Pyrolysis System for Environment-Friendly Conversion of Plastic Waste into Fuel

S. N. Waghmare, S. D. Shelare, C. K. Tembhurkar, and S. B. Jawalekar

1 Introduction

The increase in plastic using up has been going on speedily since the last 5–6 decades because of lightweight and ability of plastic to form. Today, the principal interests are the requirement for energy and the degradation of the environment, which are because of expanding population and accelerated industrialization [1]. Actions are initiated to defeat the fossil fuel crisis by looking for options to replace gasoline and diesel. The development of alternative fuel technologies is created to give the alternative to fossil fuels [2]. The techniques focused are bioethanol, biodiesel, biodiesel derived from lipids, recycling the waste oils, pyrolysis, gasification, dimethyl ether, and biogas [3]. The use of plastic in a world was about 5 million tons annually in 1950s has enlarged to 20 times from about 100 million tons [4]. Currently, most plastic waste is disposed of in landfills or deposits, which involve our precious land spaces. The disposal methods, such as landfills, reuse, and combustion, can produce serious risks, particularly in human and environmental health [5]. Only a small percentage of plastic waste enters the reuse/recycling options, such as the use as a filler on asphalt roads or as a raw material for secondary product generation, such as recycled rubber, nonnatural barriers, or breakwaters [6].

Therefore, plastic waste can be deemed an energy resource. It has a sizeable calorific value, a high volatile content, and decreased ash content than coal and bio-ass [7]. Therefore, the residual plastic is the right suitor for the utilization of thermal elimination. These characteristics present it a perfect element for thermal processes like pyrolysis and gasification. Waste into the energy is designed to process potential materials into waste that are plastics, biomass, and rubber tires to oil [8]. The pyrolysis is growing as a substitute to give biofuel for compensation of the fossil fuel [9, 10]. Plastic waste is studied in the study as an accessible technology. The

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pre-treatment of the material is comfortable, as described in the article. The plastic is necessary to be classified and dried. Also, pyrolysis is neither toxic nor dangerous to an environment, unlike incineration [11]. Pyrolysis found enormously flexible procedure fit for large- and small-scale production [12].

2 Materials and Methods

2.1 Types of Plastics, Properties, and Its Uses

The different kinds of plastic have various features such as moisture content, heat resistant, chemical resistance, surface phenomenon, etc., which can be the prominent phenomenon for typical household uses [13]. The classification of plastic based on properties is listed in Table 1.

2.2 Principle of Pyrolysis

Pyrolysis is an endothermic process, an ecologically attractive method to treat plastic waste. The method practices average temperatures (300–700) °C and an oxygen-independent atmosphere for chemical decomposition of solid plastic waste into coal, oil, and gas, as per Fig. 3, which produces a minimal discharge of the nitrogen oxide and sulfur compared to incineration, the most popular method of industry [14]. Pyrolysis method consists of a collection of waste plastic, weighing and adding a waste plastic including catalyst into the reactor, pyrolysis of this waste plastic and collection, analyzing the extracted oil of a waste plastic [15]. The systematic flowchart of this process is presented within the Fig. 1.

The feedstocks utilized for the experiments were waste plastics having polyethylene terephthalate and high-density polyethylene and the same were obtained from the dumping place, and the little plastic recycling at Nagpur City, Maharashtra, India. The appearance of these feedstocks such as the collection of waste plastic, cleaning it, and shredding the waste plastics are shown in Fig. 2.

2.3 Experimentation on Pyrolysis Setup

Pyrolysis set-up as in Fig. 3 mainly comprises of reactor, GI coupling, GI pipe, condenser, water inlet, water outlet, RB flask, condenser, LPG gas cylinder, and iron stand.

The specification for material, top and bottom diameter, depth, volume, and weight of the reactor for pyrolysis setup is listed in Table 2.

Table 1 Plastic categorization depending upon properties and its uses

Type	Properties	General uses
1. Polyethylene terephthalate	Apparent, excellent gas properties, high heat resistance, hard, tough, microwave transparency, solvent resistant, unique moisture characteristics	Crystal liquid, fizzy liquid, and brew containers, pre-prepared meal platters and roasting cases, soft beverage and water containers, a string for clothes and carpetings, strapping, mouthwash bottles, shampoo bottles
2. Higher density polyethylene	Strong and semi-flexible, Perforable for gas, Smooth glassy cover, Superior chemical protection, HDPE films crinkle for touch	Surfactant, greenhouse fixtures, compost boxes, textile conditioning vessels, dolls, pots, thick pipes, roses containers, plastic timber, lunch box, drinks containers
3. Polyvinyl chloride	Excellent transparency, hard, rigid (flexible when plasticized), excellent drug immunity, extended time security, unique weathering capability, constant electrical characteristics, moderate vapor	ATM strips, carpeting lining, and different ground surfacing, windowpane and doorway frames, guttering, pipelines and fixtures, wiring, artificial skin goods
4. Low-density polyethylene	Robust and flexible, waxy surface, soft scratches quickly, good transparency, low melting point, stable electrical properties, excellent unique moisture characteristics	Films, fertilizers pockets, rejected pouches, packaging sheets, balloon cover, soft containers, watering troughs, compact purchasing handbags, wiring cord applications, any jar covers
5. Polypropylene	Hard and flexible, waxy surface, high melting point, translucent, sturdy	Larger-size bags/fabrics, bottle tips, bowls, short parcels, store containers, silages, joined food cases, refrigerated boxes, salsa and syrup bottles.
6. Polystyrene	Clear to the opaque, glassy surface, hard/foamed, brittle, great purity, influenced by lipids/solvents	Yogurt bowls, egg cases, ready meal dishes, video covers, trading containers including disposable cutlery, grain plates, clothes racks, low-cost brittle toys
7. Other	Other polymers have a broad scope to use, especially in manufacturing areas. These are recognized as number 7 and another	Multiple element-blended polymers, acrylonitrile butadiene styrene, nylon

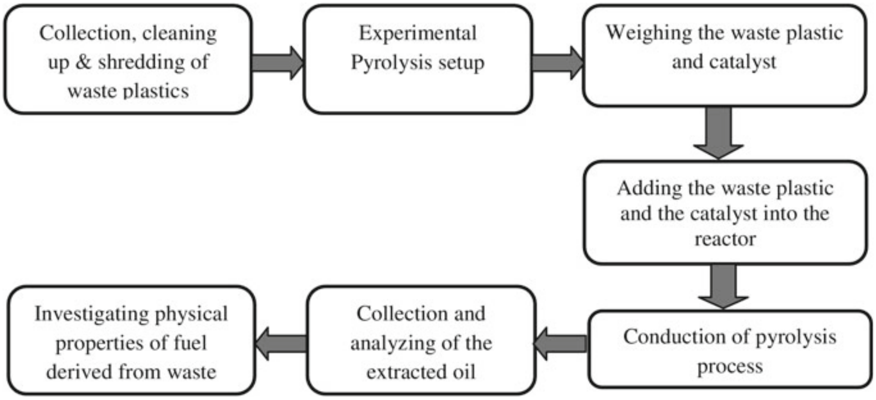

Fig. 1 Flowchart for pyrolysis process

Fig. 2 Typical pyrolysis process

In this process after the entire setup of pyrolysis was done, as it turned on and fired with the help of matchbox along with turning on the flow of cold water into a condenser and left for observation. The reactor gets consistently heated, which further raises a temperature of the reactor, causing the waste plastics to break and release vapors [16]. The air-packed manufacturing of reactor gives no leakage to the system and allows a vapor for flow through the outlet pipe, which then goes into the inner glass tube of the condenser [17, 18]. Meanwhile, the noncondensable vapors get out within the environment from the loosely tightened end of the condenser and the RB flask [19, 20]. The condensable vapor sticks to the inner wall of the tube and simultaneously forms droplets of oil as a result of heat exchanged with the cold water and get collected into the RB flask. After sometimes, it is seen that the flow of oil from the condenser stops, which shows that the number of plastics added into the reactor is pyrolyzed [21, 22]. Still to confirm that there are no leftover condensable vapors the reactor is heated for a few more minutes.

Fig. 3 Typical pyrolysis process, where 1—reactor, 2—GI coupling, 3—GI pipe, 4—condenser, 5—water inlet, 6—water outlet, 7—RB flask, 8—condenser, 9—LPG gas cylinder, and 10—iron stand

Table 2 Dimensions of different elements of the setup

S. No.	Particulars	Specification
1.	Material	Mild steel
2.	Top diameter	248 mm
3.	Bottom diameter	248 mm
4.	Depth	267.5 mm
5.	Volume	9 L (approx.)
6.	The diameter of the outlet GI pipe	15 mm
7.	The diameter of waste inlet GI coupling	59 mm
8.	Weight of reactor	5 kg

Subsequent cooling of reactor, remaining ash is there and plastic compressed like char, which needs to be separate using sieving. The char can be further utilized in road construction.

In the experimentation, 180–400 gm of the feedstock was supplied to a pyrolysis reactor. After this, pyrolyzer unit plus reformer was heated up to selected temperatures. Output obtained from a process in liquid form were got inside the RB flask

3 Results and Discussions

The amount of weight plastic 180 gm, 380 gm, 400 gm was tested for 1 h, 2 h, and 2 h 15 min, respectively. Amount of oil collected from waste plastic is, as presented in Table 3.

The amount of fuel getting collected in the RB flask and fuel collected at the end of the experimentation is as presented in Fig. 4.

Table 4 reflects the various properties of the liquid product for diesel grade.

Table 3 Observations during experimentations

Particulars	Observation stage		
	I	II	III
Weight of plastic waste	180 gm	380 gm	400 gm
Weight of catalyst (fly ash)	720 gm	1520 gm	1600 gm
Total time of heating	1 h	2 h	2 h, 15 min
Amount of oil collected	8 ml	25 ml	27 ml

(a) (b)

Fig. 4 **a** Fuel getting collected in the RB flask, **b** Fuel collected at the end of the experiment

Table 4 Physical properties of fuel extracted

S. No.	Properties	Value
1.	Flashpoint	87 °C
2.	Density	800 kg/m^3
3.	Fire point	92 °C
4.	Calorific value	19 MJ/kg
5.	Viscosity	3.8 °C

4 Conclusions

The conclusions reached by experimentations are,

1. Pyrolysis method looks an efficient waste-to-energy converter which is considered reasonable to turn plastic into liquefied outputs and to enhance the waste plastics.
2. Pyrolysis could be carried under minimal expenses for small-scale waste plastic oil extraction, and 10–20 ml could be obtained by burning 180–380 gm of plastic.
3. Rather than direct burning of plastic into the atmosphere, converting into fuel decreases 80 percent of CO_2 emission in the atmosphere.
4. Fewer emissions of unburned hydrocarbons in plastic pyrolysis waste oil as comparing to diesel.
5. Obtained diesel oil or oil has better performance and, as compared, has 30–40% low production costs.
6. The waste plastic recycling will perform a crucial task in the transformation of a newer era.
7. The gas portion can be analyzed in the future with gas chromatography to know the contents of CO, CO_2, H_2, N_2, and others.

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