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REVIEW ON CONVERSION OF PLASTIC WASTE TO FUEL

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ABSTRACT

Plastics are an integral part of our modern life and are used in almost all daily activities. Over a 100 million tons of plastics are produced annually worldwide. Plastics have become common materials of our everyday lives, and many of their properties, such as durability, versatility and lightweight, can be a significant factor in achieving sustainable development. Plastic wastes (low density polyethylene) were used for the pyrolysis to get fuel oil that has the same physical properties as the fuels like petrol, diesel etc. The waste plastics are subjected to pyrolysis, catalytic degradation, pyrolysis-catalytic cracking upgrade and gasification to obtain different value-added fuels such as petrol, kerosene, and diesel, lube oil etc. Pyrolysis process in which batch reactors are used and temperature ranges between 370 to 550℃ under atmospheric pressure. Converting waste plastics into fuel hold great promise for both the environmental and economic scenarios. Thus, the process of converting plastics to fuel has now turned the problems into an opportunity to make wealth from waste. The aim of this review was focused on the introducing of the technologies used to conversion waste plastic to fuels.

Keywords: Fuel, Plastics waste, Pyrolysis, Energy Recovery, Thermal, Environmental Issues.

1. INTRODUCTION

Plastics are synthetic substances produced by polymerization and chemical reactions. Almost all plastics are made from petroleum (Sangawar and Deshmukh, 2012). The global production of plastics from 2009 to 2010 increased by 15 million tonnes (6%) to 265 million tonnes, confirming the long-term trend of plastics production growth of almost 5% per year over the past 20 years. In 2010 Europe accounted for 57 million tonnes (21.5%) of the global production and China overtook Europe as the biggest production region at 23.5% (Alla *et al*., 2014).

There are two main types of plastics: thermoplastics and thermosetting polymers. Thermoplastics can repeatedly soften and melt. Thermo settings can melt and take shape only once (Beyene, 2014). Plastic waste legal a growing social problem, because of the loss of natural sources, the environmental pollution, and the depletion of landfill place. (Aguado *et al*.,2008). Plastics play an important role in daily life time, as in certain application they have an edge over conventional materials (Raja and Murali, 2011). Plastics are produced in large quantities due to the high demand of their use in agriculture. Plastic waste can be classified into atleast two categories: municipal and industrial (Bidhya et al.,2016).

Plastic recycling able to reduce some amount of plastic waste, the more faithful and sustainable method has been installed. The conversion of plastics to valuable energy recovery is possible as they are derived from petrochemical source, essentially having high calorific value. Hence, pyrolysis is one of the routes to waste minimization that has been gaining interest recently (Sharuddin *et al.*, 2016). In general, the conversion of waste plastic into fuel requires feed stocks which are non-hazardous and combustible. In particular each type of waste plastic conversion method has its own suitable feedstock (Gaurav *et al*., 2014).

2. SCENARIO OF PLASTIC WASTE MANAGEMENT

It has been estimated that almost 60% of plastic solid waste is discarded in open space or land filled worldwide. According to a nationwide survey conducted in the year 2003, more than 10,000 MT of plastic waste is generated

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daily in our country, and only 40 wt% of the same is recycled; balance 60 wt% is not possible to dispose off. Today about 129 million tons of waste plastics are produced annually all over the world, out of which 77 million tones are produced from petroleum (Al-Salem *et al*.,2010; Sarker and Rashid, 2013). India has been a favoured dumping ground for plastic waste mostly from industrialized countries like Canada, Denmark, Germany, U.K, the Netherlands, Japan, France, and the United States of America. According to the government of India, import data of more than 59,000 tons and 61,000 tons of plastic waste have found its way into India in the years 1999 and 2000, respectively (Patni *et al*., 2013).

Plastics are non-biodegradable they cannot be easily returned to the natural carbon cycle; hence the life cycle of plastic materials ends at waste disposal facilities. There are several methods for disposal of municipal and industrial plastic waste, i.e. landfill, incineration (energy recovery), true material recycling (similar recycled product or monomer recovery), and chemical recovery (Alla *et al*., 2014). On assessment and quantification of plastics waste generation in MSW in 60 major cities of India (Central Pollution Control Board, 2015) suggests that out of total plastics Waste, thermoplastics content is about 94% (Recyclable) and rest 6% belong to family of others including thermoset plastics (Non-Recyclable). The data mentioned in Table 1 indicates that the majority of the plastics waste (PW) obtained about 66% generated by HDPE/LPDE materials which is of mixed plastic wastes.

Table 1: The consolidated details of classification of different constituents of plastics

S.No.	Description	Total Percentages obtained
1.	PET	8.66
2.	HDFE/LDPE	66.91
3.	PVC	4.14
4.	PP	9.9
5.	PS	4.77
6.	Others	6.43

(Source: CPCB, 2015)

2.1. Present Scenario in India

In India the grown of population and industries are very rapid in urban area and therefore plastic waste problem is generated. The plastics include polystyrene, poly (vinyl chloride), polypropylene, polystyrene terephthalate, acrylonitrile-butadiene-styrene (Prajapati, 2018). India recycles about 60% of its plastics, compared to world's average of 22%. Plastic waste contains the calorific value equal to fuel. The Brihan Mumbai Municipal Corporation, which handles more than 5,500 metric tones MSW per day shows that plastic waste is 0.75 %. In Europe and U.S.A, plastic waste makes up 8 % of total MSW. The rest is made up of organic materials (33%), paper and paperboards (30%), glass and metals (16%) and others (13%) (Sangawar and Deshmukh, 2012).

Table 2: plastic waste generation of Indian cities

City	PET	HDFE/LDPE	PVC	PP	PS	OTHERS
Lucknow	2.4-9.1	19.42-48.16	1.42-4.77	4.14-13.93	0.66-6.31	55.59-62.93
Allahabad	3.5-6.0	8.6-40.40	1.06-6.78	7.78-17.43	0.0-1.72	4.06-23.90
Chandigarh	0.0-0.8	8.0-21.60	0.2-5.6	0.32-9.6	0.8-3.2	4.0-13.6
Delhi	1.41-5.98	85.24-67.34	0.85-2.63	2.92-9.33	6.42-17.22	1.0-9.29
Faridabad	8.73-15.36	74.4-104.54	0.32-1.65	1.14-7.79	4.3-6.99	0.0-1.0
Jammu	0.32-2.56	16.32-36.88	0.64-14.16	12.16-28	4.48-8.16	7.2-34.08
Srinagar	2.32-10.4	16.68-25.06	4.0-5.68	9.11-10.56	2.32-5.76	1.52-9.04
Shimla	1.56-3.68	13.64-26.64	0.56-1.32	8.04-20.24	1.0-3.36	4.2-13.44
Amritsar	0.0-03.04	15.04-28.32	0.0-2.26	9.92-23.2	1.44-5.6	0.0-15.52
Dehradun	5.10-10.35	36.21-43.15	2.57-7.41	6.14-9.61	1.56-4.34	2.17-5.33
Agra	8.74-10.33	42.68-45.0	5.97-8.22	6.74-10.16	0.18-1.24	7.67-11.01
Meerut	1.55-6.49	41.10-42.26	3.022-6.92	4.77-7.11	0.62-2.48	3.40-7.24
Varanasi	2.84-12.37	13.03-42.89	2.58-15.27	3.98-10.05	0.54-2.21	3.53-10.2
Kanpur	3.36-8.36	40.19-53.15	4.26-8.17	2.08-7.02	0.34-0.95	1.03-3.44

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Patna	1.0-1.67	33.25-46.56	0.42-6.93	1.70-9.63	1.68-6.8	2.12-10.76
Ranchi	0.65-1.02	35.64-42.54	0.36-1.19	5.71-7.0	3.36-5.89	6.02-9.31

(Source: CPCB, 2015)

In most developed societies domestic organic waste, including plastics packaging, is disposed of in sanitary land filled or by incineration. During early 2000, the largest amount of plastic wastes is disposed of by land filling (65–70%), and incineration (20–25%). Recycling is only about 10%. In India, during 1998 around 800,000 tonnes representing 60% of plastic wastes generated in India was recycled involving 2000 units. This level of recycling is the highest in the world. The corresponding figure for Europe is 7%, Japan 12%, China 10%, and South Africa 16%. In Europe 2006 marks a milestone as the first year when recovery and disposal rates of used plastic were equal (Alla *et al*., 2014).

In almost all the cities the MSW generated from different sources like door to door, community bin at the street corners and from markets are collected by the municipal trucks or by the firms under contract to the government and dumped in the open dump yard. The plastic waste generation in Indian cities as per the survey done by CPCB are summarized above in Table 2.

Above data in Table 2 indicates that the average waste generation of PET plastics is higher in Faridabad city. Similarly, the average waste generation of HDPE/LDPE plastics is found to be higher in Faridabad. Also, the average waste generation of polyvinyl chloride plastics is higher in Varanasi. The average waste generation of polypropylene and polystyrene plastics is found to be higher in Amritsar and Delhi (Hussain *et al*.,2018).

2.2 Statistics of consumption of plastics and generation of plastics waste

The fact that plastic is lightweight, does not rust or rot, low cost, reusable and conserves natural resources is the reason for which plastic has gained this much popularity. If we were to substitute all plastics in all applications with the prevailing mix of alternative materials and look from a life cycle perspective, then 22.4 million additional tons of crude oil per year would be required (Panda *et al*.,2010).

India has a plastic consumption of 3.2 MT during 2000 and is expected to reach nearly 12.5 MT by 2010 (Muthaa *et al*., 2006). The growth of the Indian plastic industry has been phenomenal equal to17% is higher than for the plastic industry elsewhere in the world (Narayan et al., 2001). Hindu Business line, January 21, 2006 reveals India will be the third largest plastics consumer by 2010 after USA and China.The reason of highest growth rate in last few year in India is due to the fact that, one third of the population is destitute and may not have the disposable income to consume much in the way of plastics or other goods.

Table 3: Plastic waste consumption (Sangawar et al., 2012).

S.No.	Description	World	India
1.	Per capita per year consumption of plastic (kg)	24-28	6 -7
2.	Recycling (%)	25	60
3.	Plastic in Solid Waste (%)	7	9

Source: **(**CPCB, 2009**)**

India recycles about 60% of its plastics, compared to world's average of 22%. Plastic waste contains the calorific value equal to fuel. India has among the lowest per capita consumption of plastics and consequently the plastic waste generation is very low as seen from the Table 3.

Current low per capita consumption level of plastic products as compared to developed countries per capita consumption as shown in Figure 1 suggests that India offers a huge opportunity over long term (Hussain et al.,2018).

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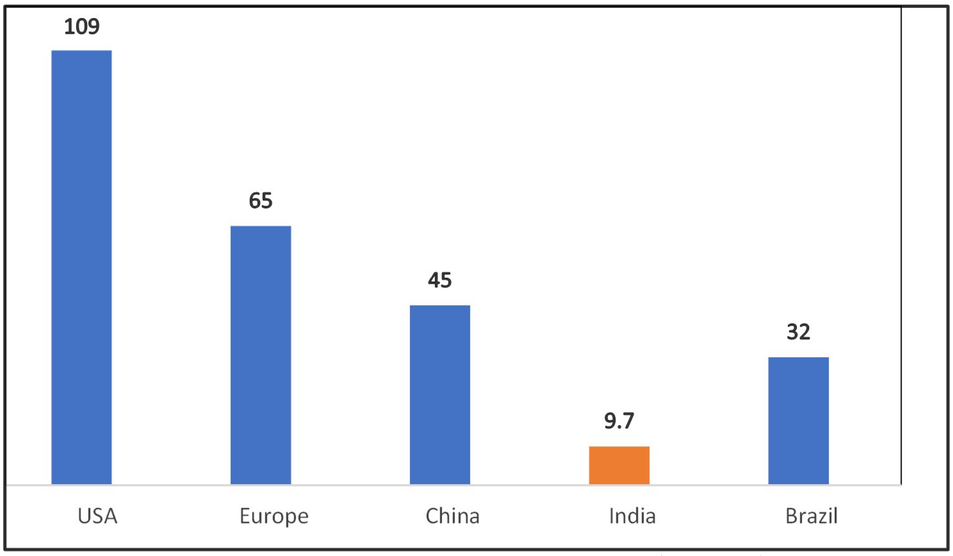

Figure 1. Per capita plastic products consumption (kg/person)
(Source: A report on plastics industry, FICCI-2014)

3. METHODS OF CONVERTING PLASTIC WASTES TO FUEL

3.1 Thermolysis Schemes and Technologies

3.1.1 Pyrolysis (Thermal Pyrolysis)

Pyrolysis is generally defined as the controlled burning or heating of a material in the absence of oxygen. In plastics pyrolysis, the macromolecular structures of polymers are broken down into smaller molecules or oligomers and sometimes monomeric units. Thermolysis is the treatment of PSW in the presence of heat under controlled temperatures without catalysts. Thermolysis processes can be divided into advanced thermo-chemical or gasification (in the sub-stoichiometric presence of air usually leading to CO and CO_2 production) and hydrogenation (hydrocracking) (Ahrenfeldt, 2007). Pyrolysis provides a number of other advantages, such as (i) operational advantages, (ii) environmental advantages (iii) financial benefits and (iv) income advantages. Operational advantages could be described by the utilisation of residual output of char used as a fuel or as a feedstock for other petrochemical processes. An additional operational benefit is that pyrolysis requires no flue gas clean up as flue gas produced is mostly treated prior to utilisation. Environmentally, pyrolysis provides an alternative solution to landfilling and reduces greenhouse gas (GHGs) and CO_2 emissions. Financially, pyrolysis produces a high calorific value fuel that could be easily marketed and used in gas engines to produce electricity and heat (Al-Salem *et al*., 2009).

Pyrolysis is the thermal decomposition of materials at elevated temperatures in an inert atmosphere (SBM, 2019). Pyrolysis, involves the degradation of the polymeric materials by heating in the absence of oxygen at a temperature between 300 – 900 ºC and results in the formation of a carbonized char (solid residues) and a volatile fraction that may be separated into condensable hydrocarbon oil consisting of paraffins, isoparaffins, olefins, naphthenes and aromatics, and a non-condensable high calorific value gas (Panda et al.,2010). Pyrolysis technology is thermal degradation process in the absence of oxygen. Plastic waste is treated in a cylindrical reactor at temperature of 300ºC – 350ºC (Ingawale, et al.,2017). Pyrolysis of clear and contaminated waste plastics in a tubular reactor, applying 500°C temperature. Y-zeolite catalyst was applied to reduce the contaminant level in the products and the effect of pre-treatment of raw materials was also studied. Thermal degradation of contaminated plastic wastes resulted in higher yields of volatile products than the Pyrolysis of pre-treated or original raw material (Gourav *et al*., 2014).

3.1.2 Pyrolysis-Catalytic Cracking Upgrade

The pyrolysis by direct heating was adopted to produce the paraffin and crude oil from the plastic wastes in the 1990s. The small-scaled process is featured by facilitation, convenience and low equipment investment However, the temperature caused by pyrolysis is higher and all the reactive time is longer than the other methods. Although

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this process is simple and convenient, the converting rate and yield is still lower. The total yield of fuel oil is 50-65% (Raja and Murali, 2011).

An improved apparatus apart from the pyrolysis reactor, consists of a cylindrical rectangular vessel heated by electrical heating coils or any other form of energy, the said vessel is made of stainless or mild steel, surrounded by heat reflector and insulator to avoid heat loss. It is provided at its side an outlet vent which connects with the condensing section which is made up of stainless or mild steel provided with an outer jacket for circulating cold water or any coolant, the condenser is connected to the receiving section and to a gasometer. The receiving unit is maintained at - 40°C to higher temperature to collect the distillate.

Table 4: Degradability of different waste materials.

Type of litter	Time for degradation
Organic wastes, paper, etc	1-3 weeks
Cotton cloth	8-20 weeks
Wood	10-15 years
Tin, aluminium, etc	100-500 years
Plastics	A million years??

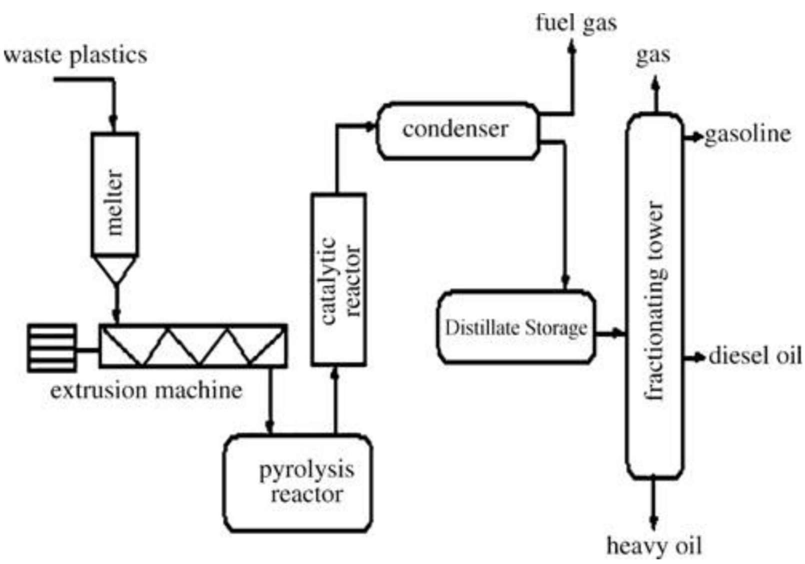

Figure 2: Pyrolysis catalytic cracking technique of plastic wastes

3.1.3 Catalytic Degradation

This process is also known as cracking process. The process includes breaking down the plastics at high temperatures (thermal degradation) or at lower temperatures in the presence of catalyst (catalytic degradation), which contain smaller carbon chains. In this method, a suitable catalyst is used to carry out the cracking reaction. The presence of catalyst lowers the reaction temperature and time (Patni *et al*., 2013). The process results in much narrower product distribution of carbon atom number and peak at lighter hydrocarbons which occurs at lower temperatures. The cost should be further reduced to make the process more attractive from an economic perspective. Reuse of catalysts and the use of effective catalysts in lesser quantities can optimize this option. This process can be developed into a cost-effective commercial polymer recycling process for solving the acute environmental problem of disposal of plastic waste. It also offers the higher cracking ability of plastics, and the lower concentration of solid residue in the product (Panda *et al*.,2010).

The plastic pyrolysis in fluidized bed reactors were carried out normally at temperature as low as 290–850°C for both thermal and catalytic process. The comparison between HDPE and PP in catalytic degradation in fluidized bed reactor was using silica–alumina catalyst. The author reported that the liquid produced by PP was 87 weight%

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while HDPE produced lower at 85 weight% liquid composition at 500°C. This result was expected since HDPE had higher strength properties than PP (Luo *et al*., 2000 and Sharuddin *et al.*, 2016).

3.1.4 Gasification

Gasification and bioconversion are mainly used for organic materials. Gasification and blast furnace of plastics waste to produce gases that are carbon dioxide, nitrogen, carbon mono oxide, hydrogen and methane at higher temp above 800°C (Joshi *et al*., 2014). The plastics are directly converted to short chain gases and the yield of non-condensable gases in the product is maximized. High heating rate is required to minimize the proportion of solid char production and rapid quenching favours the liquid production before further cracking into gaseous products (Lee, 2006).

The processes proposed for plastics waste pyrolysis are flexible and may treat both mixtures of plastics and mixtures of these with residual materials (such as wood and agro forest wastes and tire derived fuel. With an aid of additional facilities to incinerators for controlling harmful substances released, pyrolysis and gasification of waste plastics is a process being developed around the world that could result in recovery of high energy content of plastics as well as chemical composition of plastics given the high calorific value, plastics can be recycled for energy recovery (Sarker and Rashid, 2013). Gasification involves the partial oxidation of organic matter at high temperatures (typically between 1200-1500ºC) under mildly oxidizing conditions (usually steam, carbon dioxide or Sub-stoichiometric oxygen) for the production of synthesis gas (syngas). This gas, consisting primarily of carbon monoxide and hydrogen, has application in the synthesis of chemicals like methanol and ammonia, and can be used to produce synthetic diesel or may be combusted directly as a fuel (Beyene, 2014).

4. CONCLUSION

Thermal pyrolysis of plastic waste leads to the production of fuel oil, valuable resource recovery and reduction of waste problem. Thermal pyrolysis of waste plastic waste has also several advantages over other alternative recycling methods. In India the grown of population and industries are very rapid in urban area and therefore plastic waste problem is generated. The global production of plastics from 2009 to 2010 increased by 15 million tonnes (6%) to 265 million tonnes, confirming the long-term trend of plastics production growth of almost 5% per year over the past 20 years. The optimization of conversion parameters such as the choice of catalysts, reactor design, pyrolysis temperature, and plastic-to-catalyst ratio plays a very important role in the efficient processing of gasoline and diesel grade fuel. Large amount of plastic wastes produced may be treated with suitably designed method to produce fossil fuel substitutes. The method is superior in all respects ecological and economical if proper infrastructure and financial support is provided. By converting plastics to fuel, we solve two issues, one of the large plastic seas, and the other of the fuel shortage. It is very important to consider recycling and energy recovery methods in plastic manufacturing and converting facilities. several tertiary and quaternary technologies appear to be strong to warrant further research and development in the near future.

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