Pyrolysis of Waste Plastic and SEM Analysis of its Burnt Residue

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Abstract: *Pollution and the unavailability of fossil fuels are the two major problems faced by the mankind in the 21st century. Due to the increase in the usage of IC engines after the industrial revolution, the demand for fossil fuels has increased exponentially. It is estimated that the existing fossil fuel reserves can serve up to one and a half century. On the other hand, the synthesized nondegradable plastics are either buried or burned causing air and soil pollution. Since recent years the presence of plastics in water bodies are increasing rapidly. Even though there are many plastic recycling methods, plastic pyrolysis is considered as a sole solution for converting waste plastics into fuel in the absence of oxygen using a catalyst at medium temperatures or without catalyst at elevated temperatures which helps in bond degradation. Catalysts like zeolite salts are substituted with carbonates of Barium, Calcium, Magnesium, and Sodium at temperatures ranging from 350° to 500°C. The products achieved are liquid fuel, a semi-solid compound at every joint of the piping system and char residue. The properties of the obtained liquid fuel are examined. The nanostructure of the char obtained is analyzed and compared to coal.*

Key Words: Plastics, SEM, Char.

1. INTRODUCTION:

Since the invention of the plastics, it became one of the reliable material in everyday life. The reasons behind this is its malleable and plastic behaviors. They can be molded into any desired shapes and volumes. A survey states that around 100 million tons of plastic are produced every year in which the USA and Europe lead with 30%, 24% of the total production [1]. There is a vast range of application of plastics ranging from packaging, storage, agriculture to space industry. Being lighter in weight, durable, more flexible and availability made plastics a paragon in daily life [2]. In contrast to these advantages, there are few notable disadvantages such as disposal. In earlier days, most of the plastics are either buried or burned resulting in 65-70% of landfilling and 20-25% of incineration [3]. Organic wastes such as paper, cotton cloth, and wood takes few weeks to ten years, metals take 100 to 500 years to degrade [4]. In contrast, Plastics take millions of years to degrade due to the presence of strong bonding between atoms resulting in loosening the soil and infertile [5]. Moreover, when plastics are burned, toxins like Dioxins, Furans are released into the atmosphere resulting in air pollution [6].

Furthermore, it is estimated that 15-25% of the municipal waste is plastic [3]. High-Density Polyethylene (HDPE) constitutes the major part of the plastic waste disposal followed by Low-Density Polyethylene (LDPE) and Polypropylenes (PP) [3-7]. Recycling is considered as a sole solution for this problem and the decrease in the percentage of landfilling in recent years describes the success of recycling or energy recovering [7]. Recycling can be broadly classified into two categories, Mechanical and Chemical recycling [3-6]. In Mechanical recycling, the size and shape of the plastics are reduced either by using tools or heat. On the other hand, Chemical recycling involves the reduction of long polymer chains into lighter hydrocarbons [3]. As plastics are petroleum derivatives containing anti-oxidants, colorants, and stabilizers [8], conversion of plastics back into crude oil is feasible and safe. Moreover, the calorific value of plastics ranges from 20 MJ/kg to 44 MJ/kg [9]. Hence pyrolysis can be considered as one of the best plastic recycling techniques [5].

In pyrolysis, plastics undergo thermal degradation in the presence of catalysts at a lower temperature or without catalyst at a higher temperature to form smaller and lighter hydrocarbon chains in anaerobic condition. The main products produced during this process are oil, gas, and char which are further refined to obtain a range of products. There are numerous factors that influence quality and quantity of the products obtained; size and quality of the raw materials, type of reactor, operating conditions which include temperature, pressure, heating rate, time, type and amount of catalyst. The increase in temperature results in more gaseous products, more oil and reduction in char yield. The oil produced has various industrial applications [5-7]. The char produced contains 51.40% volatile matter, 46.03% fixed carbon, 2.41% of moisture and little amount of ash. When individual components are considered Carbon composed of 42.65% and followed by Hydrogen and Nitrogen. When this char is activated using Oxygen at 900^0c, BET Surface area and pore volume increase by 55% and 44% respectively resulting in the conversion of char into activated carbon. This activated carbon is turned into briquettes which can be used as a solid fuel [7].

2. EXPERIMENTAL SETUP:

As in pyrolysis, initially the solid Plastic is liquefied and further gasified by external heating. The gaseous content is to be liquefied for the sake of obtaining liquid fuel. A furnace is required to heat the Plastic and an efficient metal piping to pilot the hot gaseous fuel in a required path. In order to remove heat from the gaseous fuel and convert it into liquid state a heat exchanger is to be set up. Thus, the setup can be broadly divided into three parts, they are Reactor unit, Piping unit and Condensing unit.

2.1. Reactor unit:

In Reactor unit the Solid plastic is converted into Gaseous fuel due to the external heat provided. The heat can be provided either by burning a Solid fuel or Liquid fuel or Electric current. The Reactor unit is further divided into three parts; Furnace, Crucible, and Airflow unit.

- **Furnace**:

The furnace is a device used to maintain higher temperatures for longer periods. The frame used for the furnace is made up of stainless steel. The inner wall is covered with brick insulation to protect the steel furnace from elevated temperatures by reducing heat loss from the furnace (Fig 1). The bottom part of the furnace is insulated with plaster of Paris on which grooves are made on the top to distribute the air from a hole made to the wall at the bottom of the furnace. A blower is used to supply the air to the furnace.

Fig no: 1. Brick insulated Furnace

- **Crucible**:

The Crucible is a modified fire extinguisher with a removable lid, containing two holes on the top of the lid to host Thermocouple and a Pressure sensor. This crucible holds the plastic and receives heat from the furnace. The gap between the crucible and the brick insulation is filled with coal. The top part of the furnace is closed using a detachable lid to prevent the exposure of flames (Fig2).

Fig no: 2. Reactor unit

- **Air Flow Unit:**

To keep the Coal burning, air is to be supplied continuously. As the Furnace is closed from all the sides, there is requirement of external mechanism that circulates air. In this case a blower is used to pump air through a hole in the furnace.

2.2. Piping unit:

The Reactor unit and the Condensing unit are joined using stainless-steel pipes. At the middle, a Ball Valve is used which aids in building the pressure and temperature inside the crucible to initiate the melting process also regulating the flow of gaseous fuel.

2.3. Condensing unit:

Condensing unit is the heat exchanger which condenses the hot gaseous fuel into liquid fuel by exchanging heat between hot fuel gases and another cold medium (cool water). Condensing Unit is further divided into two parts, Copper piping, and a Container with Cool water.

3. EXPERIMENT:

Fig no: 3. Setup

All the three units namely Reactor unit, condensing unit, and piping unit are arranged as shown in fig 3. Waste plastic is washed thoroughly, dried and trimmed into small pieces (2x2 cm). The crucible is filled with these pieces of waste plastic (HDPE) and catalysts namely Calcium Carbonate, Barium Carbonate (similar proportions) are added in the proportions 4:1 (plastics: catalyst). Here the catalysts are not mandatory at higher temperatures. But, if catalysts are used, pyrolysis can be done at medium temperatures. The crucible is inserted in the brick insulated furnace. A pressure sensor and a temperature sensor are installed to the crucible lid and the lid is covered with an Aluminium foil to make sure there is no loss of gas due to leakages (Fig3).

Initially, the ball valve is closed to develop pressure and temperature inside the crucible. The Furnace is ignited, and the Blower is switched ON for steady airflow to keep the solid fuel burning. When the temperature is raised to 270°C the plastic inside the crucible began to vaporize resulting in pressure development inside the crucible. The ball valve is opened to let the hot vapors flow through the piping to the Condensation unit. The vapors began to condense as they flow through the copper piping which is immersed in cold water. The gas vapors got condensed due to the heat exchange between Gas and Icy water and floats on the water surface, which is collected and further distilled.

This entire experiment took around 20-30 minutes and the products obtained are oil and wax like material at every pipe joint due to leakages, Fuel gas and carbon residue (20-30%).

4. ANALYSIS:

4.1. Fuel analysis:

The Fuel collected from the surface of the water is distilled using different filter papers and fractional distilled. There are various parameters that affect the properties of the fuel. Of them, the length of the reactor outlet pipe plays a crucial role. Longer the length of the pipe the higher efficiency of condensation with high reflux rate. The oil obtained has lesser molecular weight and is transparent. The oil from low reflux rate process has higher molecular weight which is Yellow and creamy in nature and can further turn into a clear liquid when heated (Fig4). The experiment is done with variations in the length of the outlet pipe.

Fig no: 4. Fuel obtained due to different reflux rates

Table no: 1. various parameters of the fuel (fuel with high reflux rate) obtained from pyrolysis.

S.no	Parameters	Value of given sample
1	Density (g/cc)	Vary from 0.7355 to 0.7423
2	Viscosity (Centistokes)	3.811
3	pH	4.70
4	Color	Yellowish brown
5	Odour	Unpleasant smell

4.2. Char analysis:

After the plastic is turned into gaseous fuel, Char residue is analyzed under Scanning Electron Microscope to find whether pyrolysis led to the development of any carbon nanotubes which may result in greater strength and higher Thermal conductivity while being lighter in weight. Microstructures of the residue are observed at different magnifications which conclude that the microstructure of residue is similar to that of coal. But, as assumed there is no formation of carbon nanotubes (Fig 5-12).

In the SEM images, few places are bright due to their exposure to light and the structures have very sharp edges and are brittle.

Stress analysis is done for both residue and coal of same weight. It is found that the residue can withstand a maximum weight of 15kg which is nearly half that of coal i.e. 30.6kg.

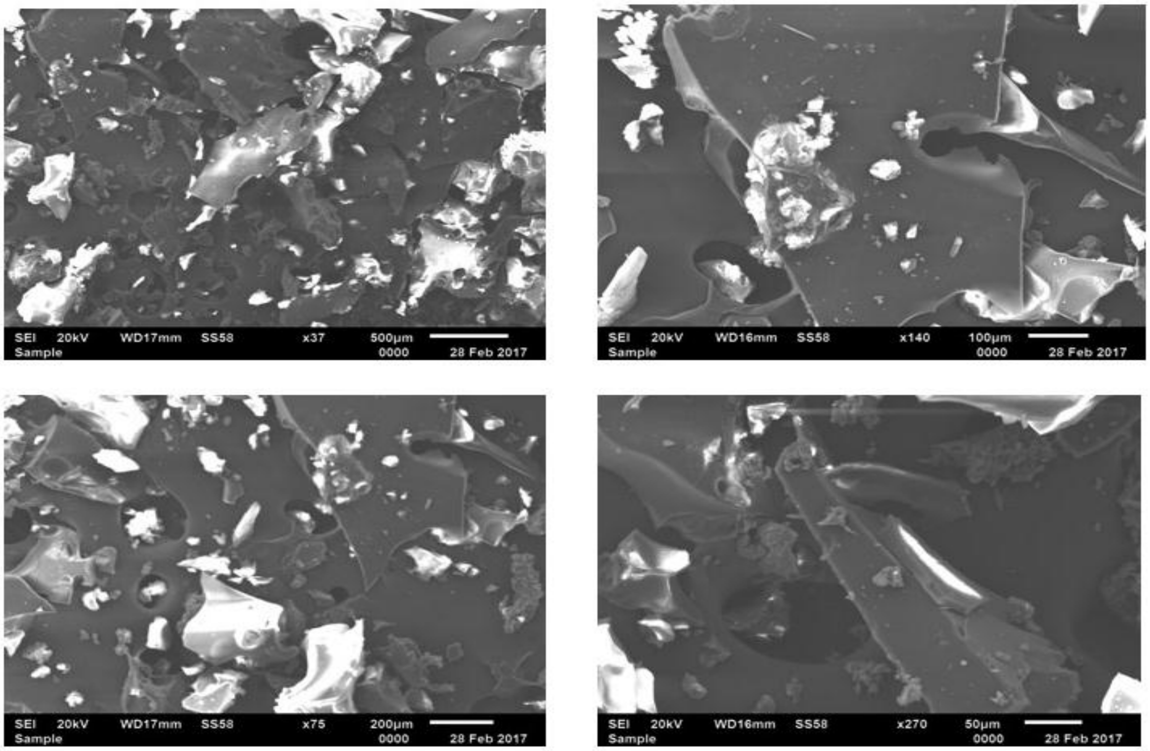

Fig No. 5-8; SEM images of char residue at magnifications ranging from x37-x270

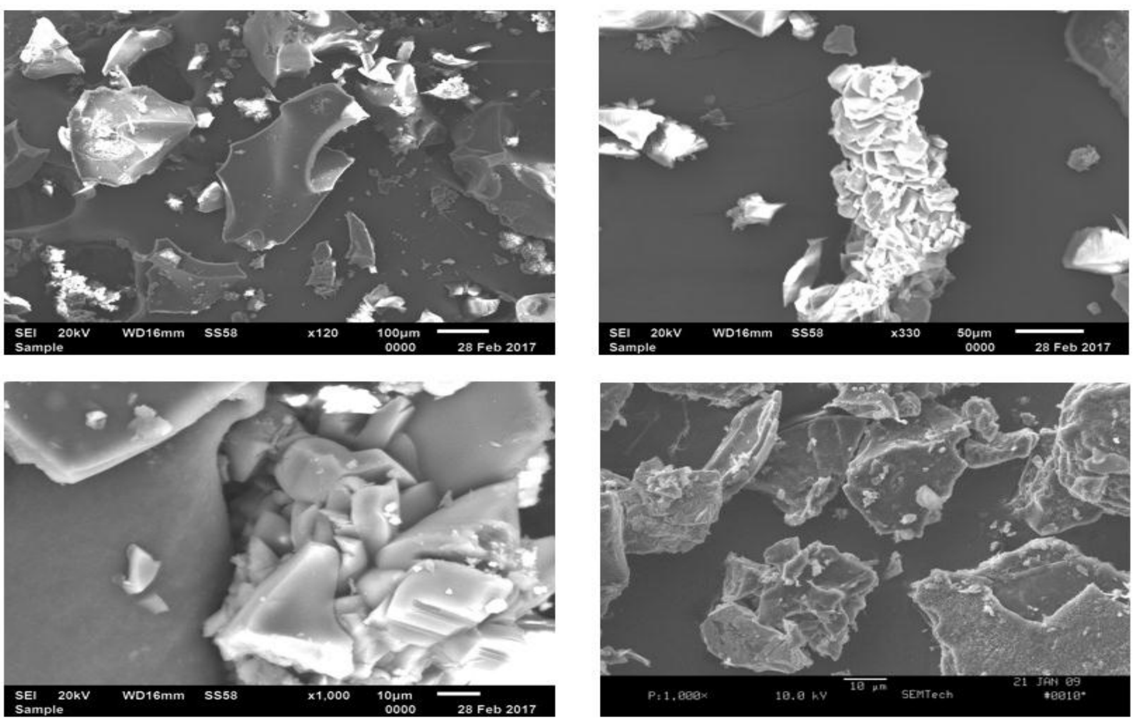

Fig No. 9-11; SEM images of char residue at different magnifications
Fig No. 12; SEM images of coal

5. CONCLUSION:

From this experiment, it is clear that there won't be any high amount of wastage, as all the plastic will be converted into either semi-solid/ liquid/gaseous fuel. The liquid fuel obtained have comparable properties to that of fossil fuels. The solid residue can be converted into briquette which can be used as an alternative to coal, thus solving the problem of plastic disposal and Fossil Fuel Wastage.

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Bibliography:

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