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Conversion and Management of Plastic Waste into useful Resources – A review

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Abstract

The objective of this review paper is to focus few of the notable research that has been carried out to tackle the problems of disposal of plastic waste and its effective utilization into useful products. Due to less weight, low cost, non-corrosiveness of plastics have led to excessive usage and thus increasing its production resulting in the accumulation of waste plastic in the environment. The previous studies report several techniques to recycle and convert unwanted plastics into alternative fuels. This would be an added advantage to solve the problem of shortage of conventional fuel and thereby promote a sustainable environment. Nevertheless, further research is necessary to report some of the issues that have not yet been addressed.

Keywords: *Alternate fuel, Plastic waste, Pyrolysis, Recycle, Waste management*

1.0 Introduction

The decline in the reserves of fossil fuel such as oil, coal, natural gas and petroleum has encouraged the scholars to invent new alternative sources [1]. Globally, the biomass energy is gaining attention and found to be a promising solution to replace the conventional diesel fuel in automotive sector [2, 3, 4]. Similar efforts are currently attempted by researchers to find new technologies which are eco-friendly and have high efficiency to convert the biomass energy or any other available substitute source to replace fossil fuels [5]. During the last thirty years extensive research focused on biomass as renewable energy (56%), then followed by solar energy (26%), wind power (11%), geothermal energy (5%), and hydropower (2%) worldwide.

MSW (municipal solid waste) which is generated abundantly in urban areas of developing countries could be a valuable source of biomass [6, 7]. Plastic waste has become an ineradicable constituent of MSW which is being used in varied range of consumables [8] as they remain in environment and non-biodegradable for hundreds of years which in turn causes environmental issues, causing health hazards to humans and animals by entering into food chain [9]. The plastic waste is a combination of variety of products which are made up of polypropylene (PP), poly vinyl chloride (PVC), low density polyethylene (LDPE), polystyrene (PS), high density polyethylene (HDPE) etc. PS and PE are the major components of MSW [10]. The release of toxic gases such as dioxins, hydrogen chloride and carbon dioxide by incineration of polymer creates air pollution problems and also it is disagreeable to discard in land fill which leads to land

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scarcity, deterioration of top soil resulting in unbalanced environment [11]. Prior studies show that the heating value of polymers such as PE, PP is 47 and 46.4 MJ/kg which is higher than the heating values of conventional fuels petrol, gas about 44 and 36MJ/kg respectively [12,13]. According to statistics provided in world population review 2022; around 8 billion tonnes of plastics is generated by humans since 1950 out of which only 9% could be recycled whereas remaining is discarded in landfills [14].

Hence, this paper present the reviews of various recycling techniques and approaches such as liquefaction, pyrolysis, gasification, thermal and catalytic cracking etc. available to manage the plastic waste which is helpful in promotion of sustainable environment.

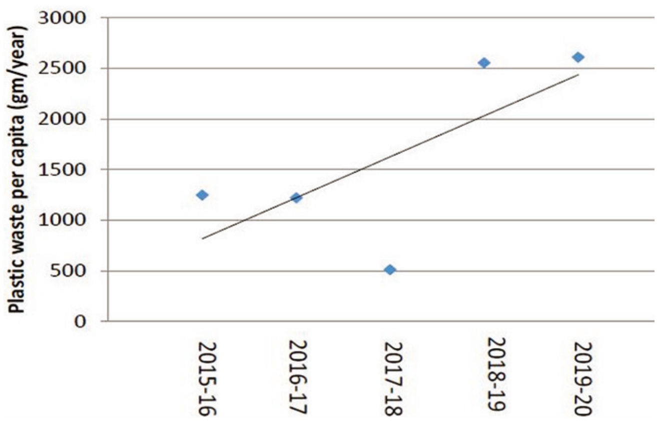

Fig.2: Per capita plastic waste production [15]

2.0 Scenario of Plastic Waste

According to the reports released by CPCB (2019-20), India generates about 3.4 million metric tonnes of plastic waste every year [15] while it was 3.36 million metric tonnes in 2018-19 and 2.38 million metric tonnes in the year 2017-18. Due to deficiency of active solid waste management system in the nation leads to burden on landfills and also affects the health condition of rag pickers. According to the reports stated in Australia based Minderoo Foundation [16], Singapore stands first in per capita plastic waste generation followed by Australia which is about 76kg and 56 kg respectively while India's is around 4kg annually. The reports also expresses that China is the largest generator of single use plastic waste annually followed by United States and India. China generates about 25.36 million tonnes of single use plastic waste annually which is higher than India and US producing 5.58 million tonnes and 17.19 million tonnes respectively. Since India's per capita generation of waste plastic is lower; though being the third highest producer of waste plastic places India in a constructive situation compared to China. The Fig.1 display's the distribution of plastic waste production in different states across India during the year 2019-20 [15]. It can be observed that Maharashtra is highest contributor to plastic waste followed by Tamil Nadu. The Fig.2. shows the variation of per capita generation of plastic waste based on the states which submitted the data. It can

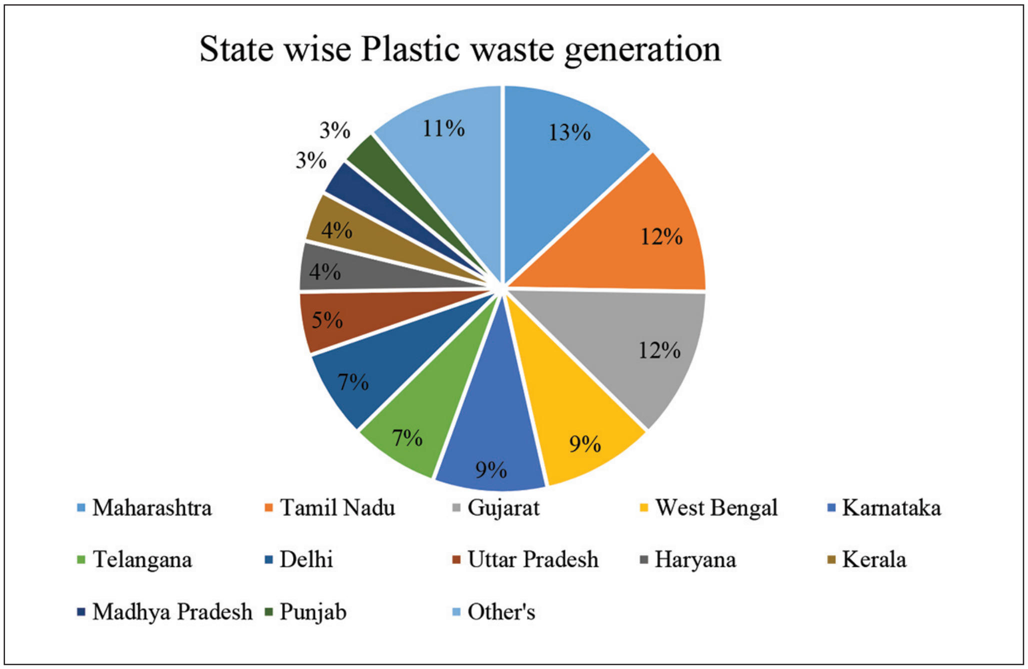

Fig.1: Plastic waste production in different states [15]

be observed that the per capita plastic waste production is increased year by year and over a duration of five years from 2016-2020 it is nearly doubled. The Ministry of Environment, Forest and Climate Change has notified the ban on the usage and manufacturing of several items made up of single use plastic (<100 microns thickness) which has high littering potential with effective from 1st July 2022 to curb the menace of plastic pollution[16].

3.0 Plastic Waste Management Techniques

3.1 Recycling of Plastic Waste [17, 18]

3.1.1 Primary Recycling

In this recycling method, the recycled product is produced with the similar specifications to that of original material since, the pellets of waste plastic is fed during the original production of basic material. Thus, it requires clean plastic; free from contamination and of original resin which makes this technique quite costly in comparison with other methods of recycling

3.1.2 Secondary Recycling

This recycling method produces a new product by mechanical means using filler's, recyclates etc. which does not have the physical properties similar to the virgin product. This technique allows the usage of uncleaned or contaminated plastic waste thereby reducing its recyclability and demand.

3.1.3 Tertiary Recycling

This recycling technique uses waste plastic as a raw material in a process that produces fuels and chemicals. The waste plastic is broken down to monomers by reactions occurring at high temperature or at low temperatures in presence of catalyst thereby making the process expensive and more energy consumption. The examples of tertiary recycling are mechanisms of glycolysis, methanolysis etc.

3.2. Incineration

Incineration is a method of generating heat energy by burning the waste plastic at thigh temperature in a reactor called incinerator [19, 20] and disposing the by-product ash into landfills. During this process, several pollutants such as oxides of sulphur, nitrogen and carbon is released in exhaust gases [21] which causes air pollution and health hazards to human beings.

3.3. Pyrolysis

The organic polymers are converted into liquid oil, solid char and gases through thermal degradation in absence of oxygen by a tertiary recycling technique called pyrolysis [22, 23]. A temperature range of 500ºC-550ºC is found to be optimum for pyrolysis of plastic waste [24]. Kumar and Singh [25] conducted pyrolysis studies of HDPE at different range of temperature varying from 400ºC to 550ºC and reported that there is decrease in retention time with increase of temperature. Similarly other research scholars such as Lopez et.al [26] performed pyrolysis studies for different retention time. The most important reaction parameters considered for optimizing the pyrolysis process are retention time, composition of feed stock, temperature, moisture content, type of catalyst and heating rate [27, 28].

3.3.1 Thermal Pyrolysis

Thermal pyrolysis is an endothermic and non-catalytic process in which catalyst is not used. The thermal pyrolysis of polypropene and polyethylene is required to be carried out at elevated temperatures for its decomposition while it is easier for polystyrene [29]. This process yields liquid oil of inferior quality due to occurrence of solid residues and impurities such as sulphur, chlorine, phosphorus etc. in it with low Octane number.

3.3.2 Catalytic Pyrolysis

Catalytic pyrolysis is a process in which a suitable catalyst is used to breakdown the polymer. The presence of catalyst yield's high quality fuel oil with less concentration of solid residue. In addition, the retention time and reaction temperature is also reduced in comparison with thermal pyrolysis [30, 31]. Hence, this process could be a cost effective and viable solution to manage the plastic waste disposal. Some of the catalyst used are FCC, Cu-Al_2O_3, Zeolite, and Fe_2O_3 etc. According to the experimental results of Hazrat et.al [32], maximum output of HDPE waste was achieved with low residue at a temperature of 400ºC to 500ºC using kaolin clay as a catalyst. Aboulkas et.al [33] reported that the cost of fuel produced by using Zn composites is more as the catalyst itself is expensive and not recommended for industrial production.

Maniet.al [34] test results reveal that operating a diesel engine using liquid fuel produced by pyrolysis obtained a brake thermal efficiency in the range of 14% to 30%.

The summary of the pyrolysis process carried out for few polymers is displayed in Table 1.

3.4 Gasification

Gasification is a thermochemical process which involves converting the solid feed stock to gaseous product which is

Table 1: Summary of Pyrolysis Process [35]

Sl. No	Type of plastic	Suitability for pyrolysis	Inference
1.	Polystyrene	Good with exceptional fuel properties	(a) Requirement of temperature is low in comparison to PE and PP (b) Viscosity of fuel oil is less in comparison to PE and PP
2.	Poly Vinyl Chloride	Not suitableVery few reports available	(a) Chlorine gas is released and hazardous (b) The catalyst activity is affected by the presence of chlorine
3.	Polypropylene	Very good	(a) Requirement of temperature is high (b) Thermal pyrolysis of PP is difficult in comparison to PE
4.	Polyethylene	Suitable and very good	(a) Temperature >500ºC is required (b) Wax is produced instead of fuel oil in thermal pyrolysis

combustible using a gasification agent in heterogeneous reactors [35, 36]. In this process, producer gas and char are produced by partial combustion of biomass. The CO_2 and H_2O in producer gas is further reduced to CO and H_2 by using charcoal. The different components of a gasification system includes a gasifier (to produce ignitable gas), gas clean up system (removal of toxic compounds from gas) and energy recovery system. Few auxiliary systems are also used to prevent environmental pollution.

3.5 Advancements in Plastic Waste Management [37]

3.5.1 Plastic Coated Bitumen Road

The clean and dried plastic waste is shredded into small sizes (2-4 mm) and added in appropriate proportion (about 5-10% w/w) to heated (160-170ºC) stone aggregate; mixed thoroughly to obtain uniform coating at surface of aggregate. Further, the coated aggregate is mixed with hot bitumen and the composite is used for laying of the roads.

3.5.2 Co-processing of Plastic Waste in Industries

Plastic waste is used as an alternative fuel in cement industries to recover the energy by replacing with conventional fossil fuels. The different varieties of plastic waste can be effectively used without polluting the environment as the cement kiln operates at high temperatures of 1200-1400ºC with residence time of 4-5 secs.

3.5.3 Plasma Pyrolysis Technology

The intense heat generation capacity in plasma pyrolysis makes possible to dispose all types of waste plastic. The plastic waste is dissociated to gases at high temperature in a primary chamber is further combusted with excess oxygen in secondary chamber. The hydrogen, hydrocarbons and carbon monoxide is converted into water and carbon dioxide.

4.0 Conclusions

This review paper has been focussed to highlight the different plastic waste management techniques and recent advancements in usage of plastic waste to minimize the disposal of waste plastics on landfills. The pyrolysis of waste plastic into liquid fuel oil in presence of catalyst is found to be more efficient by improving the oil quality with reduction in process temperature and residence time, while the only limitation being cost of catalyst. As seen, a significant amount of work has been conducted on the noted topics, leading to a great number of publications. The technical factors, social behaviour issues and economic issues related to recycling of waste plastics and its replacement to the original material poses some major challenges and further needs to be addressed.

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