

Plastic Waste to Fuel: A Sustainable method for Waste Management

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Abstract – The synthesis of petroleum based fuel from plastic waste by carrying out pyrolysis under catalytic action is been presented. Pyrolysis involve breaking down of polymeric chain in presence of proper catalyst and in absence of oxygen. The waste plastic select are mainly LDPE (Low Density Polyethylene). The work involve production of oil samples from plastic with the help of different catalyst. The catalyst reduces the reaction time and increase the output oil. The catalyst used are Alumina silica and Barium Carbonate Under thermal degradation the plastic melts and form vapor which when condensed give liquid hydrocarbon product. The other by product is the residuals which is carbon black wick can be used for making bricks or in tarring. The parametric study of the synthesized oil sample was conducted. Based on the study the catalyst for the reaction was selected. The proportion of polymer to catalyst ratio in the pyrolysis is 10:1. The temperature maintained about a range of 300- 450 °C.

Index Terms-Plastic wastes, barium carbonate, aluminum silicate, plastic fuel, Pyrolysis, Glass condenser, Optimum properties, waste management, and oil production

1 INTRODUCTION

Plastics are non-biodegradable material. The disposal and decomposition of plastics has been a major issue which led to a number of research works to be carried out. Current solutions adopted for treating plastic wastes are incineration, landfill, recycling-separation at the factory, thermal recycling, and chemical recycling. Of these methods, chemical recycling is a research field which is gaining much interest now a days, as it turns out to be that the products formed in this method are highly advantageous.

The fuels obtained from this process do not contain any sulphur content because there is no sulphur in the waste plastic. This is an advantage compared with the main fossil fuels such as diesel because sulphur content in the fuels after combustion could form SO₂. SO₂ could cause severe air pollutions, which affects human health and cause damage to concrete structure. Therefore, this technology is environmental friendly and has significant positive impact on the local government and community.

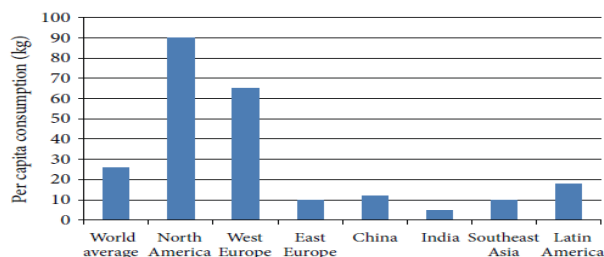


Fig.1 Global per capita consumption of plastics

The advantages of plastics are it is lightweight, low cost, doesn't rust or rot, reusable and conserves natural resources, because of these advantages plastics has won much popularity. Plastics production has increased by almost 10% every year since 1950 on a global basis [1]. Asia accounts for 40% of the global consumption and has been largest plastics consumer in the world for several years. The main segment continues to be the packaging, which has accounted for over 35% of the global demand [2].

The global production of plastics has seen an increase from around 1.3 million tonnes in 1950 to 245 MT in 2006 [1]. In recent years, significant growth in the consumption of plastic globally has been due to the introduction of plastics into newer application areas such as in automotive field, rail, transport, aerospace, medical and healthcare, electrical and electronics, telecommunication, building and infrastructure, and furniture. This significant growth in the demand for plastic and its forecast for future have certainly proved that there has been a quiet plastic revolution taking place in every sector.

| Type of plastic | Consumption % |
|---|---------------|
| Polythene (PE) | 33.5 |
| Polypropylene (PP) | 19.5 |
| Polyvinylchloride (PVC) | 16.5 |
| Polystyrene (PS) | 8.5 |
| Polyethylene terephthalate (PET) and polyurethane (PU) | 5.5 |
| Styrene copolymers (ABS, SAN, etc.) | 3.5 |
| Blends, alloys, high performance and specialty plastics, thermosetting plastics, and so forth | 13 |

Table.1: Global consumption of individual plastics

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2 DIFFERENT METHODS OF PLASTIC WASTE MANAGEMENT

2.1 Landfill

The major portion of the waste plastics are managed by the method of landfill. But the disposal of the waste through landfill is now regulated by law. It is expected that there will be 35% reduction in landfilling by 2020. Also the rise in cost and paucity of land, the production of explosive greenhouse gases (such as methane), a high volume to weight ratio of plastics, and the non biodegradability of commonly used packaging polymers also make it an unattractive option.

2.2 Recycling

Recovery of the used plastics to form new similar products is termed as mechanical recycling. In this method, the products recycled are with almost same or less performance level than the original product. Even if the technique seems to be "a green operation," it is not cost effective as it requires high energy for cleaning, sorting, transportation, and processing to make a functional product. Practically it is seen that reprocessing of mixed contaminated plastics yields mechanically inferior products which lacks durability compared with the original polymers. Types of recycling are: (i) Primary, (ii) Secondary, (iii) Tertiary, (iv) Quaternary.

2.3 Biodegradation of degradable Polymers

Biodegradable polymers are polymers which can be converted back to the biomass in a realistic time period. However, there are number of difficulties over the use of degradable plastics. First, appropriate conditions are necessary for the degradation of such plastics, like presence of light for the photodegradable plastics. Second, greenhouse gases such as methane is released when plastics are degraded anaerobically. This is by enabling microorganisms in the environment which metabolizes the molecular structure of plastic films to produce an inert humus-like material that is less harmful to the environment.

2.4 Incineration

Incineration of plastics waste is an alternative method in which energy is recovered from waste polymers. These hydrocarbon polymers can be a substitute for fossil fuels and thereby reduce the CO₂ burden on the environment. Polyethylene is having calorific value close to that of the fuel oil, and the energy produced by incineration of polyethylene is of the same magnitude as that used in its manufacture making it an attractive option. However, this method produces green house

gases and toxic pollutants which is a big disadvantage.

2.5 Thermal Cracking

Cracking is a process that breaks down the long polymeric chains into useful smaller molecular weight compounds. The products obtained from this process are highly useful and can be utilized as fuels or chemicals in various applications. The pyrolysis reaction can be executed without or in the presence of a catalyst. If without catalyst, it is thermal cracking or thermolysis, and if it is in the presence of catalyst, it is catalytic pyrolysis.

Thermal cracking or pyrolysis is the degradation or cracking of the polymeric materials by heating them to a very high temperature. The heating must be carried out in the absence of oxygen to make sure that no oxidation of the polymer takes place. The temperature range is between 350 and 900°C. The products formed include a carbonized char (solid residues) and a volatile fraction. A part of the volatile fraction can be condensed to give paraffins, isoparaffins, olefins, naphthenes, and aromatics, while remaining portion is a noncondensable high calorific value gas. The products formed and their exact composition depend on the type of the plastic waste and the process conditions. In catalytic cracking, the same process is carried out in the presence of a catalyst. The prominent advantage of this method is that the presence of catalyst drops the reaction temperature and time. Another added advantage is that in thermal cracking a broad variety of products are formed by the breaking of the polymeric chain, while in catalytic degradation the product distribution will be a much narrower, with a peak at lighter hydrocarbons. The importance of this work lies in comparing the performance of different catalysts like barium carbonate and alumina silica for the thermal cracking of waste polythene and selecting the most suitable catalyst based on their yield and thermophysical properties of the hydrocarbon oil obtained.

3 LITERATURE REVIEW

There are a few examples of plants where plastic wastes are converted to Fuel. It is very common in all cases that they are subjected to scrubber for facilitating PVC cracking as it is not that suitable. It is understood that chlorine is undesirable in fuels as they can lead to corrosive actions. These plants are sophisticated and are not that suitable for small scale production. The plants make use of catalysts for the upgradation of quality of the product of pyrolysis in the several existing devices. Those equipments embedded with catalysts have some weaknesses in form of larger material resistance period, an undesirable contact between plastic and catalysts, and requirement of high heat transfer rate, and also the cost of the catalysts.

| Fuels | LPG | Petrol | Kerosene | Diesel* | Heavy Fuel oil |
|--------------|----------------------------------|-----------------------------------|------------------------------------|------------------------------------|------------------------------------|
| Hydrocarbons | C ₃ to C ₄ | C ₄ to C ₁₂ | C ₁₂ to C ₁₅ | C ₁₂ to C ₂₄ | C ₁₂ to C ₇₀ |

TABLE 2 Hydrocarbon range in commercial fuels

It is particularly applied to petroleum fuels. Petroleum gases, petrol, kerosene, diesel and wax are the distinct groups to which products of pyrolysis can be classified to. The fuels contain hydrocarbon group with different carbon chain lengths as given in table above. There are also other ways to describe the hydrocarbons such as boiling range, phase of products at room temperature etc.

3.1 Effect of Catalyst

The impact of catalyst in pyrolysis is crucial. silica alumina, zeolites (beta, USY, ZSM-5, REY, clinoptilolite, etc.), and MCM-41 are the most predominantly used catalysts in the pyrolysis process generally. More the number of acid sites, more the catalyst activity in polyolefin pyrolysis. Due to this, zeolite-based catalysts showed greater conversion compared to nonzeolitic catalysts. Polyethylene to transportation fuel conversion using rare earth metal-exchanged Y-type (REY), and HZSM-5 zeolites, HY and silica-alumina (SA) is achievable and it has been verified by studies. It was inferred from study that REY zeolite was the most effective catalyst in producing plastic oil with the highest octane number value and gasoline yield. This zeolite also had large pores and had fine acidic strength too. The Y-zeolite and ZSM-5 zeolite were observed to generate oils having a high research octane number which in some way was comparable to the one from REY, but the yield quantity was still low. It is seen that the catalyst significantly reduces the degradation temperature as compared to pure thermal degradation in the absence of a catalyst. Hydrocarbons in the C₃-C₁₅ range are the normal products of catalytic degradation. The catalyst was highly acidic, producing oil with high octane number. With silica alumina combined with two different SiO₂/Al₂O₃ proportions; that is, SA-1 (SiO₂/Al₂O₃ ratio of 83.3/16.7) and silica alumina SA-2 (SiO₂/Al₂O₃ = 21.1/78.9) were studied by a researcher Uddin et al. [5]. The liquid yield obtained had 68 wt% for SA-1 in comparison to 77 wt% for SA-2. So, the SA-1 catalyst degraded the polyethylene good into much lighter hydrocarbon oil than SA-2 catalyst. A yield and composition of the liquid products can be managed by varying the SiO₂/Al₂O₃ ratio. The liquid products are distributed in C₅-C₂₀ range, which basically falls in gasoline and diesel ranges. Jan et al. [6] carried out a study on the influence of nonacidic catalysts on pyrolysis of plastics. He observed that the % oil yield (33.5%) was greater with MgCO₃ as compared to the % oil yield (29.65%) obtained with

BaCO₃ catalyst. Another inference he made was CaCO₃, when used as a catalyst under the similar reaction conditions, the obtained % oil quantity was 32.18%.

3.2 Effect of Catalyst Contact Mode

For catalyst to be added to the reactor, basically two methods are found: liquid phase contact and vapor phase contact. In the former case, the catalyst and polymer are mixed together, and then they are settled into the reactor and is heated to the reaction temperature. In the latter case though, the polymer is initially subjected to thermolysis that generates volatile fraction. The catalyst is introduced in the way of the travelling vapour, and as the vapour progress through the catalyst, hydrocarbon vapour degradation occurs and required product distribution is seen. In case of the quantity there isn't much difference observed among the two cases.

3.3 Effect of Polymer to Catalyst Ratio

Upto to a certain limit, higher amount of catalyst produces higher yield. There is an optimum ratio and it resides on the type of catalyst. The ratio we determined and took forward was 10:1. Our experiment was completely carried out at this proportion ratio. From literature studies it is observed that though even smaller ratio can give good yield but it requires higher temperature. Therefore clearly there is a crucial need for optimisation between catalyst ratio and temperature, so as to ensure that the entire experiment proves economical along with being effective.

3.4 Effect of Temperature

There is an increase in the bond breakage at high working temperature and greater heating rates during pyrolysis, which causes generation of smaller molecules. The conversion rate increases with increase in temperature, and at this increased rate, gaseous products dominates over liquid products or yields. With increasing temperature, the effect of catalyst nature becomes less significant. The reaction taking place will be similar to the process of thermal degradation [8].

4 WASTE PLASTIC OIL PRODUCTION

Polythene is been chosen as the main source of waste plastics since it account for highest percentage of the waste plastic produced. The catalysts used for the study include alumina silica and barium carbonate. The pyrolysis reaction is carried out in the polymer to catalyst ratio of 10:1. The temperature ranges between 300 and 450°C at which the reaction takes place. Based on the literature survey these selections have been made out. The experimental setup is as shown in Figure 2. The setup consists of a electric heater (reactor), a 250 ml

glass conical flask, glass column condenser, 100ml glass beaker as oil collectors. The maximum loading capacity of the reactor was 100g of waste plastics.

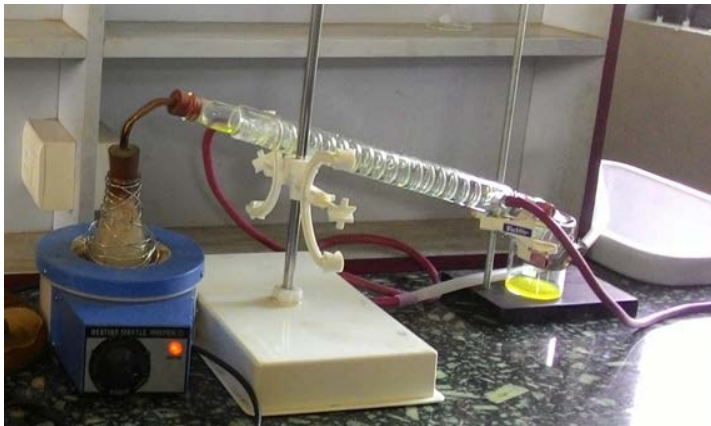


Fig. 2 Experimental setup

The reactor consists of electric heater of 100 W power, arranged in series over a copper pipe of 12 mm diameter and 60 mm length. The column condenser is used as a parallel flow heat exchanger of length 50 cm. Water at around 28°C (room temperature) is used as the coolant in the condenser. The waste plastic is placed inside the 250 ml conical flask container. Rubber corks are used to keep the flask and condenser air tight holes are provided to connect the copper pipe between the two. Then this container is finally placed inside the heater.



Fig. 3: chopped plastics

The waste plastic was chopped into small piece and mixed with the catalyst before it is being supplied to the heater. Then heater is switched on and is set at maximum 100W. The vapor formed during the pyrolysis process flows out of the reactor. The gas mixture is cooled in the condenser. Water at ordinary room temperature is supplied for cooling action in condenser. The vapour fraction will be condensed and collected in a glass beaker fitted to the condenser end. The remaining uncon-

densed part will be entrapped in the beaker and will condens with time.

The oil samples are obtained using barium carbonate and alumina silica as catalysts at reaction temperatures ranging from 300°C to 450°C.

The polythene waste is first chopped to sizes of 1-2 cm and then mixed with the test catalyst (polymer to catalyst ratio of 10 : 1) uniformly. The mixture of plastic and catalyst are then inserted into the heater assembly and are heated to the required temperature of approximately 400°C. Once the temperature is attained, it is maintained for a preset reaction time (say 4 hours). After the reaction time is over, the heater is switched off, but the reaction is allowed to take place for another one more hour, so that maximum volatile fraction formed will pass through the heat exchangers. The condensed volatile fraction is finally collected from the collecting beaker and is then filtered. Now the process is repeated for other catalyst also. The other by product obtained in the process is carbon black which could be very well used to make bricks or for road tarring.

5 YIELD OF BIO-OIL AND OIL PROPERTIES

The characteristics of the oil samples produced by the two different catalysts are shown in the table 4 below. Also their properties on different aspects are also mentioned. It was noted that the liquid yield was available only at temperatures above 350°C for both the catalysts. From the obtained results of liquid yield and its properties, the catalyst Alumina silica is selected as the best catalyst with the optimum reaction temperature as around 418°C. The oil produced using this optimum catalyst was produced in adequate amount. The oil is produced using barium carbonate catalyst at a temperature of 403°C (shown in figure 4).

From the table the various properties of these samples are compared.



Fig. 4. Oil sample with barium carbonate catalyst

TABLE 4:
OPTIMUM PROPERTIES OF PLASTIC OIL WITH DIFFER-

| PROPERTY | BARIUM CAR- BONATE CATALYST | ALUMINA SILICA CATALYST |
|---|-----------------------------------|-------------------------------|
| TEMPERATURE (C) | 403 | 418 |
| LIQUID-COLLECTED(mL) | 32 | 150 |
| AFTER FILTRATION (mL) | 26 | 130 |
| CALORIFIC VALUE(MJ/Kg) | 35.87 | 42.23 |
| VISCOSITY(X10 ⁻³ Ns/m ²) | 1.6123 | 1.2756 |
| DENSITY (g/cc) | 0.9723 | 0.9491 |
| FLASH-POINT (C) | 43 | 30.3 |
| FIRE POINT(C) | 49 | 35.8 |

ENT CATALYST

6 CONCLUSION

- A petroleum based fuel has been produced from waste plastic (polythene).
- The optimum catalyst and reactions temperature for catalytic pyrolysis of polythene have been found. Based on the yield and different thermophysical properties Barium carbonate and alumina silica were selected as catalyst.
- The properties of the plastic oil with two different catalyst have been compared.
- Alumina Silica was found be the better catalyst.
- Rather than considering it just as an alternate fuel, the practical importance of this method in waste plastic management adds its value as an alternate fuel.

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