Alteration of Plastic Waste into Thermal Fuel by Pyrolysis – A Review

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Abstract: *Due to the rapid increase in the human population, around 960 million tonnes of plastic waste are produced every year which is approximately equal to the weight of the entire human population. Plastic waste can affect ocean, land as well as waterways. This plastic has some acute effects on the environment like climate change as it increases the greenhouse gases, pollutes land by releasing harmful chemicals in the surrounding soil. Plastic pollution also affects human health (like asthma, liver and kidney damage, cancer, diabetes, birth defects, etc). if a fish consumes plastic, then that same fish is ultimately served on our plates which means it is harming every single part of our food chain. This indicates plastics have reached in our food chain too. So it is need find some another methods where we can use this waste plastics and convert into some useful by-product without producing any harmful effects on environment. In this review paper the literature survey is carried out to study the extraction of the fuel from the waste plastic. As we know that to develop power Oil, coal, and natural gas are the types of fossil fuels used. These different sources of fuel like petrol, diesel, coal and gas are depleting at a fast rate. In recent years we will need alternatives of fuel because nowadays fuel is extremely important which urges a demand for generating different sources of fuel. Thus, pyrolysis is an effective technique used to convert plastics into useful fuel. This technique provides several benefits such as reducing the reliability of fossil fuels, improving the waste management system, increasing energy sources and also prevents contamination to the environment. According to this review paper it is recommended to select LDPE ,HDPE , PET ,PS , PP as plastic waste material for extraction of plastic oil fuel as these types of plastics gave a high quantity and quality of liquid oil yield. The high qualities of hydrocarbon fuels are extracted through the catalytic cracking extraction process as the effective reaction of catalysts with plastics which leads to reducing the thermal energy input and degradation time.*

Keywords: Catalyst, Fossil Fuel, Plastic Waste, Pyrolysis.

1. INTRODUCTION:

Due to the rapid increase in the human population, around 960 million tonnes of plastic waste are produced every year which is approximately equal to the weight of the entire human population [10]. Plastic is in high demand because of its various characteristics like easy manufacturing, durability, lightweight, electrically insulating, and so on. So, due to these factors, we are falling into the trap of plastics. We are using plastics majorly in packaging, textiles, domestic products, transportation, in electrical and electronics products, and construction industries. On large scale, we are using high-density polyethylene (HDPE), low-density polyethylene (LDPE), polyethylene (PS), polyvinyl chloride (PVC), polypropylene (PP) and polyethylene terephthalate (PETE) [8]. This plastic waste is a threat to our environment, marine life, and other ecosystems as it all ends up on the earth's surface and water bodies themselves. Around 14 million tonnes of plastic waste end up in oceans every year which is in itself an alarming figure [4]. Major sources of plastic waste are packaging (161 million tonnes), building and construction (72 million tonnes), textiles (65 million tonnes), consumer products (46 million tonnes), transportation (30 million tonnes), electrical (19 million tonnes) and others (52 million tonnes) [11]. This plastic has some acute effects on the environment like climate change as it increases the greenhouse gases, pollutes land by releasing harmful chemicals in the surrounding soil and when these chemicals sweep down, they also pollute the groundwater also a study revealed that people may be ingesting around 3,000 to 4,000 microparticles of plastic from tap water per year, it also affects human health (asthma, liver and kidney damage, cancer, diabetes, birth defects, etc). But this does not stop here because plastics have reached our food chain too, for example, if a fish consumes plastic, then that same fish is ultimately served on our plates which means it is harming every single part of our food chain. Plastic is non-biodegradable due to which it takes around 450 years to decompose. Currently, we are only decomposing plastic by landfills, mechanical and thermal recycling [8]. That's why there is a dire need of converting this hazardous waste called plastic into something serviceable to society.

From the bodies of tiny plants and animals that died millions of years ago, Fossil fuels are made up of carbon-containing (organic) molecules left over. Fossil fuel deposits were formed 54 million to 65 million years ago, its waters teemed with algae, bacteria and other tiny organisms when earth's climate was warmer and wetter.

Oil, coal, and natural gas are the types of fossil fuels. Now a days, most countries Complete their growing energy demands from the fossil fuels. Rassia, China, and United States have the world's largest coal deposits. In the Middle East, Roughly half of the world's oil and natural gas reserves. Petroleum is produced in 32 states in USA and in coastal waters, most of which is found in Alaska, California, New Mexico, North Dakota and Texas states.

Currently, 80% of the world's energy supply provided from fossil fuels. Out of this, oil provides about 40% of the total global energy needs and fuels around 90% of the transport sector. The remains of marine microorganisms deposited on the sea floor forms the liquid as oil. The most widely used fossil fuel is oil. By using refining process, Crude oil is transformed from different organic compounds. In 2010, the global oil production has reduced to 26 Mb/day which is continuously reducing in coming decades. Approximately 98.27 million barrels per day worldwide oil consumption reached in 2019 and since 1998 it was increased by 20 million barrels per day. Over the past two decades the global oil consumption has been steadily increasing.

Natural gas is a gaseous fossil fuel that is relatively clean compared to coal and oil, abundant and versatile. In developed countries Natural gas is widely sued as compare to coal. Natural gas mainly consists of methane (CH_4). The natural gas is available at large depths in the earth in compressed form. it is brought to the surface by drilling similar to oil. Global proved natural gas reserves are increasing over time at a rate of 400 BCF/year. In 1995 Natural gas production rate was 204.5 BCF/day, in 2005 it is 268.8 BCF/day and in 2014 it is 329.4 BCF/day. But the gas production rate has been increasing at a lower rate of 3.4 BCF/year. During 2000 to 2010, the Natural gas production has increased from 2300 to 2750 MTOE. Experts believe this rate will peak at 3200 MTOE in 2025 then decline to 1300 MTOE by 2050.

Over millions of years by decay of land vegetation the solid fossil was formed know as Coal. Deposits are turned into coal, when layers are compacted and heated over longer time. Coal is usually extracted in mines. As cost of oil and natural gas is very high so that many developing countries depend on coal for energy provision. India and China are major users of coal for energy provision. Coal fired power plants produce 14–15 Gt of CO_2 every year which is 49–50% of global CO_2 emission. Global coal production rate was 2.867 GTOE in 2000 and in 2014 it is 3.901 GTOE. At a rate of 19.20 GTOE/year, the world coal production is increasing. World coal consumption was 2.2146 GTOE in 1990, in 2000 it was 2.3429 GTOE and in 2014 it was 2.9297 GTOE. At an average rate of 103 MTOE/year world coal consumption rate has been rising. Coal production has increased in year 2000 from 2400 to 3450 MTOE in 2010 and it will be continuously increasing at 3650 MTOE by 2035 and decline to 2700 MTOE in 2050 [20]. Summarising all this discussion shows how different sources of fuel like petrol, diesel, coal and gas are depleting at a fast rate. In recent years we will need alternatives of fuel because nowadays fuel is extremely important which urges a demand for generating different sources of fuel. One of which is the idea of converting plastic into fuel by pyrolysis. As plastic is petroleum-based material we can do its chemical decomposition and convert it into hydrocarbon compounds. Thus, pyrolysis is an effective technique used to convert plastics into useful fuel. Renewable fossil fuels can take millions of years to replenish inside the earth's surface and only a few minutes to fetch them out and burn them in the air which means very soon we will run out of them. Hence converting plastic into fuel is a sustainable solution to the problem.

2. LITERATURE REVIEW

In 2011 Mr. Sachin Kumar conducted an experiment on conversion of waste plastic (mainly HDPE) into hydrocarbon that could be used as fuel or as a source of chemicals. Normal pyrolysis reactor was used with temperature range of 400^{0}C to 550°C. He found that at temperature of and below 450 °C an oily liquid was the prime product and as the temperature was above 475 °C it gradually converted into a viscous liquid or waxy solid and finally at 600 °C the product was only wax. He also found that liquid yield increased when the holding time was increased from 1 hr to 4 hr and decreased from 4 hr to 6 hr. About reaction time he found that with increase in temperature the reaction time was decreased. In his experiment he also noted the physical properties of pyrolytic oil like specific gravity (0.7835/15°C), density (0.7828 kg/cc), Gross calorific value (10244 Kcal/kg) etc. At the end he culminated that the distribution and the yield of different products like oil, gas, was and some residue was significantly depending on temperature, reaction time and holding time.[1]

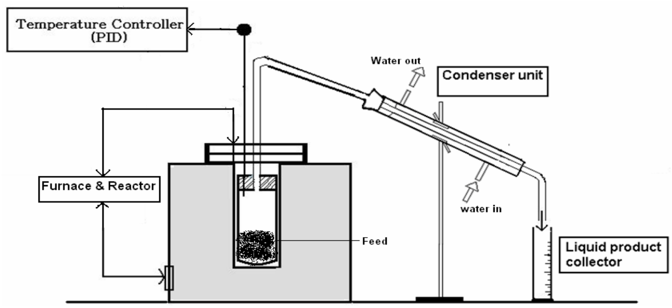

Fig. No. 1: Pyrolysis setup

Table 1- Distribution of the different fractions at different temperatures in the HDPE pyrolysis

Temperature (°C)	Oil (wt.%)	Wax (wt.%)	Gas/ volatile (wt.%)	Residue (wt.%)	Reaction time (min)
400	11.2	0	84.2	4.6	760
450	23.96	0	72.24	3.8	290
500	21.87	50.38	24.75	3	68
550	7.86	71.22	18.42	2.5	54

Ms. Neha Patni conducted a research on how economic growth of society is unsustainable without saving fossil energy in 2013. Also, how important it is to switch on alternative fuels and waste management methods. As plastic is a very resourceful and low cast material its consumption has increased at very exorbitant rate. She thus suggested that recycling plastic and converting it into fuel (plastics calorific value is comparable with that of fuel) is the best possible way. She divided recycling in total 4 categories: primary, secondary, tertiary and quaternary. After that she also mentioned some methods of converting plastic into fuel named as: Thermal degradation (pyrolysis), Catalytic degradation and Gasification. She also discussed the mechanism of Catalytic degradation with chemical equations as Initiation, propagation and Termination. At the end she concluded that an apt pyrolysis reactor must be designed in such a way that it can use mixed plastic waste, can be used at both small and middle scale production, has low operating cost as well as is budget friendly. [2]

Table -2 : *Main operating parameters for pyrolysis process*

Parameters	Conventional	Fast	Flash
Pyrolysis temperature (K)	550–900	850–1250	1050–1300
Heating rate (K/s)	0.1–1	10–200	>1000
Particle size (mm)	5–50	<1	<0.2
Solid residence (s)	300–3600	0.5–10	<0.5

In 2013 Mr. Jindoporn Jamradloedluk conducted an experiment on characterization of char derived from fast pyrolysis of HDPE waste at 400-450°C. Pyrolysis and gasification generates a solid residue known as char. This char was collected and analyzed. He observed that char contains volatile matter (51.4%), fixed carbon (46.03%), moisture (2.41%), ash (0.16%). Its contents were found as carbon, hydrogen, nitrogen and sulphuras 46.65%, 3.06%, 0.43% and 1.80% respectively. He explained that chare when crushed into powder and extruded produced briquettes. This briquettes when used to boil water in cook-stove was able to boil it within 13 minutes along with an evaporation rate of 1.04 Kg/h. He also told that atmospheric pressure thermal activation at 900°C for 3 hours was carried out to boost the surface area and specific pore volume of char. This ultimately led to increase BET surface area and pore volume by 55% and 44% whereas pore size reduced by 5%. At the end of his experiment, he noted that the density and calorific value of char was found out to be 1.59 g/cm^3 and 4,500 cal/g. [3]

Table- 3: *Characteristics of chars derived from different thermochemical processes of plastic wastes*

Description		Fast pyrolysis	Gasification
Proximate analysis (% wt)	Moisture Volatile matter Fixed carbon* Ash	2.41±0.36 51.40±0.28 46.03±0.32 0.16±0.23	0.43±0.37 46.57±0.12 53.74±0.18 nd
Ultimate analysis (% wt)	C H N S	42.65±0.98 3.06±0.06 0.43±0.04 1.80±0.02	31.97±0.30 3.03±0.03 0.99±0.04 1.86±0.04
Particle density (g/cm^3) Calorific value (cal/g)		42.65±0.98 4,500	31.97±0.30 4,950

In 2014 Mr. Gaurav conducted an experiment on converting plastic waste into a better product called fuel. In this way we can solve both the problems of fuel shortage and plastic recycling together. In this experiment he used LDPE (300g LD Polyethylene and 300g LD polypropylene) for thermal pyrolysis at 100-400°C. He also said that as pyrolysis is carries out in absence of oxygen and at high temperature which erected the need of fabricating a reactor to provide the needed temperature for the reactions. He said that various value-added products like petrol, diesel, kerosene, lube oil etc. were obtained when plastic waste was put on to depolymerisation, pyrolysis, thermal cracking and distillation. At the end he noted the density and calorific value of the fuel as 702.5 Kg/m^3 and 43796.02 KJ/Kg which were very close to the properties of petrol and further experiments and studies could yield much better outcomes. [4]

In 2014 Mr. Nosal Nugroho Pratama conducted two experiments for an outright study of Waste Plastic Pyrolysis Oil (WPPO) its applications and characteristics. In his first experiment characteristics of oil extracted from pyrolysis process at 500-450°C in 2 stages batch reactors (Pyrolysis & catalytic reforming reactor) were look overed. He used Waste Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyethylene Terephthalate (PET) and others as raw material. Indonesian natural zeolite was used as catalyst and 0.8 l/minutes Nitrogen flow rate was used to rise oil weight percentage. Second experiment was performed on Diesel Engine Test Bed (DETB) with a blend of WPPO and biodiesel fuel at volume ratio of 1:9. He found that Highest wt.% of WPPO was found from the mixture of PE (50%wt), PP (40%wt) and PS waste (10%wt). The more wt.% of PE in the base material resulted in less wt.% of WPPO. Due to more percentage of C12-C20 content in WPPO, calorific value of WPPO is increases. Characteristics of WPPO such as, Specific Gravity, Flash point, Pour Point, Kinematic Viscosity, Calorific value and percentage of C12-C20 were also noted and found to be very close to that of diesel. So, he concludes that plastic waste composition highly influences all the major properties and fractions of fuel. [5]

Table 4: *Oil Properties of WPPO and Diesel Fuel*

Oil property	Unit	WPPO				Diesel Fuel
		A	B	C	D	
Specific Gravity at 60/60°F	-	0.81	0.86	0.86	0.87	0.844 5
Kinematic Viscosity at 40°C	mm²/s	1.19	1.18	1.05	1.29	4.012
Flash Point	°C	Already flashed at 10°C				66.5
Pour Point	°C	6	3	-21	-6	6
Water Content	% Vol.	0.4	0.6	0.6	0.6	0.05
Ash Content	% wt.	0.53	0.00 1	0.05	0.03	0.01

In 2014 Mr. M.A. Hazrat conducted a study on various thermolysis processes and the dissolution effect of several plastic polymers into bio-solvents. He suggested that, since plastic ploymers are formed from petroleum resources best way is to convert this waste into fuel which will defineately help in saving our environment. He thus conclued that thermo-catalytic process and dissolving polymers into bio-solvents with appropriate catalyst and bio-solvents can help developed countries to reduce plastic and also genetrate clean fuel for transpot industries and factories.[6]
In 2015 Mr. Vijaykumar B. Chanashetty conduced a study on how efficiantly plastic can be converted into fuel and how this method will help our socity to fight against the increasing tonnes of plastic along with the improvement of economical senerio. He told that pyrolysis, thermal pyrolysis of polyolefin and catalytic cracking of polyolefin is the main methods used. Temperature range of pyrolysis was 350-500°C and LDPE was majorly used in the process. Also the main devices of pyrolysis plant, advantages of pyrolysis, mechanism of thermal degradation were discussed by him in detail. At last he concluded that the properties of the plastic fuel matches with that petrol and diesel at great extent and this plastic fuel generation will provide a big boon to the economy. [7]
In 2015 Dr. L. Nageswara Rao performed an experiment on conversion of waste plastic around us into alternative fuel source. He suggested that catalyst cracking is a very usefull process of converting waste plastic into liquid hydrocarcon and its products which can be further used as fuel in various fields. He used Polyethylene Terephthalate (PET), Low Density Poly Ethylene (LDPE), High Density Poly Ethylene (HDPE), Polypropylene (PP) Polystyrene (PS) as raw material and Aluminium silicate as the catalyst. The process took place at 330-450°C. He also mentioned that the gaseous by products when collected can be used for domestic purposes and for running gas turbines too. Also, many mixtures were also used in this experiment like 40% oil + 40% petrol, 10% oil + 90% diesel, 30% oil + 70% diesel, 50% oil + 50 % petrol so that best mixture with highest yield could be found out. Since fossil fuels like petrol, diesel, crude oil etc. are depleting very fast this thermos fuel is truly a very feasible waste solution. [8]

In 2016 Mr. Loannis Kalargaris conducted an experiment of converting plastic waste into useful fuel and tested it on internal combustion engine so as to produce power and heat. He used a mixture of different plastics for pyrolysis and found its properties very close to that of diesel fuel. Then he tested a variety of blends of plastic pyrolysis oil (PPO) and diesel on four-cylinder direct injection diesel engine from 0% to 100% at various engine loads 25% to 100%. He also compared PPO with diesel fuel for engine combustion characteristics, performance and exhaust emissions operation. At last, he suggested that a blend of 60%-70% operating at 80%-90% engine load for long term running seemed to give the best possible results and had potential to give the finest engine performance. [9]

Table – 5: *PPO and diesel properties*

Property	Method	PPO	Diesel
Density @15˚C (kg/l)	ASTM D4052	0.9813	0.8398
Kinematic viscosity @40°C (cSt)	IP 71	1.918	2.62
Flash point (˚C)	ASTM D93	13	59.5
Aromatic content (%)	IP 391	65.5	29.5
Acid number (mg KOH/g)	IP 139	41	0
LHV (MJ/kg)	ASTM D240	38.3	42.9
Water content (mg/kg)	ASTM D6304	1190	65
Ash content (wt.%)	IP 391	0.166	<0.001
Carbon residue (wt.%)	ASTM D4530	4.83	<0.01
Hydrogen content (wt.%)	ASTM D5291	8.5	13.38
Carbon content (wt.%)	ASTM D5291	87.9	86.57
Oxygen content (wt.%)	ASTM D5622	3.3	0.05
Sulphur content (wt.%)	ASTM D5453	0.155	0.0014
Nitrogen content (mg/kg)	ASTM D4629	820	44

In 2016 Mr. manjunath S conducted an experiment on how we can fight aginst this plastic pollutanat and convert it into something propuctive withou harming our environment.

Thus he performed an expertiment for generatinf fuel from the plastic using thermal and catalytic pyrolysis above 500. He use LDPE as raw material in a newly designed reactor. Firstly thermal pyrolysis took place which resulted in conversion of 98.16% and 84.6% oil yield. Later when catalytic pyrolysis took place with CaCO3 as catalyst it gave coversion of 99.25% and oil yiels of 86%. Here catalyst to plasic ratio was 0.2. Later he subjected the obtained fuel to atmospheric disstilation so as to obtain Gasoline, naphtha, kerosene, light gas oil, heavy gas oil and many other componts of carbon. So, his experiment resulted that pyrolysis is a great process to get an alternative fuel and solve the problem of plastic pollution. [10]

An experiment was conducted by Mr Athanasios Dimitriadis in 2017 to reduce the environmental problem occurring due to accumulation of plastic waste with the help of waste-to-fuel technology. In this experiment he converted the plastic waste into automotive diesel fuel with the help of two thermo-chemical processes depending upon pyrolysis and hydrotreatment . At first pyrolysis was performed which converted plastic waste into plastic oil (consisting middle-distillate hydrocarbon mostly) and then diesel fraction this plastic oil was fractionated and further upgraded its parameter by catalytic hydrotreatment . After the successful hydroprocessing of the pyrolysis oil he observed that the properties like density, viscosity, cetane number, flash point etc of the oil was improved and matched the requirements of EN 590 standard of automotive diesel .[12]

A study was conducted in 2017 by Mantesh Basappa Khot on how to convert plastic waste into fuel using pyrolysis . In this study he used only Low Density Polyethylene (LDPE) as a raw material which is fed in the stainless steel reactor operating at temperature between 350 - 500 ^0C for pyrolysis specifically. LDPE degradation took place by thermal cracking without a catalyst during this process light gases like methane, ethane, propane, butane are produced . Condenser was used after the pyrolysis to convert gaseous degraded LDPE at 300 ^0C into liquid LDPE fuel at 30-35 ^0C . He found out that after completion of process liquid yield of 90%, solid black residue of 4% and gases of about 6% were obtained . The liquid fuel obtained is further purified and filtered giving 4 liter of useful plasto-fuel. He tested this plasto-fuel to measure its properties such as specific gravity, density, dynamic viscosity, kinematic viscosity, calorific value . He observed that these properties of plasto-fuel generated by LDPE by the experimental process of pyrolysis are comparable with petrol and diesel. These results of the study conclude that plastic waste pyrolyised fuel can be a good alternative for petrol and diesel engines with the help of proper treatment, collection and sustainable systems .[13]

Table -6: Comparison of obtained Plasto-Fuel with Regular Petrol and Diesel

Properties	Regular Petrol	Regular Diesel	Plasto–Fuel
Specific Gravity	0.742	0.85	0.775
Density (Kg/m^3)	742	850	755
Kinematic Viscosity (centistoke)	2.42	3.05	2.525
Dynamic Viscosity (centi-Poise)	1.796	2.592	1.957
Gross Calorific Value (KJ/Kg)	46858	42000	42686
Flash Point (^0C)	23	50	29
Fire Point (^0C)	29	56	36
Sulphur1 (%w/w)	0.0015	<0.002	0.002
Carbon Residue (% w/w)	<0.01	0.01	Nil

Mr. M.A. Quraishi conducted a study on production of engine fuel from plastic waste with the help of pyrolysis process and its performance in C.I engine with diesel blend in 2017. In this study two experimental setups are used, one to carry out pyrolysis for fuel conversion and other for performance evaluation. He used 20 gm of packaging plastic waste as feed for conversion which took place inside the batch reactor operating at the temperature range of 400-500 ^0C. After pyrolysis, both the condensable liquid products that were collected through the condenser and the solid residue left inside were weighed. He observed that approximately 65-67% of plastic oil yield was produced. He used this plastic oil to blend with pure diesel in different percentages and used it in diesel engines at various compression ratios with various loads to measured the performance of the blend in CI engine with the help of characteristics such as engine brake power, brake thermal efficiency, specific fuel consumption and exhaust emission. After evaluation of different characteristics through experimental setup he found out that up to 40% of diesel can be saved without loss of power on using plasto-diesel fuel blend and it does not differ with change in compression ratio. He also found out that Brake Thermal Efficiency (BTE) increases, specific fuel consumption decreases and exhaust emission reduces significantly with the addition of waste plastic oil. The study finally concluded that the blend ratio with 40% of WPO has comparable characteristics with respect to the pure diesel for all compression ratios so it can be used in CI engines with further research [14].

Table 7 : properties of waste plastic oil and diesel

Properties	Measuring Technique	B100 (measured)	DIESEL (Pawar et al..2013)
Density (kg/m^3)	Hydrometer cylinder	860	890

Calorific value (kJ/kg)	Bomb calorimeter	39500	42000
Flash point (^{0}C)	-	36	> 52
Fire point (^{0}C)	-	41	> 55

Mr. Aditya Machiraju in 2018 conducted an experiment for conversion of plastic waste into liquid hydrocarbon fuel. He used pyrolysis as the process for conversion. In this experiment first he collected 1kg of the plastic waste from municipal solid waste and sorted them in different types of plastic like PET bottle, Polypropylene, Polystyrene, HDPE and LDPE. He then shredded them and fed it to the reactor operating at the temperature range of 150-200 ^{0}C. Inside the reactor plastic waste is melted and produces gases which are then condensed to liquid with help of a condenser and both the condensed as well as uncondensed gases can be used in the engine as fuel. After this he tested the plastic fuel obtained for properties like calorific value and viscosity, and compared them with conventional fuel. He observed that 75 % useful liquid hydrocarbon fuel can be generated from 1 kg of plastic waste .He finally reached to the conclusion that the properties of the plastic fuel obtained are almost similar to the conventional fuel like diesel therefore it can be considered as a good alternative for the diesel engine [15].

Table No. 8 : Comparison of properties of Plastic Oil with conventional fuels

Properties	Plastic Oil	Gasoline	Diesel
Calorific Value (kJ/kg)	46.057	48,000	42,000
Density (kg/m^3)	691.66	719.7	812
Viscosity (centistokes)	2.1	0.71	3.05
Fire point (^{0}C)	41	40	74

An experiment was conducted by Mr Ramli Thair in 2018 for optimization of liquid product of pyrolysis. In this experiment he used 500 gm of Polypropylene (PP) plastic waste as a feed to fixed bed type reactor operating within the temperature range of 500-650 ^{0}C. The vapour generated is passed through 4-tray distillation bubble cap plate column for fractionation. In this distillation bubble cap plate column each tray has different liquid fuel characterization yield based on the different pyrolysis temperature. The analysis of the characterisation of any condensate tells about the type of fuel obtained. The tray 1 at temperature range of 500-560 ^{0}C, 580-600 ^{0}C and 620-650 ^{0}C fuel condensate yielded liquid fuel with kerosene, gasoline and mixture of polymer (wax) and diesel. Tray 2 fuel condensate yield liquid fuel with specification of gasoline and kerosene at temperature range of 540-620 ^{0}C and 650 ^{0}C. Tray 3 fuel condensate yield liquid fuel with specification of gasoline at temperature range of 580-650 ^{0}C and similarly tray 4 fuel condensate yielded gasoline fuel at the temperature range of 600 - 650 ^{0}C. The experiment results concluded that properties of fuel obtained from plastic such as calorific value, density, viscosity and ash content as similar to the properties of fossil fuel therefore with Integrated Pyrolysis Method with refinery distillation Bubble Cap Plate can be used directly for transportation fuel gasoline and kerosene type whereas diesel can be recycled [16]

Mr Rajkumar G conducted an experiment in 2019 to obtain eco-friendly energy from plastic waste materials with the help of an automated waste management system by using an arduino board. He modified the simple pyrolysis decomposition method into a hybrid pyrolysis method giving a better yield than other methods. In this experiment he used 250g plastic waste slurries as feed to a cylinder with length 147 cm and diameter 39 cm. one end of the outlet of the cylinder was sealed and the other with an automated waste management system connected to an arduino board. He used a PID controller which is also connected with an arduino board and controls the temperature. The results of the experiment shows that 65 ml of liquid fuel can be obtained from 250 gm of plastic waste slurries and with the increase in temperature from 400-420 ^{0}C different volatiles fraction are obtained varying from 84.3-87.7 wt %. He also observed that the reaction rate of pyrolysis depends on the HDPE ratio used with respect to temperature as well as time therefore with the increases of temperature reaction rate also increases. At last he used FTIR analysis to identify the sample functional group and the results of the analysis identified the C-H functional group with the stretching vibration having wavelength 2796 cm^{-1} and 2936 cm^{-1}. He concluded that modified pyrolysis can be utilized to generate liquid fuel from plastic waste and FTIR analysis can identify the functional group [17]

Mr. Farizal with the support of the University of Indonesia in 2019 conducted an experiment for optimization of different parameters governing the pyrolysis process such as plastic type, residence time and temperature with the help of factorial design to obtain the maximum yield of liquid products of pyrolysis. In this experiment he used homogenous plastic of PP and heterogenous plastic like PET, LDPE, HDPE, PS as a raw material which he feeds in a stainless steel reactor with a length, width and height as 60 cm, 69.5 cm and 77 cm operating between 175 -250 ^{0}C with residence time of 180 and 300 minutes. He obtained liquid, char and gas as products then he find different properties like mass, density, viscosity of these products. He separated the liquid yield and used its results for data analysis with the help of variables assigned to parameters by performing 2k factorial design for each factor. He then found out that homogeneous plastic waste gives the biggest oil yield of 88.5% by weight with a temperature of 250 ^{0}C and residence time of 300 minutes. While char obtained was 2.03% by weight on the other hand, heterogeneous plastic waste gave the biggest oil yield of 49 % by weight while char obtained was 18.81% by weight for the same temperature and residence time. He finally came to the conclusion that type of plastic and residence time are the significant factors in pyrolysis and the liquid yield of 80.90% can be obtained from Polypropylene (PP) at temperature 250 ^{0}C and residence time of 300 minutes with the help of optimization. The liquid yield product obtained from pyrolysis can be used as fuel along with the conventional fuel in the engine with the consequences of corrosion which may occur due to high ash content and acid number in liquid [18]

Table No. 9: Variable Level

Properties	Homogeneous Plastic	Heterogeneous Plastic	Diesel Standard
Cetane	48.1	48.3	Min 48
Acidic Value	43.88	4.04	Max 0.6
Viscosity 40 ^{0}C (cst)	2.28	2.4896	2-4, 5
Density 15 C (kg/m^3)	805.4	806	Max 860
Water Content (mg/kg)	18.6	271.6	Max 500
Ash Content (%v/v)	1	1	Max 1

In 2020 Mr. Mohd Wasif Quadri conducted a study to find the potential of different pyrolysis processes provided by the researchers in order to obtain valuable products like liquid fuel from plastic waste. He started by analysing various parameters affecting the liquid oil yield and its quality. He found out that each different parameter results in different liquid oil yield and the most critical factor was the temperature as different degradation temperatures can be observed in different types of plastic based on their chemical structure. Other process parameters such as pressure, type of reactors, heating rate and pyrolysis duration also depend on optimum temperature. He also found that nitrogen gas was used as a fluidizing medium in all experiments. He noted that not all types of plastics can be used for pyrolysis as few plastics like PET and PVC results in low liquid yield and degraded quality due to generation of toxic products. To optimize the liquid yield in plastic pyrolysis the most effective temperature range was 500-550 ^{0}C. The liquid oil yield can be improved by the use of catalyst in the process as it lower down the optimum temperature up to 450 ^{0}C required for pyrolysis . The highest liquid yield that can be obtained in case of polyolefin plastic type like LDPE was 93.1 wt % followed by HDPE and PP with 84.47 wt % and 82.12 % of total liquid oil yield. Out of all the types of plastic PS is exceptional as it does not require a catalyst to improve the liquid yield because it can be degraded easily with optimum temperature and results in 97 wt% of total oil yield produced. Therefore he concluded that PS is the best plastic to obtain highest liquid oil yield and quality and the liquid yield of other types of plastic like HDPE, PP can be maximized to 90% with the addition of catalysts like FCC [19]

Table No. 10: Pyrolysis Reactors

Reactor type	Heating methods	Heating rate
Fluidized Bed	heated recycle Fire tubes	High Moderate
Entrained flow	Recycles hot sand	High
Fixed bed	Heated recycle gas	Low
Rotary Kiln	Wall heating	Low

TABLE No. 11 : Comparison Of HDPE Pyrolytic Oil And Conventional Fuel Properties

Type of oil	HDPE pyrolytic oil	HDPE pyrolytic oil	Conventional fuel	conventional fuel
	Boiling point (C)	CV (MJ/kg)	Boiling point (^{0}C)	CV(MJ/kg)
Gasoline	82-352	42.9	40-200	43.4-46.5
Kerosene	-	-	150-300	43.0-46.2
Diesel	-	-	150-390	42.8-45.8

3. RESULTS/DISCUSSION AND CONCLUSION

Highest yield of liquid product was found high temperatures and highly volatile products can be obtained at low temperatures. In today's time plastic waste is increasing at an alarming rate as well as its very difficult to make end meet with the growing need of fuel for economic development of any country. Therefore, pyrolysis is the best available method for recycling plastic waste as it solved the two main problems i.e., generation of fuel and reduction of plastic waste. Also, this thermal fuel we get has properties very close to that of petrol and diesel. Some other processes were thermal degradation, catalytic degradation, dissolving into bio-solvents and gasification.

Also, char (solid waste) derived from fast pyrolysis of HDPE contained various volatile matter and thus when crushed and extruded produced briquettes which is used to boil water in a cookstove. Different ratio mixture of plastic was used. And the result showed that if more % of PE was used less % of oil was formed. And highest was recovered from PE (50%), PP (40%) and PS (10%). Higher calorific value of plastic fuel was observed when more % of C12-C20 content was used. When we used ratios like 50% oil & 50% diesel and 40% oil & 60% petrol, we were getting results closer to that of 100% diesel and petrol. Problems faced during the execution of this process are as follows: -

- Segregation of different types of plastic which demand for such type of set up which can use all types of plastic waste.
- More fuel was used to generate plastic oil than the fuel generated.
- Problem of waste generated by pyrolysis.
- Pyrolysis set up must be suitable for both small and large scaled industries.

The properties of the pyrolysis like density, viscosity, specific gravity, flash point, cetane number can be enhanced such that they become comparable to the conventional fuel with the help of catalytic hydrotreatment using middle - distillate hydrocarbon fraction in the plastic oil . If we use LDPE alone as a raw material to produce plasto-fuel with help of pyrolysis the liquid oil yield of 90 wt % along with some 4% solid residue and 6% gases can be obtained in the process . The properties of LDPE pyrolysis oil are comparable to the conventional fuel. Calorific value of the plasto-fuel obtained was 43000 KJ/Kg. The pyrolyzed oil when blended with the diesel in different ratio can be used in the IC engine as the fuel . The best quality of the blend is obtained with the blend ratio of 40% of waste plastic oil in diesel. The pyrolysis of plastic waste along with the refinery distillation bubble cap plate column can enhance the plastic fuel characteristic which enables us to use this fuel directly as transportation fuel. The liquid oil yield of the plastic waste generated by pyrolysis can be optimized with the help of factorial design optimization method .In this method the significant factors affecting the pyrolysis like the type of plastic and residence time are optimized to give best liquid yield possible. Among all the types of plastics such as LDPE, HDPE, PS, PET, PVC etc, the highest liquid oil yield is obtained by PS as it can be degraded easily without using a catalyst. The liquid oil yield obtained from LDPE and HDPE can be increased up to 90% or above with help of catalyst like FCC and the right operating temperature. The lowest liquid oil yield is obtained by PVC and PET and they also produce products harmful for the environment therefore these types of plastics are not preferred in pyrolysis. Homogenous plastic waste gives a higher liquid yield as compared to heterogeneous plastic waste.

4. CONCLUSION:

This review showed that many researchers had studied the potential of the plastic pyrolysis process in order to produce valuable products such as plastic oil which can be used as alternative to conventional fuel and the results were convincing .This technique provides several benefits such as reducing the reliability of fossil fuels, improving the waste management system, increasing energy sources and also prevents contamination to the environment. The technique can be carried out with different parameters which lead to different yields and liquid oil quality. In addition, this technique provides greater versatility and economic feasibility in terms of handling and product variability. As discussed in the previous paragraph, various parameters can affect liquid oil yield and the most critical factor is temperature. Different plastics may have different degradation temperatures depending on their chemical structures. Consequently, the effective temperatures for optimizing pyrolysis liquids also vary for each plastic and it is also highly dependent upon other process parameters. These parameters include the kind of catalyst used, the catalyst to polymer ratio, and also the type of reactors operated. According to this review paper it is recommended to select LDPE ,HDPE , PET ,PS , PP as plastic waste material for extraction of plastic oil fuel as these types of plastics gave a high quantity and quality of liquid oil yield .

The high qualities of hydrocarbon fuels are extracted through the catalytic cracking extraction process as the effective reaction of catalysts with plastics which leads to reducing the thermal energy input and degradation time. Catalysts like zeolite (ZSM, HZSM). CaCO, red mud and ZnO produced high end quality of automotive fuels. The selection of catalyst is depending upon the poisoning and deactivation with the presence of feedstock. It is recommended that the catalyst/ feed ratio 1:10 should be taken for higher yield of oil. Byproducts of plastic pyrolysis include tar, char, syngas, and gas. The proportion of byproducts in pyrolysis is strongly influenced by several parameters, including temperature, heating rate, pressure, and residence time.

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