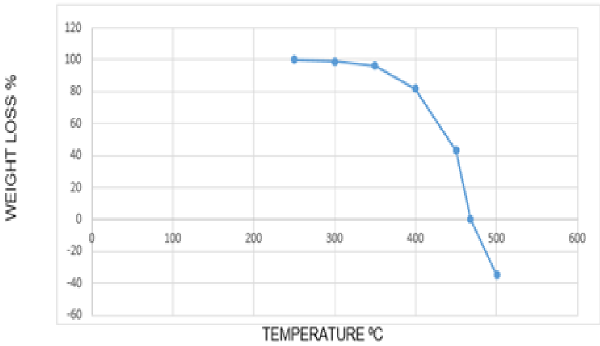

Figure 2.2.1 TGA Curve for Virgin HDPE

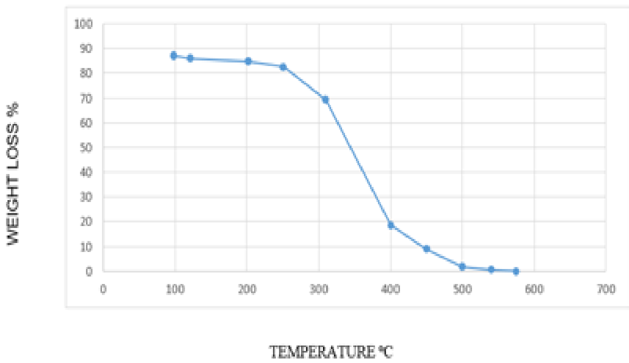

Figure 2.2.2 TGA Curve of Polypropylene

Experimental Setup

A wide range of reactors have been used on a laboratory scale for the plastic pyrolysis process. The reactor set-up in this research is a batch reactor. A common variant between the batch and semi-batch operations is the vacuum, which causes the reduction of temperature of the reaction to take place inside the Borosil round bottom flask. The pre-processed waste plastic materials were transferred into an empty round bottom Borosil glass flask of capacity 500 mL. The empty weight of round bottom flask was found to be 340.3 g. After the raw materials were loaded into the round bottomed flask, one opening was connected to a condenser and the other was used as a nitrogen inlet and then the condenser was connected to a suction flask where oil will be collected. The round bottom flask is fixed with heating mantle. The oil is collected at the suction flask end. During the whole process, the temperature was maintained around 400^0 C to 500^0 C and a vacuum pump was used to create vacuum inside the round bottom flask. The condensed oil was collected in the flask.

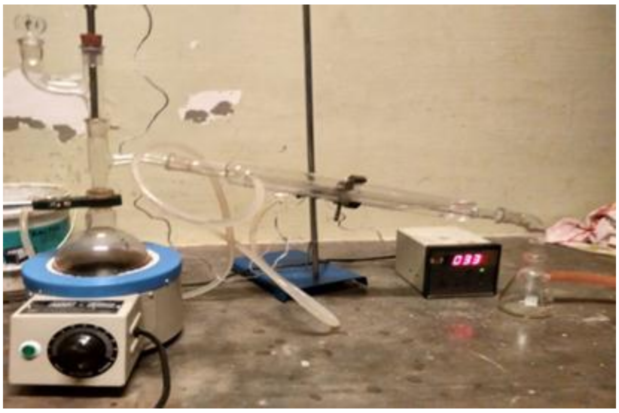

Figure 2.3.1 Experimental setup

Experimental Procedure

15g of waste plastics was taken in a Round Bottom flask fitted with delivery tube, condenser and a suction flask placed in a heating mantle as shown in Figure 2.3.1. The contents were heated to 450^0 C for 1 hour. The plastics were melted and gets decomposed into simpler hydrocarbons and appears like a coke oil. After 45 min, the vapours were distilled off and gets condensed into condenser, collected in a suction flask kept at the end of the condenser.15g of HDPE produces 8.2 ml of oil and was subjected to various analysis.

Quantity of Oil Obtained in Pyrolysis

The quantity of oil obtained during the pyrolysis of the virgin HDPE and Polypropylene at a temperature of 450^0 C is shown in Table. No. 2.5.1 and the image is shown in fig 2.5.1

Table No. 2.5.1 Quantity of oil obtained

Material	QUANTITY (g)	OIL OBTAINED (ml)
HDPE	15	8.2
POLYPROPYLENE	15	11.3

Figure 2.5.1 Image of oil obtained

Also, the quantity of oil obtained during the pyrolysis for the same quantity of HDPE at a temperature of 450^0 C with different catalytic concentration for both Nickel nano particle and Nickel oxide nano particle is shown in Table. No. 2.5.2

Table 2.5.2 Quantity of oil obtained after adding catalyst

Material (15g)	Quantity of Catalyst Added (g)	Oil obtained with Ni nano particles (ml)	Oil obtained with NiO nano particles (ml)
HDPE	0.25	12.2	10.2
HDPE	0.5	12.3	10.6
HDPE	0.75	12.2	10.6

RESULTS AND DISCUSSION

Analysis of Plastic Oil

The oil obtained in the pyrolysis process was analysed using FTIR and compared with petroleum fuel oils. Also the properties such the viscosity, flash point and fire point of the oil was also analysed.

FTIR Spectroscopy

Fourier transform infrared spectroscopy (FTIR) is a technique which is used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. The goal of any absorption spectroscopy is to measure how well a sample absorbs light at each wavelength.

The FTIR spectra of oil obtained from HDPE and Polypropylene without using any catalyst is shown in fig.3.2.1 and fig.3.2.2

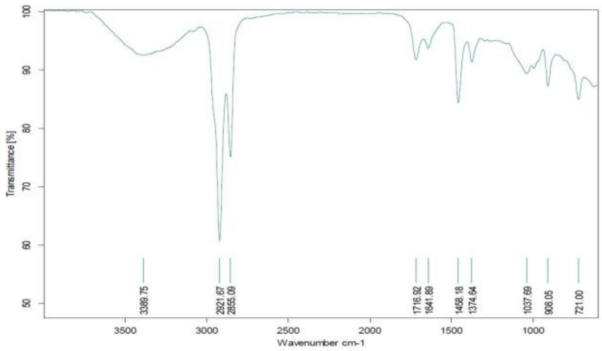

Figure 3.2.1 FTIR spectra of oil - HDPE without catalyst

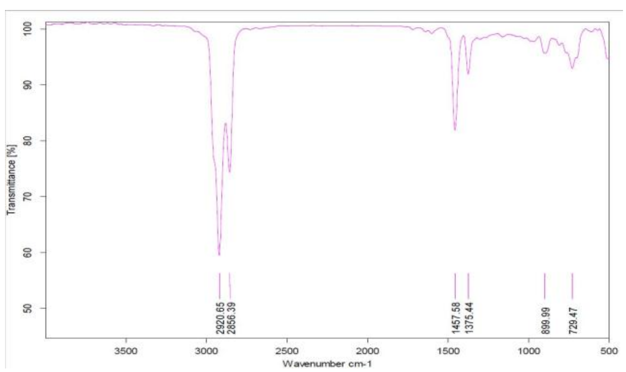

Figure 3.2.2 FTIR spectra of oil - Polypropylene without catalyst

The FTIR spectra obtained from the pyrolysis of HDPE and Polypropylene were compared with the spectra for petroleum fuel oils. The chemical analysis of the HDPE and Polypropylene pyrolytic oil showed the presence of functional groups such as alkanes, alkenes, alcohols, ethers, carboxylic acids, esters, and phenyl ring substitution bands which is similar to that of the petroleum oils.

In order to observe the improvement of the oil yield, the experiments were repeated with the presence of catalyst. So based on the feasibility Nickel nano particle and Nickel oxide nano particles were chosen as catalyst.

The FTIR spectra of oil obtained from HDPE using Nickel nano particle and Nickel oxide nano particles catalyst is shown in fig.3.2.3 and fig.3.2.4

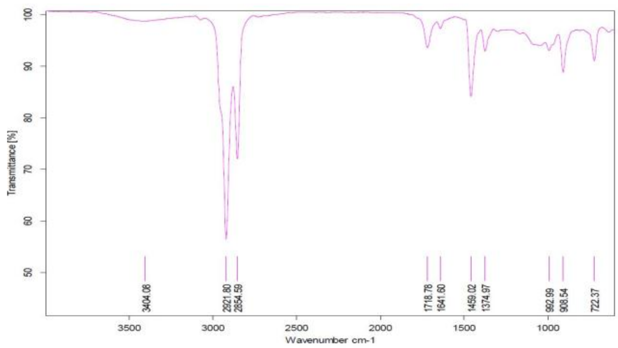

Figure 3.2.3 FTIR of HDPE oil sample obtained after adding nickel nano particles

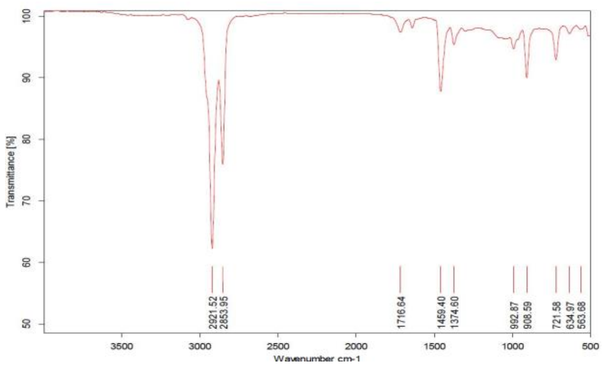

Figure 3.2.4 FTIR of HDPE oil sample obtained after adding nickel oxide nano particles

Table No.3.2.1 Wave number of HDPE oil without adding catalyst

Wave number	Name of functional group
BEEFORE ADDING CATALYST	
720	Alkene bands
908	Alkene
1458	Alkene
1641	Alkene
2855	Alkane
2921	Alkane

Table No.3.2.2 Wave number of HDPE oil with catalyst

Wave number	Name of functional group
AFTER ADDING NICKEL NANO CATALYST	
720	Alkene bands
908	Alkene
1458	Alkene
1641	Alkene
2855	Alkane
2921	Alkane
AFTER ADDING NICKEL OXIDE NANO CATALYST	
722	Alkene
909	Alkene
1458	Alkene
1641	Alkane
2855	Alkane
2921	Alkane

CONCLUSION

The chemical analysis of the HDPE and Polypropylene pyrolytic oil showed the presence of functional groups such as alkanes, alkenes, alcohols, ethers, carboxylic acids, esters, and phenyl ring. Though both HDPE and Polypropylene oil have similar composition in other parameters such as viscosity, flash point and fire point HDPE oil was better than polypropylene oil. This is because HDPE oil contains more fixed carbon than Polypropylene but the yield of HDPE oil was very low. The yield of oil was greatly improved by performing pyrolysis in the presence of Nickel nano particle and Nickel oxide nano particle catalyst. This shows that the oil obtained from catalytic pyrolysis could be used as a potential fuel.

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