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Thermal Pyrolysis of Hospital Plastic Waste

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Abstract: Plastic plays an important role in our daily lives due to its versatility, light weight and low production cost. The amount of plastic waste is growing every year and with that comes an environmental concern regarding this problem. Pyrolysis as a tertiary recycling process is presented as a solution. In this work, the pyrolysis of hospital plastic waste products was investigated using thermal non catalytic cracking techniques. The experimental work was carried out using a pyrolysis reactor operating under an inert atmosphere at 450°C. Results indicated that the waste plastic is able to give the yield of liquid product by using a pyrolysis reactor. The obtained product was fuel liked liquid heavy oil which was viscous and had a yellow color. The fuel properties of the diesel-range distillate (diesel fraction) were comparable to other conventional fuel and found its calorific value was 31 MJ/kg.

***Keywords*: Pyrolysis, Plastic Wastes, Thermal Cracking, Liquid product, Polyethylene**

I. INTRODUCTION

Increase in energy demand and depletion of conventional sources of energy like fossil fuel reservoirs, forces us to find an alternative fuel which is cheaper and environment friendly or to allow use of secondary fuels in place of primary fuels or with primary fuels to decrease the consumption of fossil fuels. Plastics, one of the most commonly used material in day-to-day life could be used as an alternative source of energy after its useful life as it derived from petroleum products. Rapid urbanization and economic development and convenience in use and manufacturing, the world plastic production increased since it was first commercially manufactured from 1.5 million tons (MT) in 1950 to 245MT in 2008 [1]. The production of plastic increased on an average of 10% every year on global basis since 1950 as continuous innovation and research for better product in the field occurred. The plastic possesses excellent properties like light weight and non-corrosive nature due to which metal and wood industries were highly affected [2, 3].

Also the environmental pollution due to plastic waste is occurring as a global phenomenon today. Recycling waste plastic into reusable plastic products is a conventional strategic way followed to address the current issue for recent years. High plastic consumption and low average life had increased the difficulties for disposal of plastic waste and emerged as an important environment challenge and the recycling process facing a resistance due to their non-degradable behavior. Recycling and reusing of plastic is gaining importance day by day as a sustainable method for disposal of plastic waste. Petroleum based plastic waste can be converted into reusable products like gasoline and heavy oils by recycling and refining for energy or chemical source from thermal treatment or its combustion [4]. As an alternative to combustion and gasification, pyrolysis of plastic waste has gained importance because of having better advantages toward environmental pollution. Absence of oxygenated compounds or oxygen in the process resists the formation of dioxins which are formed at higher temperatures. In combustion/incineration or gasification, oxygen available at higher temperature reacts with the product to form oxygenated compounds and presence of nitrogen confirms the formation of nitrogenous compounds which are harmful to the environment. Being an inert atmosphere (free from oxygen) and low temperature process, pyrolysis does not allow forming dioxins, as well as reduces the carbon footprints [5, 6].

Polyethylene is used in a wide variety of applications ranging from packaging films, tubing, and some components to hip and joint replacement implants. Polyethylene exhibits excellent chemical resistance to most chemicals or disinfectants used in hospitals and clinics. Polyethylene exists in various forms. Low-density polyethylene (LDPE) contains many long-chain branches along the polymer backbone, preventing the alignment and packing of the chains and thus forming a low density material. High-density polyethylene (HDPE) contains about 4-10 short chains along the polymer backbone. The relatively few side chains allow the polymer backbone to align and pack together to form a crystalline, high-density plastic [7].

The pyrolysis process is thermo-chemical degradation reaction operated at high temperature ranging about from 400 - 900° C in an inert environment. When it is heated above degradation temperature, those high-molecular chains are lysed to stabile low-molecular products and solid residue. Products like oil, wax, gas and char were obtained as a product of the process whose composition and yield mainly depends on plastic type, reactor type, and process condition particularly heating rate, reaction temperature and pressure. Many researchers were studied and observed thermal pyrolysis and degradation of different plastics such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) and their mixtures [8].

Ahmad et al. [9] explored the pyrolysis study of HDPE using micro steel reactor. The pyrolysis temperatures were within 300–400°C at heating rate of 5–10°C per minute. Nitrogen gas was used as the fluidizing medium. From the experiment, they found that the highest total conversion happened to be at 350°C with liquid was the dominant product yield (80.88% by weight). The solid residue was very high at 300°C (33.05% by weight) but the amount was reducing to 0.54 wt% at the highest temperature of 400°C.

Kumar and Singh [10] have done the thermal pyrolysis study of HDPE using semi-batch reactor at higher temperature range of 400–550°C. It was observed that the highest liquid yield (79.08% by weight) and gaseous product (24.75% by weight) obtained at temperature of 550°C while wax started to dominate in product fraction at higher temperature of 500–550°C. The dark brownish oil obtained from the pyrolysis had no visible residue and the boiling point was from 82 to 352°C. This suggested the mixture of different oil component such as gasoline, kerosene and diesel in the oil that matched the properties of conventional fuel. Besides, the sulphur content in the HDPE pyrolytic oil was very low (0.019%) that made it cleaner to the environment.

Marcilla et al. [11] have also studied a batch reactor to evaluate the thermal and catalytic pyrolysis of HDPE and LDPE with HZSM-5 catalyst at 550°C. As can be seen, the condensable products were the major fraction for the thermal process and no solid fraction (coke) was detected. The liquid oil yield was 84.7% and gaseous product around 16.3% by weight. This results proven that higher liquid oil could be obtained at higher temperature but there was also a limitation that should be noted. Too high temperature would reduce the liquid oil yield and increased the gaseous product since the process had passed the maximum thermal degradation point.

Mastral et al. [12] conducted the HDPE pyrolysis in a fluidized bed reactor at 650°C and they found that the liquid oil production was around 68.5% and 31.5% gaseous product by weight. This shows that the liquid was cracked to gaseous when further heated up at a very high temperature above 550 °C.

Seo et al. [13] studied the catalytic degradation of HDPE using a batch reactor at a temperature of 450 °C. The authors found that the pyrolysis performed with the zeolite ZSM-5 had higher yield of the gaseous fraction and smaller liquid fraction when compared with thermal cracking. According to them, this is explained by the properties of the catalyst. Most zeolites, including ZSM-5, showed excellent catalytic efficiency in cracking, isomerization and aromatization due to its strong acidic property and its microporous crystalline structure.

II. PYROLYSIS

The production of fuel from plastics is one of the most demanding research topics throughout the world. Hydrocracking, thermochemical, and catalytic conversion are the most widely used methods for fuel production from plastics. Among them, thermochemical conversion or pyrolysis treatment seems to be the dominant mode used [14].

Thermochemical treatment, breaks large polymers into smaller hydrocarbons of various carbon numbers and boiling points in an inert, air-free, or controlled environment at elevated temperature. The hydrocarbons between the boiling points of 35 and 185 °C can be used as motor gasoline, between 185 and 290 °C as diesel one, between 290 and 350 °C as diesel two, between 350 and 538 °C as vacuum gas oil, and >538 °C as the residue. These fractions can be obtained in different proportions by the appropriate choice of thermal treatment/degradation temperature, type of plastics, degradation time, and catalyst type. The product yields of liquid, gas, and residue vary depending on the type of polymer, degradation temperature, and atmosphere [10, 15, 16]. Although the results vary somewhat because they come from different studies, thermo-chemical treatment seems to be a promising method of producing hydrocarbons from polymers. A subset of the thermal treatment is the gasification process. In this case the plastic is decomposed to combustible gaseous products at high temperatures, usually with the help of an oxidizing or a gasification agent. Both of these tchniques to convert plastics to fuel do not have negative impacts on the environment [17].

Hydrocracking is the cracking of larger hydrocarbons, such as polymers, into fuel-range hydrocarbons in the presence of hydrogen at elevated temperatures. Scott et al. studied polyethylene hydro cracking at 600°C in an activated carbon bed. No char was formed in the process and the major products were gases that had a hydrocarbon range of C_{5+}; this process produced double the gas fractions of C_{5+} that were produced from thermal cracking in an inert atmosphere [18]. Hydrocracking is also more effective when performed with a catalyst. The most widely used hydrocracking catalysts are acidic supporting materials (alumina, silica–alumina, zeolites) loaded with transition metals (Pt, Fe, Ni, and Mo). For example, Ding et al. used a hybrid catalyst containing a 4:1 weight ratio of SiO_2–Al_2O_3: HZSM-5 loaded with Ni or Ni-Mo sulfides. The hydrocracking reaction was carried out at 375°C and 1000 psi for one hour. The optimal conditions resulted in conversions up to 99%. The product contained mostly hydrocarbons with a range of $\leq C_{13}$ [19]. In general, catalytic hydrocracking improves the conversion of polymers into hydrocarbons, compared to non-catalytic hydrocracking.

In catalytic conversion, catalysts are added to pyrolysis reactions to improve conversion, improve fuel quality, increases electivity, and lower the pyrolysis temperature and residence time. The acidic nature of most of the catalysts used enhances conversion by protonating the defective sites of polymers forming on chain carbonium ions. Selectivity and fuel quality vary with the strength of the catalyst's acidity. Acid catalysts with micro pores give higher conversion. Primary cracking takes place in the macro porous surface and, once the polymer is cracked, further cracking is enhanced by micro pores. The use of a strong catalyst results in the production of lower hydrocarbons ranging between C_3 and C_5. A polymer-to-catalyst ratio of 10:1 yields 100% conversion within an hour of contact time [20]. The catalysts used for plastic upgrading are grouped into a few main categories: fluid cracking catalysts (FCC), reforming catalysts, and activated carbon. FCC catalysts include zeolite, silica-alumina, and clay [18]. Reforming catalysts include transition metals loaded in silica–alumina [10]. Activated carbon is also widely used and can be loaded with or without transition metals. The life of a catalyst can be increased by using a two-step process that involves thermal cracking followed by catalytic cracking [14].

III.PYROLYSIS REACTORS

The type of reactors has an important impact in the mixing of the plastics and catalysts, residence time, heat transfer and efficiency of the reaction towards achieving the final desired product. Most plastic pyrolysis in the lab scale were performed in batch, semi-batch or continuous-flow reactors such as fluidized bed, fixed-bed reactor and conical spouted bed reactor.

For the case of processing high and low density polyethylene wastes, fluidized bed reactors were found to promote high gas yields around 90% with all types of catalysts. HZSM-5 and HMOR produced 60% in the range of C_3–C_5. Aromatics with a narrow distribution were mainly obtained with HUSY. When E-Cat FCC catalysts were used, higher amounts of aromatic compounds were found in the produced gasoline. While MCM-41 and SAHA catalysts promoted a wider range of carbon chains in the gasoline range. At 400– 450°C NCM and FCC catalysts gave high yields of liquid in the gasoline range of C_8–C_{13} with low sulfur contents and a little amount of gas [21, 22].

Batch, semi-batch and autoclave reactors were also tested to pyrolyse polyethylene with different catalysts. MCM-41 promoted the cracking of high-density polyethylene (HDPE) into lighter liquid and gaseous products at 380°C; Paraffins and aromatic compounds were strongly present. At 550°C, HZSM-5 favored the formation of gases in the light fraction (C_2–C_4) and the condensed products were mainly aromatics. With 430°C semi-batch experiments, a KFS-16B catalyst gave lighter condensate products and a slower deactivation in comparison to other catalysts [23]. The ZSM-5 catalyst promoted gas production significantly in the C_4–C_5 range, and gave light liquid hydrocarbons. Silica–Alumina SA-1 and SA-2 promoted liquid production with a narrow range of carbon number. A 38–57% conversion was achieved when Mordenite catalysts were used at 420°C to pyrolyse low-density polyethylene (LDPE). When a Rh/Al_2O_4 catalyst was used at 425°C, a high liquid yield of 85% was reached in a pressurized autoclave with an increased yield of alkanes at the expense of alkenes in the gas fraction. Methane gas was at a dominating fraction of 46% [24, 25].

In fixed bed reactors, the presence of a fluid catalytic cracking catalyst (FCC), KOB-627, increased the conversion of HDPE at 450–500°C and produced significant amounts of gasoline. When H-beta catalyst was used, the gas yield was richer in C_4 and C_5 in comparison to HZSM-5 but it exhibited higher production of coke deposits. Undesirable polycyclic aromatics were obtained with Zn- ZSM-11 and H-ZSM-11 catalysts at 500°C under shorter experiment residence time. As the residence time increased the yield of gaseous fractions increased and no polycyclic aromatics were detected over both catalysts at 60 min residence time [26].

Unconventional reactor systems such as conical-spouted, cycled spheres and screw kilns were also inspected in terms of yields and product quality. These were found to produce gasoline of high quality and LPG with little dry gas, and small amount of coke. In Some cases, the obtained gasoline [27] was in agreement with EU requirements containing no Sulphur, negligible benzene, and a RON index of 96.5. Furthermore, microwave assisted pyrolysis furnaces have been used as an efficient route to handle plastic waste. These pyrolysed waste HDPE to produce 49.7% liquids composed of linear alkanes, 1-alkenes, and low amounts of aromatics [28, 29].

As opposed to investigating various reactor systems, the catalyst activity and ability for regeneration during pyrolysis, received relatively less attention in literature. In a recent study, two commercial zeolites were used to study the deactivation mechanisms during the pyrolysis of polyethylene. With the help of TG/FT-IR analysis the authors noticed that as the catalysts were undergoing de-activation the process gradually became similar to thermal pyrolysis. The characteristics of the products produced with the deactivated catalysts were the same as those obtained from thermal runs and the catalyst lost its activity after six runs. In another polyethylene pyrolysis catalyst deactivation study, two different mechanisms were identified when deactivation and regeneration were conducted. A reversible deactivation by coke deposition, which can be removed by regeneration with air at 550°C, took place along with an irreversible deactivation. The coke deposited on the external surface was easily removed by regeneration. Permanent deactivation is generally caused by changes to the zeolites structure at high temperatures, formation of stable coke species and/or poisoning of the acid sites by metals originating from the polymer itself. This was not observed in polyethylene pyrolysis experiments running at moderate temperatures. In a subsequent study, the authors found that after one pyrolysis experiment the zeolite catalyst lost its activity in terms of yields and product quality. This deactivation was found to be reversible when the catalyst was subjected to regeneration at 550°C in an air atmosphere. The catalyst recovered its activity, generating similar products with equivalent proportions to those obtained with fresh catalyst [30].

In this study, the thermal non catalytic pyrolysis of hospital plastic waste is carried out in a pyrolysis reactor. The product yield and composition of the generated products are closely inspected to help elucidate the performance and limitations of the process under various conditions. The outcome from this work is anticipated to help determine the possibility of running the pyrolysis process for waste plastic from different sources.

IV. EXPERIMENTAL

The collected feedstock samples for the present study were consist of disposable saline bag, tube, syringe that were mainly made of PE, HDPE and LDPE plastic types. These waste plastic was collected from local medical college and hospital as they are the major components of hospital plastic waste found in Bangladesh. After collection, hospital waste plastic wash with water and after finished wash the waste plastic make it dry with using sun light at ambient temperature. Then hospital waste plastic was crushed to small pieces and prepare for experiment. The pyrolysis experiments were carried out using a setup similar to fig. 1 [10].

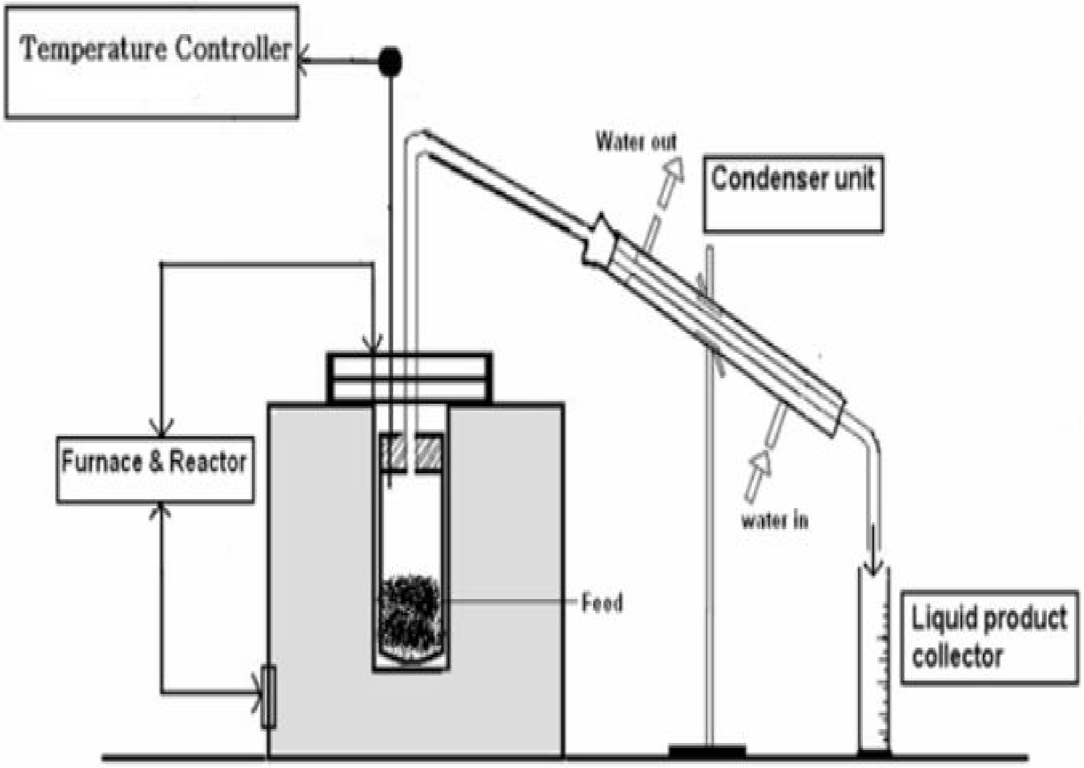

Fig. 1 Pyrolysis setup

The laboratory setup for conducting pyrolysis experiments having small pilot scale pyrolysis reactor was designed and used for the conversion of plastic waste into liquid oil and char (Fig. 2). The reactor was made of stainless steel and covered with a furnace heater which allows to obtain a maximum temperature of 600°C, having the pressure capacity of 400 psi. The height of the reactor was 480 mm with 250 mm diameter and a capacity of 24 litres. A tube type condenser with a length of 900 mm coupled with a water chiller was installed at the end of catalytic reactor. Organic vapors produced within the heating chamber at high temperature were condensed into liquid oil in the condenser (Fig. 3). Water circulating chiller with a coolant was used to decrease the temperature of condenser for the maximum condensation of organic vapors into liquid oil in the condenser. The condensed organic vapors (liquid oil) were collected from the oil collector assembly at the bottom of the condenser. While the uncondensed products (gases) coming from same liquid oil pipe were exhausted outside (Fig. 3).

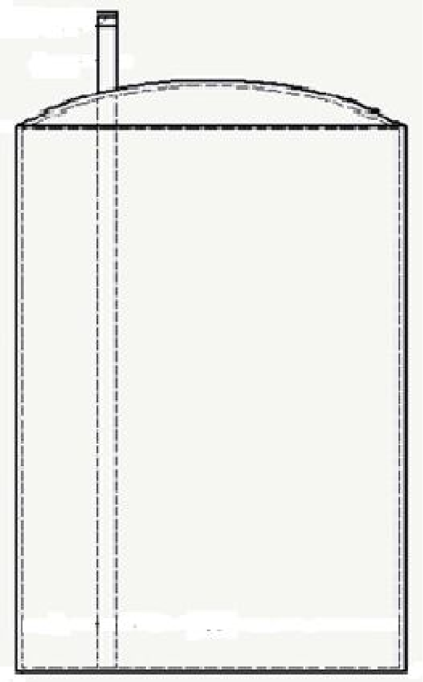

Fig. 2 Pyrolysis reactor of experimental setup

In the experiments, the hospital plastic waste was placed into the reactor which was sealed and vacuumed to ensure the absence of oxygen in the reaction place. The reactor was then heated from room temperature to 450ºC using a heating rate of 15ºC per min approximately. A retention time of 60 minute was maintained for the experiment. This optimum condition of 450ºC and 60 minute for pyrolysis process was continue under controlled condition with safety considerations of using temperatures well below the maximum achievable temperature of the pyrolysis process. The plastic waste was converted into organic vapors that were condensed into liquid oil after passing through the condenser and collected in the collection tank at the bottom (Fig. 3). The temperature of the condenser chamber was kept below 10ºC to obtain the maximum condensation of organic vapors at a coolant flow rate of 10 litre per minute. The unburnt portion (char) was collected from heating chamber at the end of each experiment after allowing the system to cool down at room temperature.

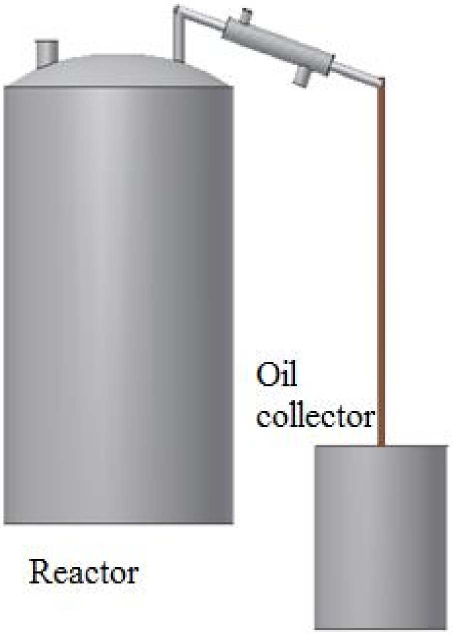

Fig. 3 Scheme of pyrolysis setup

V. RESULTS AND DISCUSSION

The experimental work was a non-catalytic thermal degradation experiment from which the achieved yield was a liquid product. The product yields from the thermal degradation of waste HDPE at 450°C are shown in Fig. 4. The wax obtained was lightly viscous and had a yellow color, whereas the light green liquid was mixed with dark brown heavy oil. It is worth mentioning that when the same experiment was carried out without any bed material in the reactor, the product yield gave 100% wax of high viscosity and dark yellow color. Usually the thermal non-catalytic experiments generated a relatively high liquid wax yield of 78.7% and 17.8% gas. The amount of un-reacted polymer was equivalent to 3.5% of the total plastic waste used [30]. The cement powder bed produced the largest amount of liquids at 82% with a gas yield of 18%. These results were compared with other results reported by different researchers. The measured physical properties such as higher calorific value of the fuel product from the experiment were 31 MJ/kg (Fig. 4) which indicates that liquid fuels represent one kind of diesel fraction.

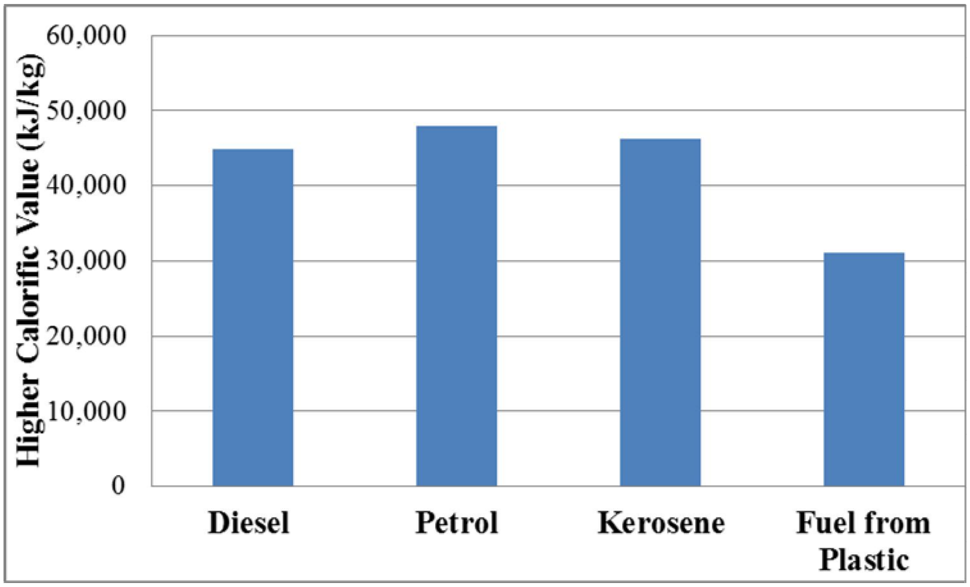

Fig. 4 Properties of fuel product from thermal pyrolysis of waste plastic at 450°C

VI. CONCLUSIONS

From this research work, it is clear that the waste plastic is able to give the yield of liquid product by using a pyrolysis reactor. The produced oil product can be fractionated into gasoline, diesel or kerosene. The pyrolysis setup successfully converts the waste plastic into liquid fuel. Higher yield of liquid products was obtained for the temperature above 430°C. The fuel oil formation is greatly affected by the rate of heat addition, a long enough retention time at previously determinate cracking temperature interval. Measured physical properties such as calorific value of obtained liquid fuel were 31 MJ/kg which indicates that liquid fuels represent one kind of diesel fraction.

Consumption of plastics has increased over the years and the concern with their waste generated too. Because of this many studies have been done with the aim to recover or recycle the waste. Pyrolysis has been effective compared to other disposal methods, because it can reuse the energy and the raw materials contained in those waste, reducing thereby the environmental impacts caused by the inadequate disposal of these waste plastics.

The pyrolysis process may be thermal or catalytic. Thermal degradation occurs by radical mechanism, and as a result of this mechanism the products formed have a broad distribution of the number of carbon atoms in the main chain. In this type of the endothermic process due to the low thermal conductivity of polymers, there is a need for high temperatures. Because of that there is a high expenditure of energy. In order to decrease this temperature, catalysts may be used.

With the catalytic pyrolysis, the products obtained have a more narrow distribution of the number of carbon atoms being directed to more specific products. The composition and amount of the obtained products are listed as type of catalyst used. Furthermore, the catalytic reaction decreases the degradation time and the fraction of solid waste formed. Generally, the catalysts used in the catalytic degradation are solid acids such as zeolites. Zeolites have a specific molecular pore size and access of such molecules to catalytic reactive sites, as well as growth of the final products within such pores is limited by its size.

The other experimental parameters such as temperature, reaction time, reactor type and flow of carrier gas also influence the composition of the products obtained. Pyrolysis can be carried out either for pure polymers or for polymer blends.

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