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A Review on Liquid Fuel Recovery from Waste Plastic Using Pyrolysis Process

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Abstract: ***The globally increasing demand for plastics is causing the increase in plastic wastes landfill which has serious environmental harms. Demand for plastic is increasing but the petroleum reserves are depleting and as plastics are obtained from petroleum, converting waste plastic into liquid hydrocarbon fuel is most suitable option for the minimizing the plastic waste which will either landfilled. Using Pyrolysis process we can convert plastic waste into liquid hydrocarbon fuel as this fuel has matching characteristics with the fuels like diesel or petrol, the process of pyrolysis is considered for conversion. In this paper the pyrolysis process is reviewed for different types of plastics and the process parameters that can affect the final end product that are gaseous, oil and char. The main parameters of the process are temperatures, type of reactors, type of fluidizing gas, pressure, catalysts, residence time.***
Key words: fuel recovery, Pyrolysis, Waste plastic

I. INTRODUCTION

Now a day Plastic is an important part of everyone's life and played vital role in enhancement of standard of living of human being for last 2-3 decades. It can be called as key material of innovation in various fields like construction, healthcare, automotive, packaging and also gives a great impact on product life cycles. The plastics demand has been increased because of the rapid growth of the world population and is still increasing. The world's plastic production has increased to 299 million tons in the year 2013 and has increased by 4% over its previous year i.e. in 2012 [19]. The continuously increasing plastic demand has caused the growing in waste agglomeration in waste stream each year. According to a report 33 million tons of waste plastic are generated in the US as on statistic of 2013. Europe has 25 million tons of waste plastic in 2012[19]. Based on the statistical report, Europe has 38% of the plastic waste is landfilled and around 26% were recycled whereas energy recovery done on 36% of waste plastic [19]. "Waste plastic recycling – Indian Scenario" mentioned that four cities of India that are Delhi, Chennai, Kolkata, Mumbai producing 689.5 TPD, 429.5 TPD, 425.7 TPD, 408.3 TPD respectively, approximately 60% of this waste is recycled [8]. This shows that most of the plastic waste is treated by landfill and it occupies a large amount of space. It takes billions of years for plastics to degrade naturally. The continuous landfilling of plastic waste would definitely cause hazardous environmental problems.

II. PYROLYSIS OF PLASTICS

The conversion of waste plastics into hydrocarbon fuels is due to the fact that they are obtained from petrochemical sources, basically with high calorific value. Thus, pyrolysis is can be the way to plastic waste disparagement or reduction that is gaining interest recently. Pyrolysis process is useful in safely converting waste plastics into hydrocarbon fuels that can be used for transportation. Pyrolysis is to decompose the organic substance chemically by heating and the word is Greek-derived i.e. pyro means "fire" and lysys means "decomposition". Pyrolysis means decompose using heat. Pyrolysis is the first reaction in burning of many solid organic substances like paper, cloth, wood, and also in some kinds of plastic [2].

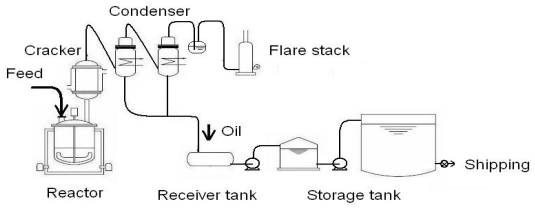

Figure 1: Schematic of a production plant of plastic derived fuel

The plastics that are non-biodegradable waste are introduced into a reactor where they will decompose at 450 to 550 ºC. Thermal decomposition of plastic will produce gaseous mixture of condensable and some non-condensable gases, these gases are passed to condenser through cracker. Waste plastic pyrolysis oil coming out from the condenser get collected into receiver tank.
Plastics that can be used for pyrolysis are High density polyethylene (HDPE), low density polyethylene (LDPE), polystyrene (PS), polypropylene (PP), polyethylene terephthalate (PET), and polyvinyl chloride (PVC).

III. REVIEW ON PLASTIC PYROLYSIS

Faisal Abnisa et al; has provided the proximate analysis of different types of plastics as per we have priory mentioned plastic types. It was author's observation that all kinds of plastics are having very high volatile content whereas amount of ash content is lower [4]. These above mentioned characteristics indicate that there is higher potential of converting plastics to useful hydrocarbon fuel using process of pyrolysis [4]. The results of plastics proximate analysis are very important for the pyrolysis process that would have major influence in the liquid production. Author also reviewed the catalysts used in plastic pyrolysis, process parameters and they also discussed about byproduct of the process and plastic pyrolysis scenarios [4].

TABLE : IProperties of WPO and DF

Physical properties	WPPO	Diesel fuel
Density (kg/m^2)	793	850
Ash content (weight %)	<1.01	0.045
Calorific value (kJ/kg)	41,800	42,000
Kinematic Viscosity (40ºC) (mm^2/s)	2.149	3.05
Cetane number	51	55
Fire point (ºC)	45	56
Flash point (ºC)	40	50
Pour point (ºC)	-4	-3.15
Sulfur content (%)	<0.002	0.035
Carbon residue (weight %)	0.01	0.2

Seyed Mousa FakhrHoseini et al; tried to convert PP, PE, and PET using pyrolysis process and temperature between 400 and 600°C. They have developed a NRTL activity coefficient model for predicting content of each produced weight. Results indicate that polypropylene gives maximum amount of liquid product that was 82% at lowest temperature increasing rate (6°C/min). All results confirm that the lower temperature increasing rate leads to higher liquid product [11]. Jane Pratoomyod et al; taken scrap or waste plastic as raw material into a reactor for thermal pyrolysis without using catalyst. The waste plastic is treated in reactor of cylindrical shape at temperature 400-500 degree Celsius to produce WPO and properties of waste plastic oil and diesel fuel are presented in the below table [12]. Mohanraj C et al; reviewed different techniques of conversion of plastic to liquid fuel. Author discussed pyrolysis processes with use of different catalysts and reactors of different types, in this they have discussed about performance of WPO and diesel blends as fuel in CI engine and they observed that BSFC decreases with 50% WPO blend with diesel and above 50% engine vibrations are higher in range consistently [5].
P. N. Sharratt et al; pyrolyzed High-density polyethylene with catalyst HZSM-5 in a specially developed laboratory fluidized-bed reactor operating with temperature range from 290 to 520 °C, at ambient pressure. The influence of reaction parameters, ratios of HDPE to catalyst feed, temperature and flow rates of fluidizing gas was examined. Operating temperatures preferred are 450-550 °C. Two types of catalysts were used for plastic pyrolysis with lab scale fluidized bed reactor. Catalysts are Silicalite (Catalyst Particle Size = 75-180 µm, Fluidizing N2 Rate=570 mL/min, Polymer to Catalyst Ratio =40 wt %, Total Times of Collection =60 min) and HZSM-5(Catalyst Particle Size =125-180µm, Fluidizing N2 Rate= 570 mL/min, and Polymer to Catalyst Ratio = 40 wt %) [37]. Finally they concluded that catalyst HZSM-5 at 360 °C, conversion to volatile hydrocarbons was around 90 wt % of feed in the catalytic fluidized-bed reactor with 15 minutes of resting in reactor, whereas silicalite yielded less than 6 wt % of feed after 60 min [13]. R. Miandad et al; examined the outcomes of different types of plastic waste such as polystyrene, polyethylene, polypropylene and polyethylene terephthalate on the yield from the each type of plastic and product quality from the pyrolysis process [1]. The plastic waste of type polystyrene showed maximum yield of liquid oil (80.8%) with minimum amount of gases (13%) and char (6.2%) in comparison with other types of plastic [1]. Upgrading of WPO using various methods of post-treatment such as refining,

distillation and blending of WPO and DF is required to be done for making the WPO suitable as a transport fuel because it contains high aromatic compounds [1]. Author used different types of plastics individually as well as in mixed proportions, temperature, quantity is provided in Table 2 and the results are provided in Chart 1. Finally they concluded that PS is having high yield i.e. quantity of waste plastic oil, addition of PS with PP further reduced the liquid oil yield down to 25% from their individual yields of 80.8 and 42% respectively. Same as this, mixing of PS with PE reduces the WPO yield in comparison to individual pyrolysis using PS [1].

TABLE-II: Experimental Scheme

Feedstock types	Qty. (kg)	Ratio (%)	Retention time (min)	Temp (ºC)
PS	1	100	75	450
PE	1	100	75	450
PP	1	100	75	450
PS/PP	1	50/50	75	450
PP/PE	1	50/50	75	450
PS/PE	1	50/50	75	450
PS/PE/PP	1	50/25/25	75	450
PS/PE/PP/PET	1	40/20/20/20	75	450

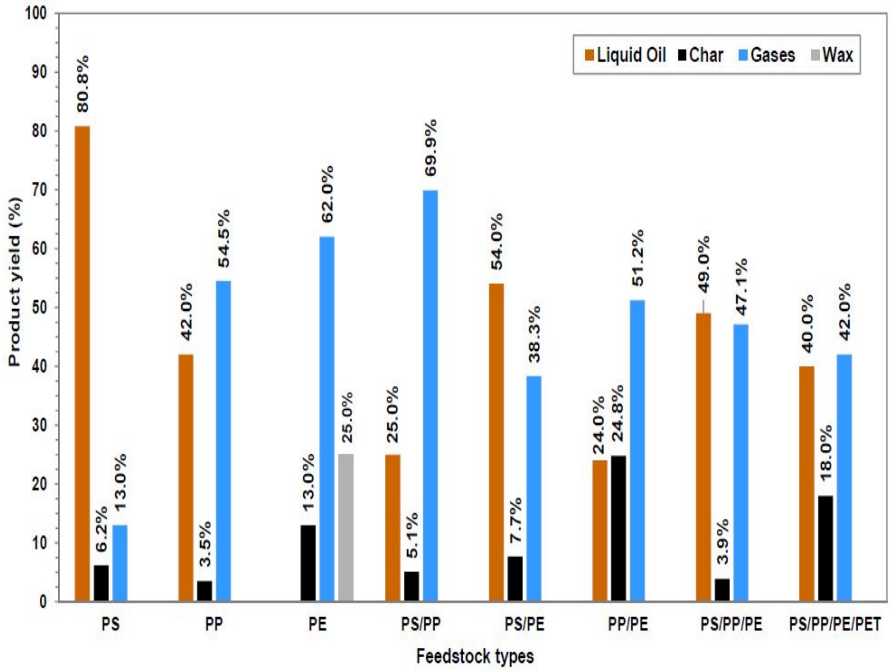

Figure 2: Effect of plastic types on Pyrolysis yield

Sachin Kumar et al; placed mixture of catalyst and waste HDPE (20 g) in catalyst to waste HDPE proportion of 1 as to 4 into the reactor of size 300-ml and the reactor was heated in the furnace to the desired temperature of 450 ºC with heating rate of 20 ºC/min [17]. Elizabeth A. et al; used most commonly found plastics in domestic waste and which has more than 66% of all polymer production in Western Europe. Their founding provides information such as Polypropylene gave the largest amount of WPO and PVC with smallest amount of yield with the respective yields being 85% and 31.69%. They also compared products from pyrolysis of different types of polymers [14].

Table- III: List of Products of Pyrolysis of Different Types Polymers

Comparison of Product Yields from the Pyrolysis of Polymers in a Fixed Bed Reactor (%)

	HDPE	*LDPE*	*PS*	*PP*	*PET*	*PVC*	*Mixture*
Gases	16·77	15·02	3·41	13·63	33·99	2·47	9·63
Oil	79·72	84·25	83·77	84·44	41·30	31·69	75·12
Char	0·00	0·00	3·50	0·15	15·55	13·78	2·87
HCl	0·00	0·00	0·00	0·00	0·00	52·93	2·31
Total	96·48	99·27	90·67	98·23	90·84	100·87	89·93

Imtiaz Ahmad et al; Investigated the Pyrolysis of polypropylene and high density polyethylene into hydrocarbon fuel products over temperature range of 250– 400ºC and they also studied product yields as a function of temperature. They concluded that total conversion of 98.66% which has liquid content; 69.82%, gas content; 28.84%, and residue; 1.34% which achieved at 300 ºC in case of PP and 98.12% having iquid content; 80.88%, gas content; 17.24%, and residue; 1.88% in case of HDPE at 350ºC. The results indicate that both liquid fractions were fuel-like meeting the fuel grade criteria [16]. N. Miskolczi et al; investigated the decomposition of different mixed proportions of the most frequently occurring waste polymers such as polyethylene, polypropylene, polystyrene, polyamide, ethylene-propylene copolymer and polyurethane rubber in a horizontal tube type reactor. They studied the effects of temperature of cracking and time of residence on the yields and structure of the products. The gas and liquid products formed were analysed by gas chromatography. The operating parameters influenced mainly the quantity of degradation products, whereas their chemical structure was not affected [15]. Senthilkumar Tamilkolundu et al; used PVC plastics for the pyrolysis, the experimental setup used by Senthilkumar Tamilkolundu is shown in Figure 2, Temperature range is around 350ºC. The FTIR spectrum is used to analyze blending process quality. The analysis of viscosity and density of these blends is done in relation with regular diesel fuel [18]. Mochamad Syamsiroa et al; studied fuel oil production from municipal plastic wastes using sequential catalytic pyrolysis. They used three different kinds of municipal plastic wastes were collected from the disposal site and a small recycling company [19]. Commercial Y-zeolite and natural zeolite catalysts were used in this study. Their results shows that type of plastic strongly affect the product yields and the quality of liquid and solid products [19]. They also come to conclusion that HDPE waste produced the highest liquid fraction. The presence of catalyst reduces the liquid fraction and increases the gaseous fraction [19]. Furthermore, municipal plastic wastes pyrolysis produced higher heating value solid products than those of biomass and low rank coal [19].

IV. DISCUSSION ON PLASTIC PYROLYSIS

This review showed that there is potential of deriving valuable liquid oils from plastic waste and these oils are having properties like gasoline and diesel oil and as discussed in previous points we get oil that can be used as fuel because plastics are made from petroleum sources. Yield from plastic pyrolysis process depends on various parameters such as heating rate, pressure, temperature, type of reactor, type of catalysts used, residence time, flow rate and type of fluidizing gas. Both yield and quality of product from plastic pyrolysis depends upon set up parameters for example if we are using catalyst for the process then definitely yield of process will be higher, with higher yield from the process quality of the product is also important when we consider it as fuel. There are few companies which are producing waste plastic oil that oil is having production cost half of the price of gasoline and they can provide it at cheaper rates than currently used liquid fuels. Most of the researchers prefer to use polyethylene, polypropylene and polystyrene. Packaging industries uses PE and PP thus waste generated from packaging industry is of PP and PE type of Plastic. Researchers mostly use PE and PP type of plastic waste with zeolite and non-zeolite based catalysts. Some of them have used mixture of various plastics like LDPE, HDPE, PET, PP and PE in different proportion; this is mostly done in case of municipal solid wastes. C. Mohanraj et al; has given different approaches for same pyrolysis process like effects of using different catalysts with different types of plastics, effects of varying process temperature and residence time. They carried out Thermogravimetric analysis on PS, PP, PET, PE PVC and they observed that minimum optimized temperature for process with complete combustion is 460ºC. They also observed that gas yield was opposite to that of liquid yield (i.e. gas yield is lower at 460ºC and higher at 600ºC and liquid yield higher at 460 ºC and lower at 600 ºC) they also compared the processes with ZSM-5 as catalyst, red mud as catalyst and they found that optimized reaction temperature is 350 ºC to 460 ºC for all kind of plastic materials. Senthilkumar Tamilkolundu and Chandrasekar Murugesan done thermal degradation at higher temperatures 300 ºC to 900 ºC, plastic used for the process is PVC and PET. They have done B5 concentration blend for performance test on single cylinder Kirlosker diesel engine with 50% load. So basically here researchers have used commercial plastic waste and they also reviewed it from the waste management point of view.

In this review we have reviewed the compendium of technologies by United Nations Energy Programme which provides detailed information about technologies for converting waste plastics into fuel such solid fuel production techniques, liquid fuel production techniques, gaseous fuel production technologies and other technologies. This shows the importance of converting waste plastics into a resource which is safe from environment point of view, valuable and economically viable for usage.

V. CONCLUSIONS

This review has provided brief information of plastic pyrolysis for each different type of plastic. We also come to know the affecting parameters on liquid oil yield. Based on the on literatures studied, pyrolysis process is most preferred method to minimize plastic waste due to its potential to efficiently energy from plastic waste to valuable liquid oil.

A. The pyrolysis can be done either in presence of catalyst or in absence of catalyst. Whereas both processes has variation of the parameters such as temperature, time of residence, heating rate, type of reactors, type of fluidizing gas in the process and flow rate of the gas.

B. The use of catalyst in process of pyrolysis provides lower temperature operating with greater yield i.e. waste plastic oil for most of the plastics with the right catalyst selection.

C. The yield of oil from pyrolysis using pure material (single type of plastic) is higher as compared to oil yield from pyrolysis using mixed plastic.

D. Physical properties of waste plastic oil from pyrolysis process vary as variation of parameters for same plastic material.

As the need of plastic usage is increasing day by day plastic waste is also increasing, but still most of the countries of the world are not curious about the process of plastic waste management. With the use of pyrolysis method, million tons of plastic waste can be most efficiently, cost effectively and with less pollution converted to liquid fuel.

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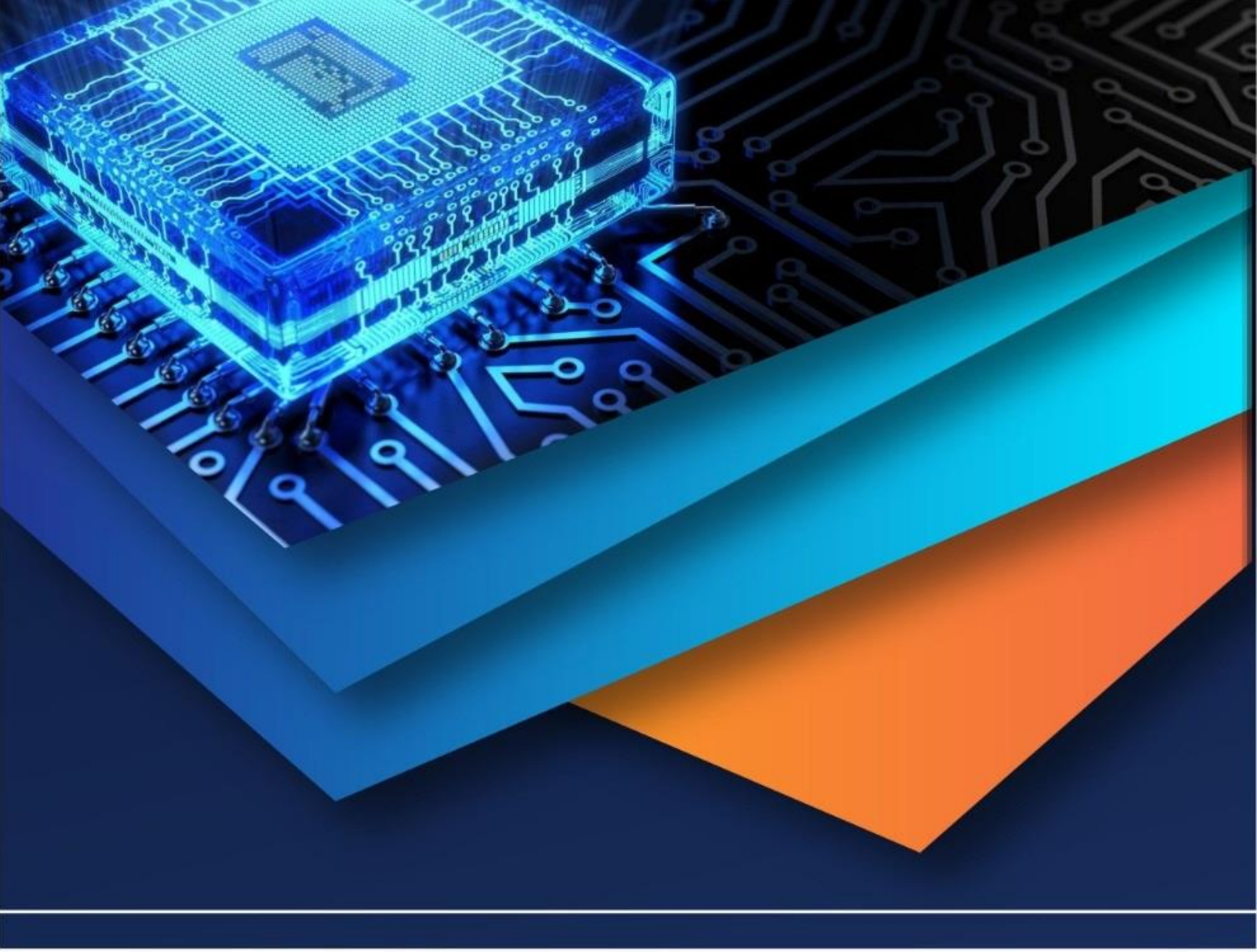

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