

Fuel Preparation for Jet Propulsion in a Cost-Effective Innovative way: Cash (Fuel) from Trash (Plastic Waste)

^{1*}Tamojit Poddar, ¹Nirnimesh De

¹Department of Mechanical Engineering Jadavpur University Kolkata-700032, India

¹Department of Mechanical Engineering Jadavpur University Kolkata-700032, India

Corresponding Author: Tamojit Poddar

Date of Submission: 08-07-2020

Date of Acceptance: 23-07-2020

ABSTRACT

Inorganic wastes, especially in the form of plastics, have become a major dilemma throughout the world paving the way for adverse climatic conditions owing to Global Warming and Environmental Pollution. Very low biodegradability of this material makes the method of its recycling process very difficult. Most of the Municipal Solid Waste (MSW) recycling facilities in the developing countries only use composting method to recover the organic fraction of the waste, while the inorganic fraction remains untreated. This project's idea is to fight against plastic pollution and convert the Oceans of Plastic Trash into valuable Fuel in an Eco-friendly process with minimum cost involved. This approach is more energy-efficient than recycling or burning waste plastic and about six billion tons of plastic wastes have been generated around the world in the past fifty years. Very little, this waste is recycled, and close to eighty percent of it sits in the landfills or in the natural environment, where it harms wildlife, leaches harmful chemicals, and emits greenhouse gases. The presented idea involves the synthesis of a petroleum-based fuel by the Catalytic Pyrolysis of waste plastics. Catalytic Pyrolysis involves the degradation of the polymeric materials (plastics) by heating them in the absence of oxygen and in the presence of catalysts. Our research presents the study of different oil samples that are produced using different catalysts under different reaction conditions from waste plastics and how they can be utilized as jet propulsion fuels. The synthesized oil samples are subjected to a parametric study based on the oil yield, selectivity of the oil, fuel properties and reaction temperature. It results to an optimization of the catalyst and reaction conditions for this technique. Gas chromatography-mass spectrometry of the selected optimized sample was done to find out its chemical composition. Polythene bags are selected as the source of waste plastics on a major basis as they are readily available in abundance. The catalysts used for the study include silica, alumina, Y- zeolite, barium

carbonate, zeolite, and their combinations. The Pyrolysis reaction was carried out at a ratio of ten parts of the polymer to one part of the catalyst. The reaction temperature ranges between four hundred degree celcius and eight hundred degree celcius. The inert atmosphere for the Pyrolysis was provided by using nitrogen as a carrier gas. Another objective of this paper is to optimize the liquid product of Pyrolysis from as much as five hundred grams of polypropylene (PP) plastic waste, using a fixed bed type reactor in a vacuum condition (-3 mm H₂O), to minimize the amount of oxygen that enters the reactor. The characteristics of fuel obtained from plastic such as density, viscosity, octane-cetane number, ash content and calorific value have similar properties with those of fossil fuels. So this process results in the production of the fuel that can be used effectively after purification, for the Jet propulsion procedure, with minimum cost being involved and this may emerge as the solution of the Energy Fuel Economy crisis in an Eco-friendly process. By Pyrolysis, plastic waste can be treated to produce liquid fuels, flammable gas and chars. Reduction in volume and utilization of the liquid and gas as fuel are the major benefits of the process. By heat integration, actually this process can become a self-sufficient system in terms of energy demand. In this study, the mixture of plastics i.e. polypropylene (PP) and polyethylene terephthalate (PET) is treated using pyrolysis method with catalysts in several operating temperatures. PET is problematic to be treated using pyrolysis due to wax-like byproduct in liquid which may cause pipe clogging but this problem can be solved by passing the fuel through Distillation bubble cap tray column chamber. The catalyst is the mixture of natural zeolite and bentonite which is able to handle PP and PET mixture feed to produce high grade liquid fuels in terms of calorific value and other fuel properties.

KEYWORDS: Municipal solid waste (MSW); Jet propulsion fuel; Catalytic Pyrolysis; Gas chromatography-mass spectrometry; Fossil fuel;

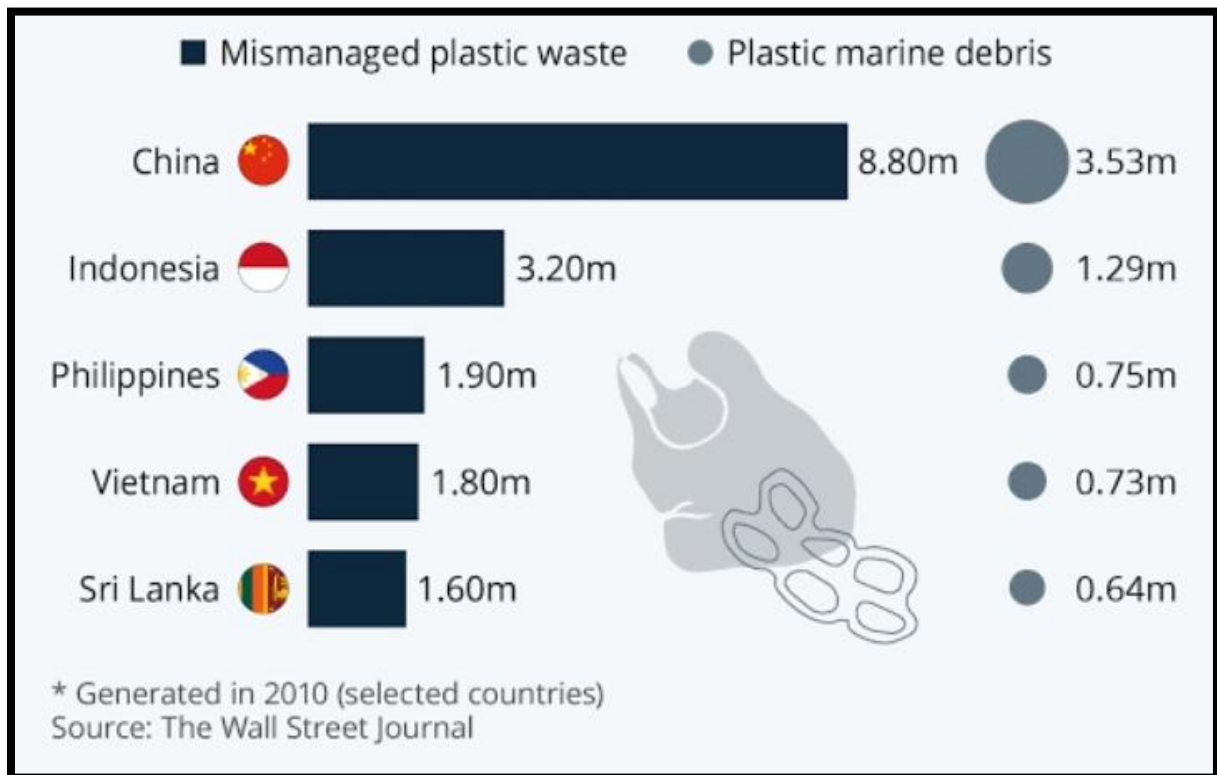
Polypropylene; Polyethylene Terephthalate; Distillation Bubble Cap Tray Column.

I. INTRODUCTION

Till date, the utilization of plastic materials in modern human life is increasingly widespread which cannot be avoided by any means, and as a result, there is a steady increment in the Global production of plastic materials annually from various Industries and households. Thus, this industry experiences progression and innovation

every now and then. Plastic materials have advantages such as its light weight, transparency, strong and cheap manufacturing processes. But used plastics will be discharged into an environment that ends up in the land or fills oceans (or any water body). Based on a data, Indonesia ranks second in the world as contributors of plastic wastes ending up in the sea which reached 187.2 million tons after China's 262.9 million tons. In the Fig. 1 given below, a brief idea is provided about the Global production of plastic trash.

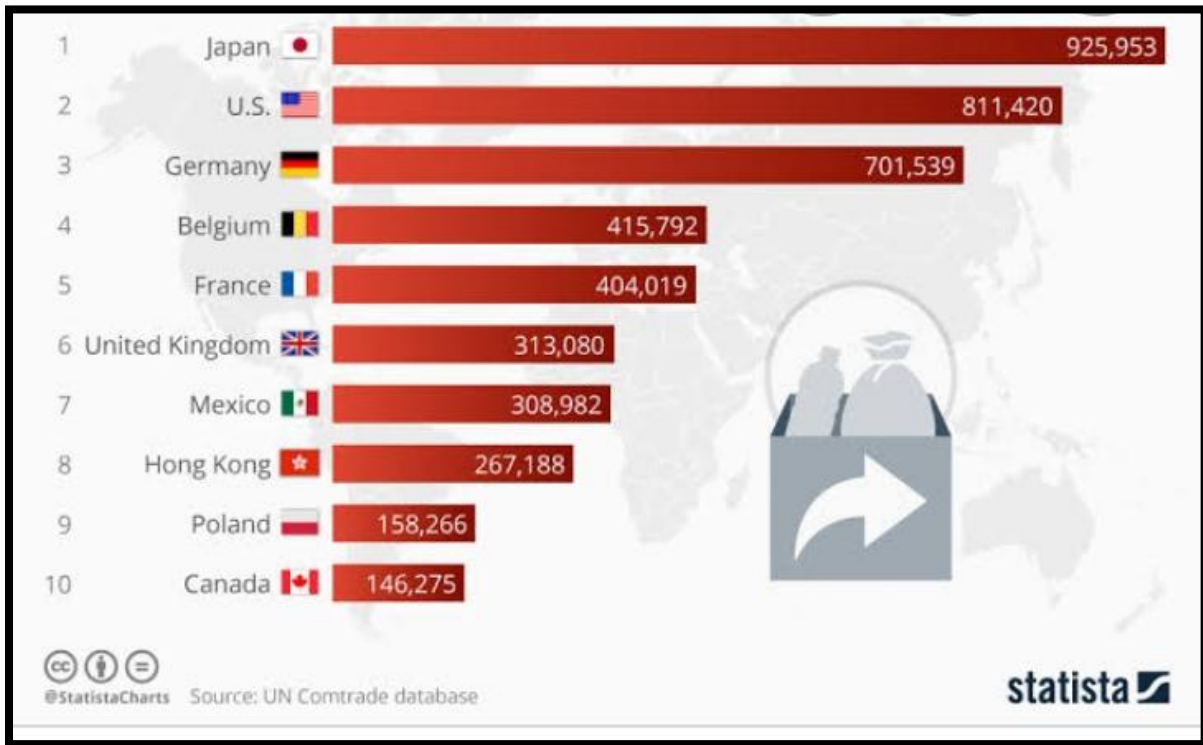
FIGURE 1: GLOBAL PLASTIC WASTE PRODUCTION BASED ON A 2010 SURVEY



At present, as per the latest survey done in 2018, the leading exporter of plastic waste and plastic scrap (in tonnes) is Japan, followed by The U.S., Germany, Belgium, France, United Kingdom etc. In 2016, the global plastic production was 335 million tons, the European production accounting for roughly 18% of the world's total production (Plastic Europe, 2017). From 2006 to 2016, the volume of collected plastic waste increased by +11%. Remarkably, recycling increased by +79%, energy recovery by +61%, while landfill decreased by -43% (Plastic Europe, 2017). In spite of the global awareness regarding recycling,

reusing, and reducing of the usage of plastic wastes, the metalized plastic waste (MPW) is largely being a challenge to most of the countries (Plastic Waste in the Environment, 2011). The MPW are largely unfit for effective recycling or reuse and therefore are not treated by waste treatment plants and being dumped in the landfills. The utilization of the MPW in construction activities may be a novel and effective way of safe disposal of waste plastics. The Fig. 2 provided below clearly depicts the amount of plastic waste and plastic scrap production on a Global basis:-

FIGURE 2: GLOBAL PLASTIC WASTE EXPORT BASED ON A 2018 SURVEY

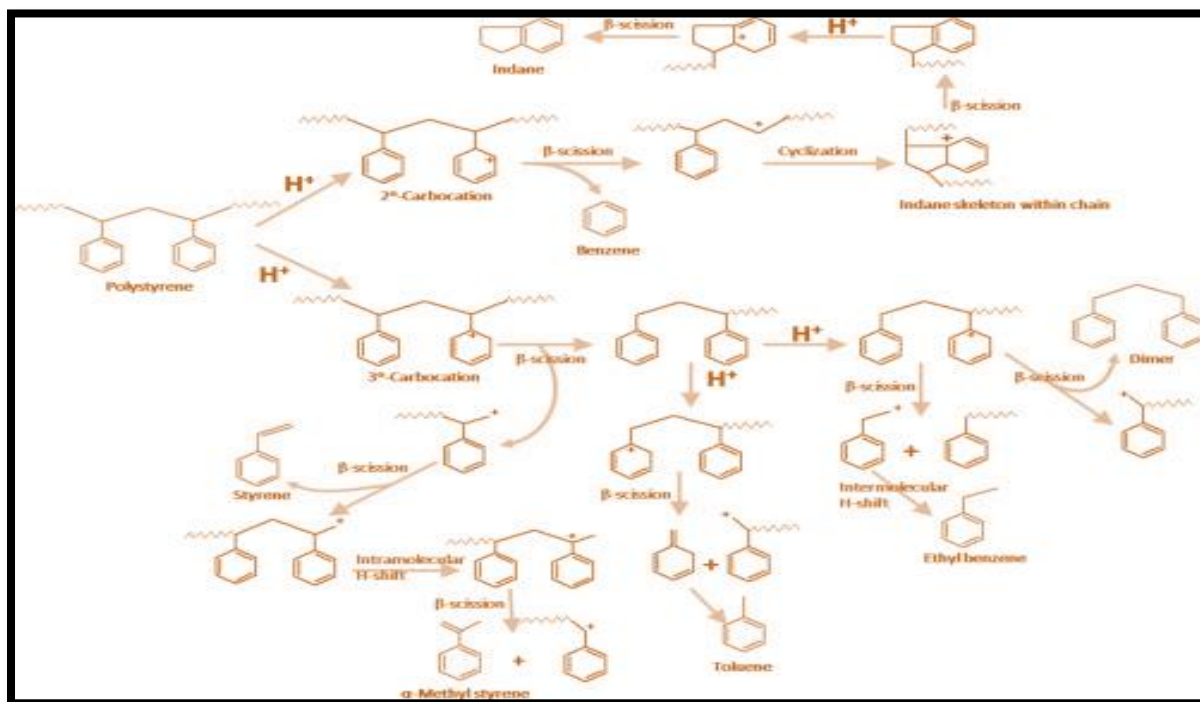


The process of plastic degradation in nature is divided into several categories i.e. Physical, Biological, and Chemical processes. The Physical degradation processes in nature occur through pressure, humidity and heat from the sun. Based on their chemical composition, plastics composed of hydrocarbon chain polymers derived from petroleum refining have the bonds between the hydrocarbon monomers so strong that they make the degradation process difficult at ambient temperature (32 °C). As a result, it is very difficult to be biologically degraded by enzymes and bacteria; therefore, it takes a very long time for the degradation process. Mechanical recycling is generally considered as the best option in plastic waste management, particularly if it produces high-quality products (pure and homogeneous secondary raw materials). This can favor virgin material substitution, thus reducing environmental impact and resource depletion.

Several alternatives have therefore been developed to conduct an efficient process of recycling plastic wastes, and such methods operate through physical and chemical processes. Physical methods are commonly referred to as “Three R”s i.e. Reduction, Reuse and Recycling. This method is inappropriate because plastic wastes return to the environment and finally ends up as plastic trash

causing pollution. In addition, it requires high labor costs for the separation process, thereby reducing the sustainability of the process. However, the chemical process through the Pyrolysis method is a more efficient and economical method of recycling, because it can restore the energy contained in plastic. Pyrolysis is a decomposition process of long-chain hydrocarbon (polymer) molecules into smaller sized molecules (monomer) with the use of high heat (400–800 °C) , in a shorter duration and in an oxygen-free environment, generating products in form of carbon, ash residues and volatile hydrocarbons which can be condensed as fuel and stored for future use. The other residues which cannot be condensed, are stored as gaseous fuel. The structure of this polymer is a weak bond chain and is damaged by increasing temperature, followed by the formation of the free radical propagation stage. These free radicals will then separate again to form smaller ones which produce more stable compounds. These smaller free radicals produce stable compounds in the form of paraffin compounds, isoparaffins, olefins, naphthenes and aromatics with the general reaction mechanism involving thermal degradation of plastics as explained by Liquid Pyrolysis of waste plastics. Fig. 3 provided below depicts the monomer products produced in the pyrolysis of Polystyrene.

FIGURE 3: PYROLYSIS OF POLYSTYRENE GIVING DIFFERENT MONOMER PRODUCTS



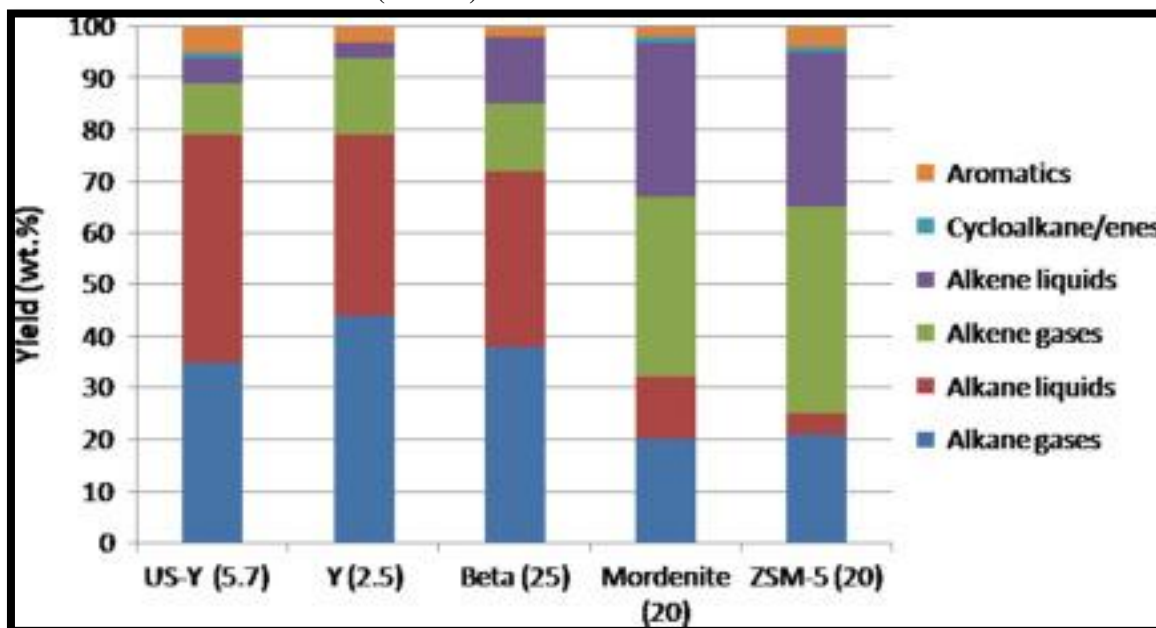
PS (polystyrene) products after catalytic pyrolysis show features similar to crude oil and its products and they also show the presence of ash and wax from raw materials, which reduces the quality, and thus results in the condensate analysis using Gas chromatography (GC-MS-FID) consisting of C7-C30 with a maximum peak in C9. An analysis of the derived gases and oils indicated that Pyrolysis gave mainly aliphatic composition consisting of a couple of hydrocarbons (alkanes and alkenes).

The catalysts used in the Pyrolysis of plastics definitely influence the products. The most commonly used catalysts for the pyrolysis of plastic wastes includes silica, alumina, zeolites (beta-zeolite, USY, Y-zeolite, ZSM-5, REY, clinoptilolite etc.) and MCM-41. With increasing number of acid sites, the level of the catalyst activity in polyolefin pyrolysis also increases. Thus, zeolite-based catalysts due to their high acid strength achieve higher conversion than non-zeolitic catalysts.

The liquid fuel obtained from the Pyrolysis process cannot be directly used as fuel, due to the presence of impurities (ash) and wax from the feedstock. Hence, the Pyrolysis product is again treated properly to reduce the ash and wax content in the fuel products. The purification of the Pyrolysis products was conducted using Distillation Bubble Cap Tray Column which reduces the ash and wax content in fuel products. Prior to this, we

also use Sulphur and HCl scrubbers to remove impurities from the fuel. Moreover, the Pyrolysis product has different boiling points depending on its different modes of application and different genres of experiments. This review therefore focuses on the effect of temperature on the Pyrolysis process whose results have been integrated with the bubble cap distillation column. This process is executed by utilizing the heat from the reactor to separate the liquid product in a vacuum condition in order to minimize the oxygen amount entering the reactor as much as possible. The obtained liquid product is analyzed to obtain its physical characteristics so that it becomes possible to determine the specific type of product and compare the obtained fuel oil with the fossil fuel. However, thermal processes can be used to convert plastics into hydrocarbon fuels such as gasoline, diesel, aviation / jet fuel, which have unlimited applications in airline industries, helicopter, heavy transportation, and electricity generation. This paper aims to give a solution by which it might be possible to obtain a comparatively cheaper Jet Propulsion Fuel and save the Environment from the clutches of pollution by using the pollutant Plastics only, in an effective way with a minimum cost being involved, for the betterment of the nature amidst the Energy Crisis. In the Fig. 4 given below, a representation of yield variation based on the use of different catalysts has been shown.

FIGURE 4: YIELD (WT. %) VARIATION WITH DIFFERENT CATALYSTS



II. AIM OF THIS PROPOSED PROCESS

Currently, if we look into the Jet Propulsion fuel composition and its cost, we can find out that it is a really expensive fuel that is required for the procedure. In general, the conversion of waste plastic into fuel requires feedstock which is non-hazardous and combustible. In particular, each type of waste plastic conversion method has its own suitable feedstock. So, with a view to reduce the cost and increase the efficiency of the process we have to find a steady solution. This project fully aims in introducing a newer type of Jet Propulsion Fuel which is on one hand, very much cost-efficient and on the other hand, beneficial for the betterment of the planet's environment. It is a completely eco-friendly process where plastic wastes and craps will be utilized as fuel for jets in an ostentatious way after their requisite pyrolysis treatments. By using plastic trash and reducing their quantity, we can reduce the amount of harmful gases produced due to burning of plastics. In this way, there will not be any further risks for the depletion of the Ozone layer forming Ozone holes. This process also lessens the Global Warming process and makes us optimistic about a promising future without any pollution. Another noteworthy point is the less cost involved in the process input as raw materials are readily available in plenty in the forms of plastic wastes, grocery store plastic bags, plastic utensils etc. The output is very good making the procedure possess a high efficiency value. Amidst a condition of Energy crisis, our proposed process may emerge as a permanent solution to this crisis.

Reusing trash (plastic) to produce cash (fuel) is the motto of this process. We will not have to do much capital investment for the jet fuels as re-usage of plastic will provide us with a much cheaper Jet Propulsion Fuel. The process involved here is catalytic pyrolysis, whereby we obtain certain valuable by-products which can be used conveniently in different zones of application. Moreover, the installation setup is really very simple and convenient for industries. Thus, the Installation setup for industries can be done at ease. This methodology may also emerge as a source of certain valuable chemicals which are hard to obtain otherwise. Once the easy installation setup is done, it'll require less man power for the procedure and this will reduce the input expenses. A brief idea of this installation setup can be obtained from the schematic provided below at Figure-6. Once this setup is aptly made, the rest of the job will become quite easier. So, if we take into consideration all the above aspects, we can find out that the proposed process has a bright future and it may establish itself as a strong solution for the current Energy Crisis situation.

III. MATERIALS DESCRIPTION

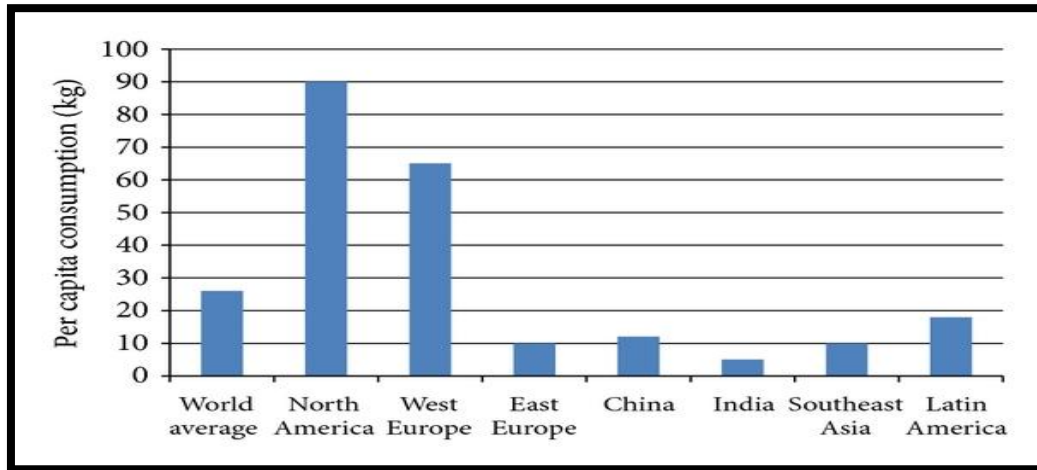
A. PLASTIC

Plastic is one such commodity that is being extensively used throughout the world and is sometimes referred to as one of the greatest innovations of the millennium. There are a numerous ways in which plastic is and will continue to be used. Different types of plastic materials have

achieved such an extensive market due to fact that they are lightweight, cheap, flexible, reusable, do not rust or rot, and so forth. Because of this, plastic production has gone up by almost 10% every year on a global basis since 1950. Asia accounts for 36.5% of the global consumption of plastic and has

been world’s largest plastics consumer for several years. The major segment of plastic use continues to be the ‘packaging’ segment, accounting for over 35% of the global demand. The global per capita consumption of plastics is shown below in Fig. 5:-

FIGURE 5: GLOBAL PER CAPITA CONSUMPTION OF PLASTICS



The global production of plastics has seen an increase from around 1.3 million tonnes in 1950 to 245 million tonnes in 2006. In recent years, significant growth in the global consumption of plastic has been due to the introduction of plastics into newer application areas such as in automotive field, rail, transport, aerospace, medics and healthcare, electrical and electronics, telecommunication, building and infrastructure, furniture etc. This tremendous growth in the demand for plastic and its forecast for future use have certainly proved that there has been a quiet plastic revolution taking place in every sector. As far as the

individual plastic material is concerned, polyolefins account for 53% of the total consumption. The consumption (in %) of the individual plastic materials have been shown below in the Table. 1. It can be seen that three-fifth of the global consumption of plastic is in the form of polythene, polypropylene and polystyrene. The growth in the global polythene, polypropylene and polystyrene demand is estimated to be around 4.4% annually up to 2020. This is the reason behind the selection of polythene or polypropylene or polystyrene as the source of raw material (waste plastic) input in this study.

TABLE 1: GLOBAL CONSUMPTION OF INDIVIDUAL PLASTICS

Type of plastic	Consumption %
Polythene (PE)	33.5
Polypropylene (PP)	19.5
Polyvinylchloride (PVC)	16.5
Polystyrene (PS)	8.5
Polyethylene terephthalate (PET) and polyurethane (PU)	5.5
Styrene copolymers (ABS, SAN, etc.)	3.5
Blends, alloys, high performance and specialty plastics, thermosetting plastics, and so forth	13

The increase in the rate of plastic consumption throughout the world has led to the creation of more and more amounts of waste, and this in turn poses greater difficulties for disposal of the wastes. This is because the life duration of plastic (the time period for which the plastic remains

in use) is very small. About 40% of plastics consumed have duration of life smaller than one month. The service life of plastic products ranges from 1 to 35 years depending on the area of application. In India, the weighted average service life of all plastics products comes to about 8 years.

This may vary with different countries depending on the type of consumption. This short service life in India reflects that a major share of the plastics consumed here are in the form of short-life products. This can be accounted for as the share of plastics used in packaging which is almost about 42%. The conversion methods of waste plastics into fuel depend on the types of plastics to be targeted and the properties of other wastes that might be used in the process. Additionally the effective conversion requires technologies to be selected according to local economic, environmental, social and technical characteristics. In general, the conversion of waste plastic into fuel requires non-hazardous and combustible feedstock. In particular, each type of waste plastic conversion method has its own suitable feedstock. The composition of the plastics used as feedstock may be very different and some plastic articles might contain undesirable substances (e.g. additives such as flame-retardants containing bromine and antimony compounds or plastics containing nitrogen, halogens, sulfur or any other hazardous substances) which pose potential risks to humans and to the environment. Hence, the types of plastics and their composition will condition the conversion process and will determine the pretreatments required, the combustion temperature

for the conversion and therefore the energy consumption required, the fuel quality output, the fuel gas composition (e.g. formation of hazardous fuel gases such as NO_x and H₂O), the fly ash and bottom ash composition, and the potential of chemical corrosion of the equipment.

Major factors to be considered during selection are as follows:-

- Smooth feeding for equipment
- Effective conversion
- Well-controlled combustion

As shown in Table. 2, PE (polyethylene), PP (polypropylene) and PS (polystyrene) thermoplastics are preferable as feedstock in the production of liquid hydrocarbons. The pyrolysis products are directly related to the chemical composition and chemical structure of the plastics to be pyrolyzed. The addition of thermosetting plastics, wood, and paper to the feedstock leads to the formation of carbonaceous substances and lowers the rate and yield of liquid products. The municipal plastic waste comprises of 80% thermoplastics and 20% thermosetting plastic. Since thermoplastics are can be further processed, basic types of thermoplastics can be used. Simple and common thermoplastics are polyethylene and polypropylene.

TABLE 2: PRODUCT TYPES OF SOME PLASTICS' PYROLYSIS

Main products	Type of plastics	Feedstock of liquid fuel
Liquid hydrocarbons	Polyethylene (PE)	Allowed
	Polypropylene (PP)	Allowed
	Polystyrene (PS)	Allowed
	Polymethyl metacrylate (PMMA)	Allowed
Liquid hydrocarbons	Acrylonitrile-Butadiene Styrene copolymer (ABS)	Allowed. But not suitable Nitrogen-containing fuel is obtained. Special attention required to cyanide in oil
No hydrocarbons suitable for fuel	Polyvinyl alcohol (PVA)	Not suitable, formation of water and alcohol.
	Polyoxymethylene (POM)	Not suitable. Formation of formaldehyde.
Solid products	Polyethylene terephthalate (PET)	Not suitable. Formation of

		terephthalic acid and benzoic acid.
Carbonous products	Polyurethane (PUR)	Not suitable.
	Phenol resin (PF)	Not suitable.
Hydrogen chloride and carbonous products	Polyvinyl chloride (PVC)	Not allowed
	Polyvinylidene chloride (PVDC)	Not allowed

For our study, we have taken Polypropylene as the raw material for the following reasons and factors.

- One of major factor to consider PP over PE is the carbon footprint as shown in the Table 3.

TABLE 3: COMPARISON OF CARBON FOOTPRINT

Kg of CO ₂ eq/Tonne	Material production	Forming	Transport	Disposal	Total Carbon Footprint
PP	1975	1250	38	193	3456
PET	2985	1250	38	250	4523
HDPE	1935	1250	38	157	3380
PVC	1915	1250	38	250	3453
PS	3415	1250	38	158	4861
PC	7776	1250	38	193	9257

- PP is abundantly used in plastic bags, plastic bottles etc. and so the raw material is easy to get.
- PP is less crystalline than PE.
- PP fuel has more calorific value as compared to the other fuels.

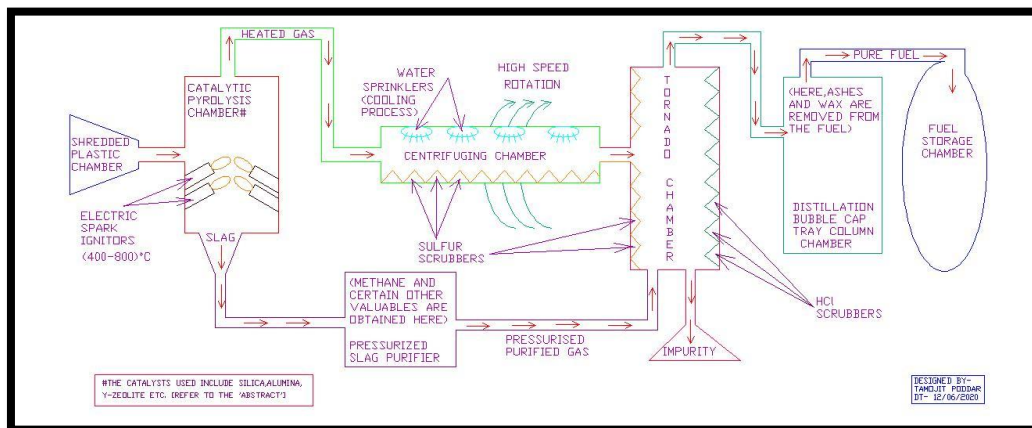
As a result, we preferred Polypropylene (PP) over Polyethylene (PE) and other polymers.

B. PYROLYSIS REACTOR

The raw materials that are utilized in this research were derived from Polypropylene (PP) type plastic Density (ρ) = 1.30–1.58 g/cc;

Crystalline melting temperature (TM) = 168–175 °C such as waste plastic bottles gathered from the surroundings. Firstly, the collected plastic wastes and scraps were washed and cleaned properly, after which they were then cut into smaller pieces, with sizes of 1.5×3.5 cm using enumerator machines, to significantly reduce the volume of the sample chamber in the reactor. Those plastics are then stored into the Shredded Plastic chamber. The Fig. 6 below shows the Integrated Pyrolysis Reactor setup.

FIGURE 6: SCHEMATIC OF INTEGRATED PYROLYSIS REACTOR



The parts of the integrated Pyrolysis reactor are described below:-

1. *Shredded Plastic Chamber*

In this chamber, the input shredded plastic is collected which is washed and shaped prior to this. So this chamber basically serves as the raw material input chamber.

2. *Catalytic Pyrolysis Chamber*

This is one of the most important chambers because in this chamber only, the input shredded plastic is heated in an anaerobic environment with the help of electric spark ignitors which can generate a temperature of (400-800) °C required for the reaction process to take place. The reaction in this chamber occurs in the presence of several suitable catalysts like silica, alumina, beta-zeolite, USY, Y-zeolite, ZSM-5, REY, clinoptilolite etc. These catalysts influence the process and thereby help in reducing the reaction temperature than the temperature that is required for the reaction procedure without catalysts. The number of electric spark ignitors can be chosen as per convenience and the reaction demand. Here, the shredded plastics get converted to heated gas with the slag being removed from the chamber. The heated gas gets passed onto the Centrifuging chamber for further processing whereas the slag enters a pressurized slag purifying chamber. In this pressurized slag purifier, the slag is freed from the unnecessary components and many valuables like methane etc. are obtained in highly pressurized condition.

3. *Centrifuging chamber*

This is another very important chamber where a lot of operations take place.

A) **Centrifugal action:** This chamber rotates at a fairly high speed that causes the particles of dirt and dust present in the heated gas to be shifted to the periphery and get eliminated. The centrifugal motion is thus utilized to primarily purify the heated gas.

B) **Water sprinkling:** There are a convenient number of water sprinklers present in this chamber for the cooling process of the incoming heated gas. They continuously sprinkle a drizzling shower of water droplets at the heated gas to cool it to some extent.

C) **Sulfur scrubbers:** Along with the above two, a number of sulfur scrubbers are provided with at the chamber to scrub off the sulfur present in the heated gas. Sulfur acts as a major impurity and its content should be reduced as much as possible.

All these three operations are clubbed together in a single chamber for increased efficiency and space reduction as much as possible. However, with

higher space provision, the steps can be executed in individual chambers also. After these, the cooled, primarily purified gas is sent to the Tornado Chamber.

4) **Tornado Chamber:** In this chamber also, a number of operations are carried out. They are elaborately discussed and listed below:-

A) **Entry of the pressurized, purified gas from the slag purifier:** The purified, pressurized gas is made to re-enter the Tornado chamber. Here, valuable organic products like methane etc. having high commercial values are added with the cooled fuel gas enriching its content and increasing its value. Moreover the pressure of the gas is released here which also adds up to the tornado action of removing the remaining dirt and dust present.

B) **Tornado Action:** In this chamber, an action analogous to the tornado action is generated whereby due very high centrifugal action, the impurities are eliminated from the gas after they get removed via the peripheral regions. The tornado action causes the particles of dirt to shift from the gas core to the periphery walls from where they can be easily removed. This action is basically comparable with the centrifugal action in the centrifuging chamber but this one is of a greater extent. The tornado action involves more high speed rotation, greater jerk and shaking and is thus very much efficient in removing the impurities.

C) **Sulfur scrubbers:** Sulfur scrubbers are present in this chamber as in the previous one and they help to remove the remaining amount of sulfur present (if any) from the gas.

D) **HCl scrubbers:** In this chamber, HCl scrubbers are also provided with because HCl also acts as a major impurity in the process and needs to be removed effectively. These scrubbers are effectively provided to react and remove the HCl contained by the gas. Their action is analogous to the sulfur scrubbers, basic difference being sulfur scrubbers remove sulfur whereas HCl scrubbers remove HCl.

The purified gas is then passed onto the next chamber for further treatment of the to-be fuel gas.

5) **Distillation Bubble Cap Tray Column Chamber:** The product from the Tornado Chamber is sent here to purify the fuel for the last and final time before it's made ready for use. Even after scrubbing off sulfur and HCl and removing the dust and dirt by centrifuging and tornado actions, traces of impurities are still present inside the fuel gas in the form of ashes and wax. If present, the wax and ashes may clog the pipeline. This bubble cap tray column distillation process completely removes the ashes and the wax content of the fuel. Hence, the

purified fuel is now ready to use and is collected and stored in the storage chamber.

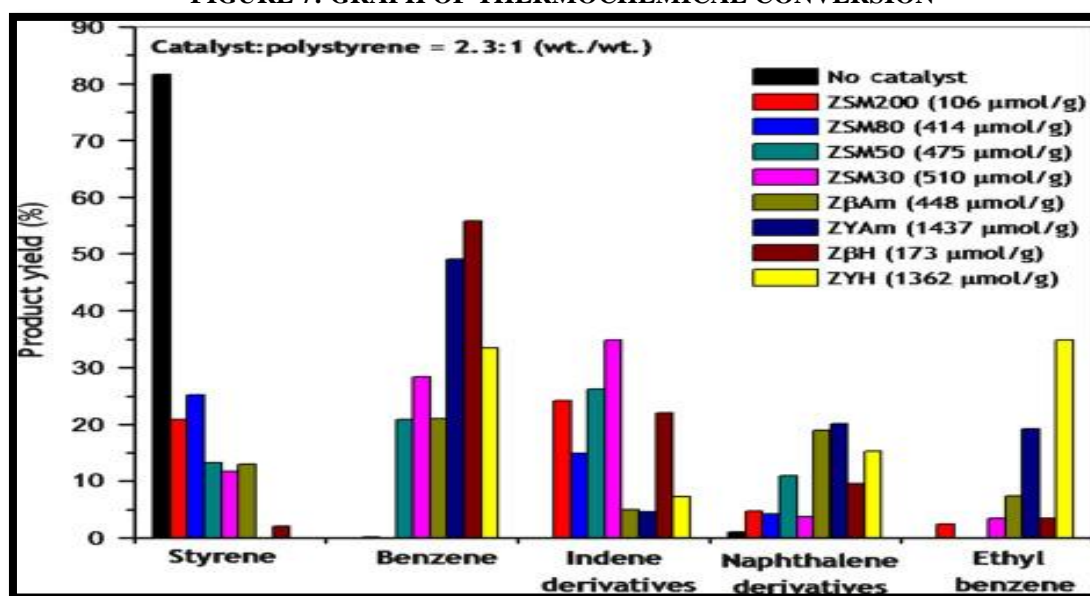
6) **Fuel Storage Chamber:** The ready-to-use purified fuel gas is stored in this chamber. The basic action of this chamber is the collection and storage of the fuel gas prior to its usage. This fuel gas can be utilized in a lot of application areas like generators, turbines, vehicles, planes, jets etc. Although, the zone of concern of this project is mainly the Jet Propulsion System.

IV. ADVANTAGES OF USING PLASTIC TO FUEL CONVERSION TECHNOLOGY

There are a lot of points to add to the merit list of the conversion process of plastic wastes to fuel. Firstly, this process basically yields cash (fuel) from trash (plastic craps) whereby pollutants like plastic wastes are utilized to produce fuel which brings about cash. Secondly, this is a process that helps everyone including the Businessmen, consumers and the Government in their own ways. The businessmen are benefitted from the point of view that with a much lower establishment cost of the integral pyrolysis setup they can obtain a much valuable output in the form of fuel. The cost of raw material is almost negligible as waste and trash plastics are readily available in plenty. The consumers are helped from the point of view that with a low establishment cost the fuel product

becomes much cheaper and affordable. The Government is benefitted from the point of view that a lot plastic trash and waste plastic products get eradicated in the process. This reduces environmental pollution, Global Warming and helps in maintaining a proper ecological balance. So directly or indirectly, with the welfare of the common mass, the Government gets benefitted. By this process, we basically add values to the waste materials and can thereby decrease the littering and burying of these non-biodegradable pollutants. In the process, ample amount of plastic wastes are consumed. By the above mentioned integral catalytic pyrolysis, plastics of lower scale (e.g.-grocery polythene etc) can also be recycled. This is an anaerobic process and hence does not involve combustion, so it's an eco-friendly process. The valuable product that is obtained can be used as crude oil for home, fuel for car, bus, ships, plane, jets etc. Just for a fact, tapping this potential, the US could support up to 600 plastic-to-fuel facilities and generate nearly 39,000 jobs, resulting nearly 9 billion \$ economic output from plastic to fuel operations. This process doesn't require huge machines for the conversion process. The size of the storage chamber can be also chosen as per convenience. Hence, the entire setup is space efficient. Finally, this process delivers a cleaner Burning Fuel which brings about environmental benefit.

FIGURE 7: GRAPH OF THERMOCHEMICAL CONVERSION

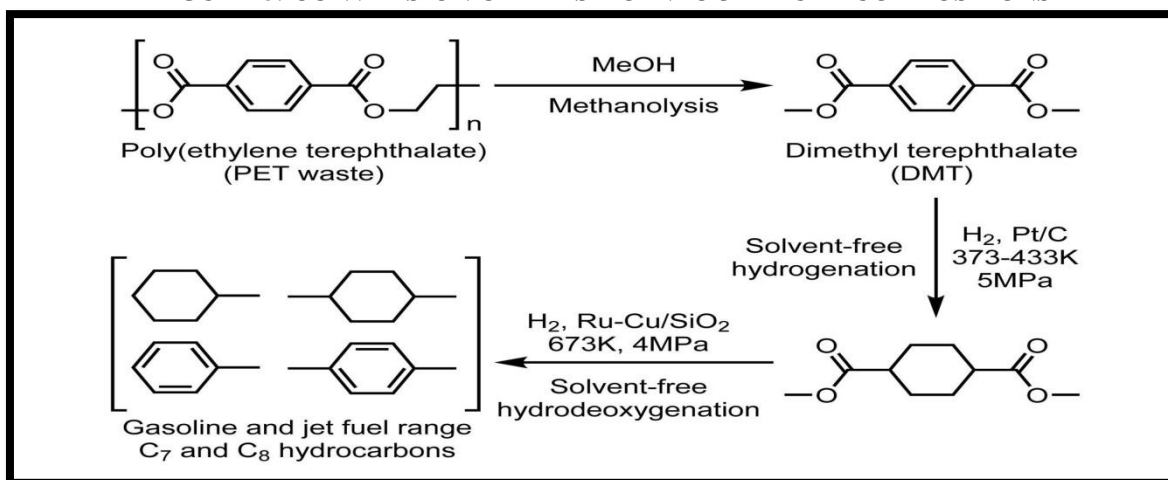


V. A BRIEF DISCUSSION ABOUT JET PROPELLANTS

Plastic is hard to break down and thus becomes the reason of pollution but if we add a catalyst to help break the chemical bonds, then there is a lot of hydrogen in plastics, which is a key component in fuel. Alkanes and Aromatics rich liquid products could be selectively achieved. The fuel is of high-grade quality and the gases produced as byproducts in the process are of high-quality and useful, too. The carbon can be easily separated and regenerated for the next batch of plastic waste. The Pyrolysis process can be scaled easily for large output production and can be even adapted for local diesel production using typical plastic waste. We

observed that the aromatic hydrocarbons and aliphatic olefins as the precursors of jet fuels could be converted into jet fuel ranged aliphatic alkanes and cycloalkanes. The hydro-treated organics from the experiment conducted at the reaction temperature of 250 °C for 2 h included 31.23% selectivity towards aliphatic alkanes, 53.06% selectivity towards cycloalkanes, and 15% selectivity towards remaining aromatic hydrocarbons, which were consistent with the specifications of JP-5 navy fuel. In this regard, the catalytic microwave degradation of plastics and the hydro-treatment of obtained liquid organics can be regarded as a clear breakthrough to producing alternative jet fuels.

FIGURE 8: CONVERSION OF PLASTIC INTO JET FUEL COMPOSITIONS



PRESENT DAY ROCKET FUEL COMPOSITION:

- I) Hydrazine
- II) Unsymmetrical Dimethyl Hydrazine
- III) Monomethyl hydrazine
- IV) Hydrogen peroxide
- V) Cryogenic propellants like liquid hydrogen (-253°C) and liquid Oxygen (-183°C)

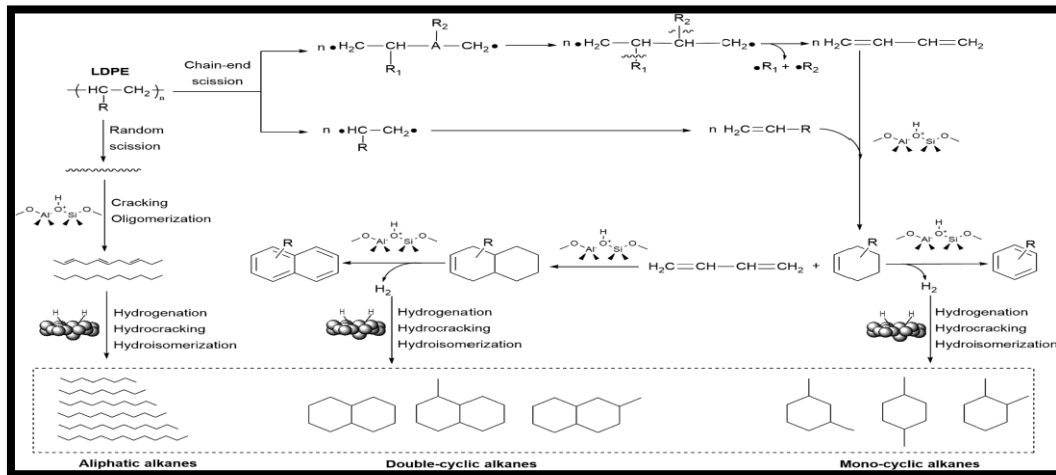
PROPERTIES OF THE PROPELLANTS TO LOOK INTO

- 1) High value of specific impulse
- 2) High combustion value
- 3) Density of the propellant (fuel should be as light as possible)

MOST RECENTLY, TWO GENERAL SOLID PROPELLANTS ARE THAT IN USE:

- 1) Double base propellant (nitrocellulose + nitroglycerin + additives)
- 2) Composite (fuel+ oxidized chemicals)

FIGURE 9: HIGH DENSITY JET FUEL PRODUCTION FLOW DIAGRAM



Here, we must try to use certain “Hypergolic” propellants as they ignite spontaneously upon contact with fuel and oxidizer (additionally, don’t require any “igniters” to start burning of the propellant).

TABLE 4: IMPULSE TIME VALUES OF DIFFERENT THERMOPLASTIC POLYMERS

NAME OF THE THERMOPLASTIC	IMPULSE TIME VALUE (in sec)
1. Thiokol or Asphalt (NH ₄ NO ₃)	170-210
2. Rubber	170-210
3. Polyurethane	210-250
4. Nitropolymer	210-250
5. Polyester	170-210
6. Thiokol or Asphalt (Potassium Perchlorate)	170-210

Another important thing to keep in mind is, “Greater the Impulse value, better the propellant material”.

TABLE 5: PYROLYSIS TECHNOLOGY CONDITIONS & PRODUCTS

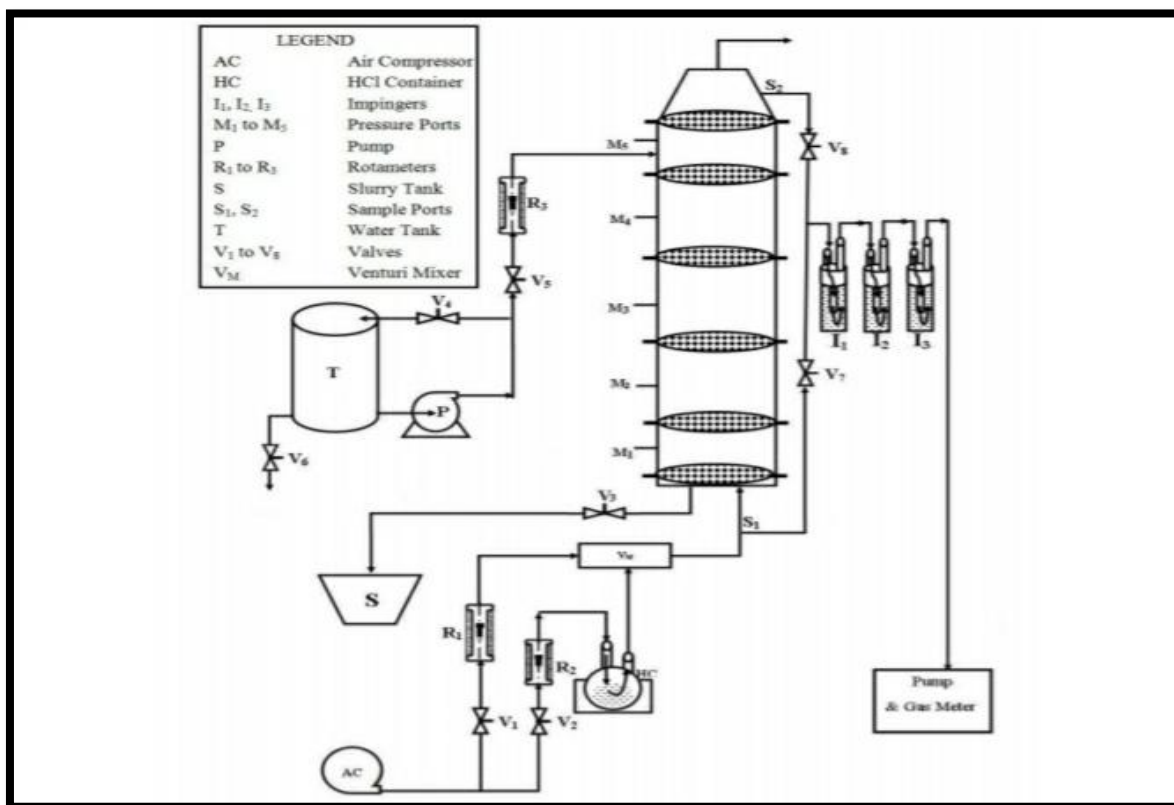
Pyrolysis Technology	Residence Time	Heating Rate	Temperature (Degree Celsius)	Major Product
Carbonisation	Hours-days	Very low	300 - 500	Charcoal
Pressure Carbonisation	15 min-2 hours	Medium	450	Charcoal
Conventional Pyrolysis	hours	Low	400 – 600	Char, oil, syngas
	5-30 minutes	Medium	700 – 900	Char, syngas
Vacuum Pyrolysis	2-30 seconds	Medium	350 – 450	Oil
Flash Pyrolysis	0.1-2 seconds	High	400 – 650	Oil
	< 1 second	High	650 – 900	Oil
	< 1 second	Very high	1000 - 3000	Syngas

VI. NOVELTY OF OUR PROPOSED METHOD

1) **HCl & Sulfur Scrubbers:** Our proposed idea has the unique HCl scrubbers that make a very eco-friendly process as well as Sulfur scrubbers to reduce pollution. This system consists of a three stage dual-flow sieve- plate column made up of a transparent, vertical Perspex glass with 2.6 m length and 0.1524 m internal diameter and fitted with an outlet at top in fructo-conical shape. The air

contaminated with HCl, enters through the inlet of the column. The inlet is fitted with a diffuser on the inner side of the column to facilitate the flow of the gas in a uniform manner throughout the column. The plates and the diffuser consist of 396 holes of 3 × 10⁻³ m size. The experimental air for the operation is supplied by an air compressor which was prepared by sucking the ambient air. The outlet of the air compressor is fitted to an air rotameter of range 0-27.65 × 10⁻⁴ Nm³/s.

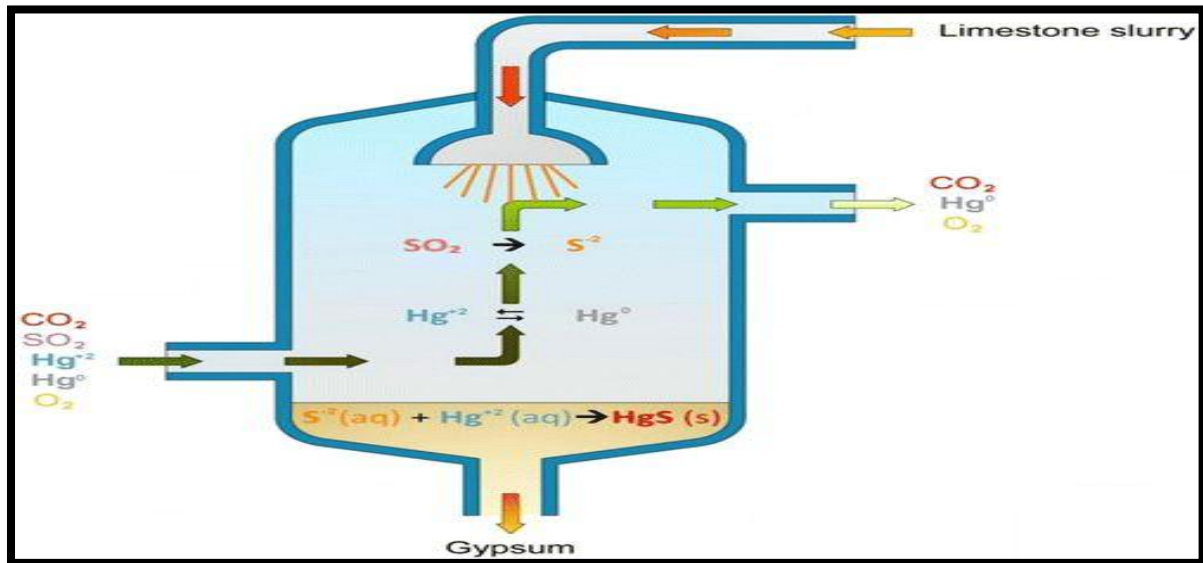
FIGURE 10: HCl SCRUBBER SCHEMATIC DIGARAM



The outlet of the rotameter is connected to the inlet of the column through a venturi-mixer. Liquid HCl of known concentration is placed in a 2-neck round bottom flask of one liter capacity. Part of the experimental air was entered into the flask from one end and bubbled into the concentrated liquid HCl to form the HCl vapours. The generated HCl vapours were then allowed to escape through the other end to enter into the venturi mixer where they were mixed with the other part of the experimental air and enter to the column at desired concentrations. The basic principle of a sulfur dioxide scrubber system is the removal of SO_2 by using its chemical characteristics to combine with water. In some cases, parallel rotating rods create a series of short throat Venturi openings. A series of low pressure, large orifice spray nozzles direct the scrubbing solution into the system. "Scrubbing liquor" is introduced into the system with the flue gas stream. Depending on the design of the scrubber, the gas can flow either concurrent (with) or counter-current (against) the scrubbing liquor. The high velocity

turbulence caused by the Venturi openings ensures maximum gas to liquid contact. It is here that the droplets absorb the SO_2 as well as impacting and dropping particulates out of the stream. The scrubbed gas is then sent through a demister or re-heater to prevent condensation and exhausted to atmosphere. The scrubbing liquor can be bubbled through a slurry or either lime $[\text{Ca}(\text{OH})_2]$, or limestone $[\text{CaCO}_3]$ and water. Either lime or limestone will combine with the sulfite ions from the flue gas to form gypsum, CaSO_4 . The SO_2 that is captured in a scrubber combines with the lime or limestone to form a number of byproducts. A primary byproduct is calcium sulfate, commonly known as gypsum. Spent scrubbing liquids are sent to clarifier where the insoluble gypsum is removed and the water is returned to the scrubber system. The addition of lime or limestone to scrubbing solution is controlled by monitoring the pH of the solution. Lime slurries are generally alkaline with a control point near a pH of 12 while limestone slurries are more neutral.

FIGURE 11: SULFUR SCRUBBER SCHEMATIC DESIGN



2) **Low consumption of Energy for**

Pyrolysis: By the advanced technology, our proposed idea can pass the plastic through a high pressure zone so that the fuel burning temperature can be decreased and efficiency increased (since, boiling point decreases with increasing pressure). Actually the process is a thermal degradation of plastic polymer that will be carried out in a stirred tank reactor by continuous flow operation under elevated pressures ranging from 0.1 to 0.8 MPa, in order to investigate the effect of reaction pressure on thermal degradation behavior of polymers. Rate of volatilization, rate of double bond formation and the distribution of degradation products were studied at various temperatures and pressures under a steady state. The interesting result is the reaction pressure had a significant effect on both rates and the distribution of degradation products during thermal degradation of polyethylene. Since there exists a one to one correspondence between the double bond formation and the scission of C-C links in polymers, it can be concluded that the reaction pressure takes part directly in the scission of C-C links during thermal degradation of polymers. With the higher pressure, the carbon number distribution of gaseous and liquid products, and the molecular weight distribution of reactor contents get shifted to the lower molecular weight side. Thermal degradation by continuous flow operation is a suitable technique for converting waste plastics into liquid hydrocarbons, which could be used as feedstock materials. The elevation of pressure during thermal degradation provides a potential alternative to control the distribution of products.

3) **Uses of the produced pyrolysis**

materials: The products from the catalytic pyrolysis of plastic are mainly combustible gases and liquids. The liquids can be either combusted for power generation or for further refining to produce high quality fuels. Diesel range products can then be distilled out as in an oil refinery process. The non-condensable gases are mainly made of hydrocarbons, and a minor amount of hydrogen and carbon monoxide. The gases can be liquefied as fuels, or used as fuels to heat the pyrolysis reactor, or if the amount is insignificant, the non-condensable gases are sent to an incinerator flaring off with the air. The pyrolysis oil's application field includes small or large scale combustion in natural gas, coal or heating oil fired boilers, furnaces, turbines, automobiles and Jet/Aviation propulsion fuel. Some of these systems are usually found in power plants where electricity, heat and steam are produced. Boilers, furnaces and turbines are also found at large industrial companies to supply their demands for electricity, heat and steam. In Jet propulsion system, this oil can be used as a fuel in an eco-friendly manner so as to achieve a more effective and cost efficient output result.

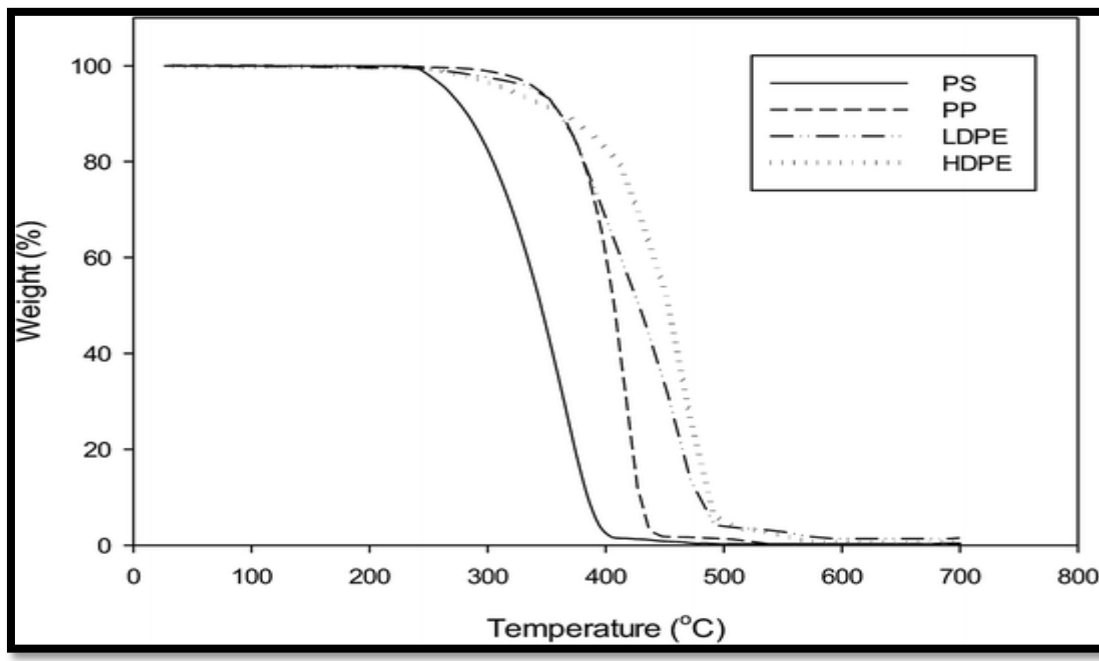
4) **Raw materials and Catalyst**

characterization: The TG curves of each plastic waste demonstrated a similar behavior; but at different thermal decomposition temperatures, as shown in Fig.12, the polycyclic structure of PS degraded between 250–480 °C, while those of plastics possessing a polyolefin structure (PP and

PE) degraded at higher temperatures of 280–520 °C and 280–580 °C, respectively. These results are in agreement with previous studies in the literature. PS was also reported to decompose at

lower temperatures than PP, LDPE and HDPE. This mean that the pyrolysis temperature of 500 °C used in this study was suitable.

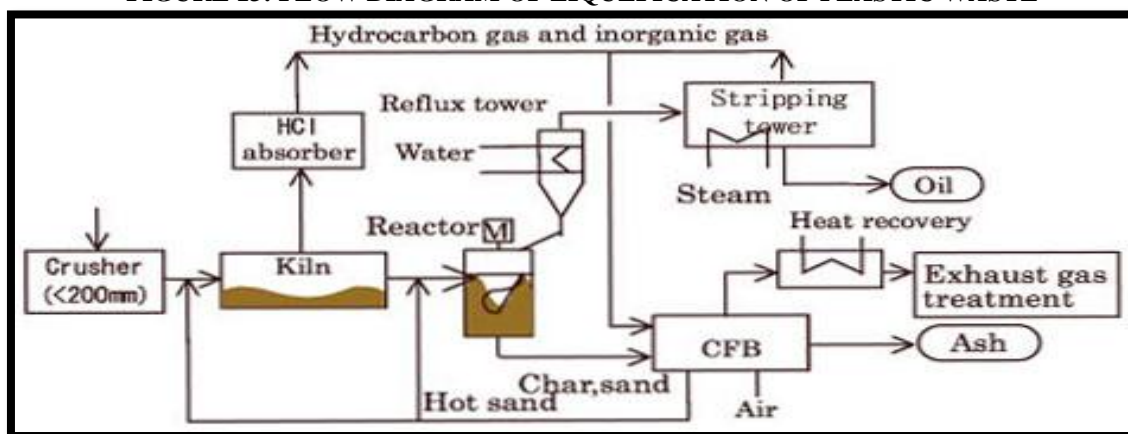
FIGURE 12: TGA CURVES OF WASTE PLASTICS HEATED UNDER NITROGEN AT 10 °C MIN⁻¹



5) **Liquefaction of Plastic Waste:** The method of converting the polymers present in the waste plastics into liquid chemical products that can be used for various activities has shown

dramatic potential results in the previous experiments conducted. This has been reported in an experiment conducted by James A. Guin and H. S. Joo.

FIGURE 13: FLOW DIAGRAM OF LIQUEFICATION OF PLASTIC WASTE



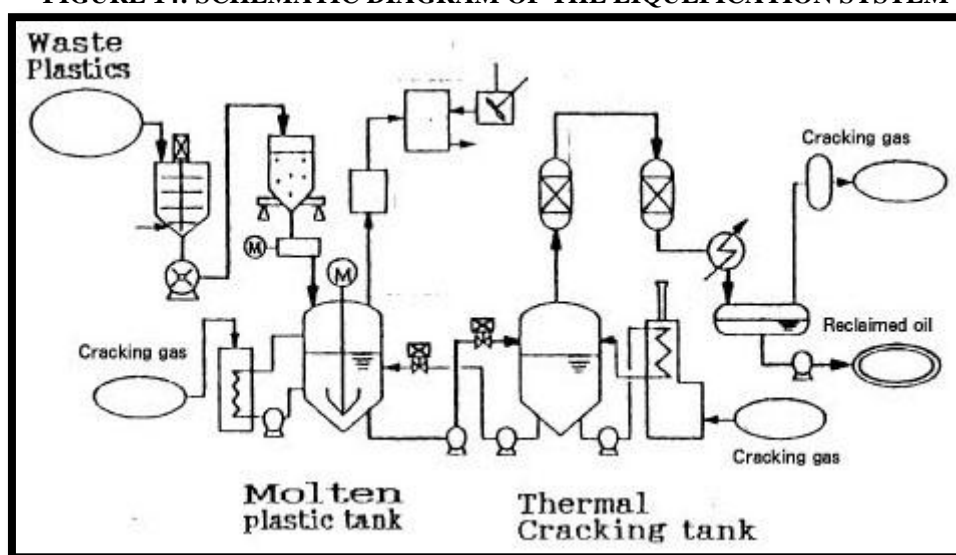
They obtained chemical product naphtha from waste polymer liquid through pyrolysis. Not only naphtha, but also reports of converting waste polymers into fuel has been reported using methods such as thermal cracking, flow cracking, catalytic cracking, and catalytic pyrolysis. In thermal

degradation process, waste polymers are heated at a temperature range of 370 - 420°C to de-polymerize the polymers of plastics back to liquid form. The conversion process yields 80 - 90% liquid, 5% light gas and 5% residue materials. The thermal de-polymerization is carried out in a fractional

distillation process, where other liquid grade fuels are also obtained based on temperature profiles used. The naphtha liquid is obtained when the temperature reaches 110°C. The general term for thermal degradation is applying heat in order to breakdown long hydrocarbon chains to form shorter ones thus producing a new substance. In order to produce and obtain different categories of liquid products, the thermal degradation process is upgraded to fractional distillation process. Fractional distillation process is basically thermal degradation except the fact that, heat applied is

divided into different groups based on specific temperatures. The long hydrocarbon chain lengths of plastics are broken down to form shorter hydrocarbon chain lengths of C3 - C27. Further, during fractional distillation, these chains are divided into different groups based on the type of liquid produced. The naphtha liquid's carbon chain is in the range of C6 - C14. Through this process, other commercial grade fuel substances are also produced. Moreover, the process is very efficient and it exerts traces of light gas, although this gas can be utilized as a heat source.

FIGURE 14: SCHEMATIC DIAGRAM OF THE LIQUEFICATION SYSTEM



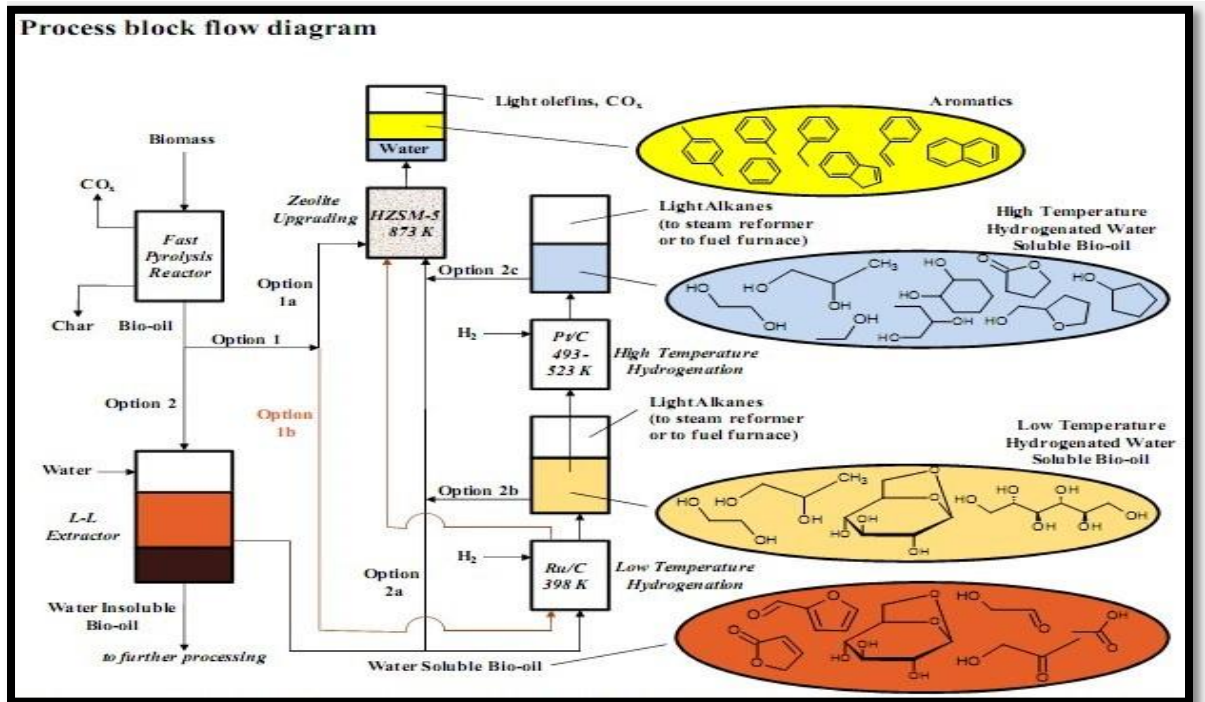
VII. SOME INNOVATIVE IDEAS TO BE IMPLEMENTED

- 1) There is the possibility to club together the Tornado Chamber with the Bubble Cap Tray Distillation Column Chamber to reduce space (if required). This will make the whole system volume decrease but in turn, increases the productivity and efficiency.
- 2) We can also reuse the ignited fuel as a compressor. We can especially use it as the gas compressor as it is one of the most energy-intensive production processes.
- 3) Nanocatalysis is one of the most important future aspect in pyrolysis of waste plastic. This process helps both from an environmental and an economic point of view, bringing out its huge potential contribution in a greener chemistry and

engineering manner. Nanoscale size of the catalysts consequently confers high surface area, enhancing the accessibility of the catalytically active sites to polymer substrate molecules, thereby increasing the TOF. This also supports catalyst use in smaller quantities. Thus the input cost is greatly reduced and affecting the process economy in a good way.

4) The impure fuel should be passed through pressurized hot air and shakers/centrifuging chambers to reduce the impurity content in the fuel gas to the highest extent. This system provides a roadmap for converting low value pyrolysis oils into products with a higher value than transportation fuels. Here is the process flow diagram in Fig.15.

FIGURE 15: PRODUCTION OF OLEFINS, DIOLS, AROMATIC HYDROCARBON AND GASOLINE RANGE ALCOHOLS FROM THIS INTEGRATED CATALYTIC PROCESSING OF PYROLYSIS OIL



VIII. PROPOSED ZONE OF APPLICATION (FIELD OF USE OF THE NEWER TYPE OF FUEL)

The Jet Propulsion procedure operates in basically 4 steps of jet propulsion procedure. The first step involves leaving the Earth's atmosphere i.e. during the initial launching process (PSLV or GSLV). The second step basically involves covering up the requisite distance after leaving the Earth's atmosphere and its gravitational field (This is our key step or the step of implementation). In this step, we can utilize the new fuel to activate the OMS i.e. Orbit Maneuvering Systems to provide the additional impulse for the requisite movements. The third step is all about the returning towards the Earth by activation of the reverse or the Retro-OMS. The fourth step i.e. the final lap constitutes of re-entering the Earth's atmosphere. These 4 steps generally make up an ideal Jet Propulsion procedure.

IX. CONSTRAINT OF APPLICATION TO BE CONSIDERED

Although this process has a plethora of advantages, but when we are concerned about Jet Propulsion in specific, we must apply this newer type of fuel in the second stage of the Jet Propulsion process just after leaving the Earth's

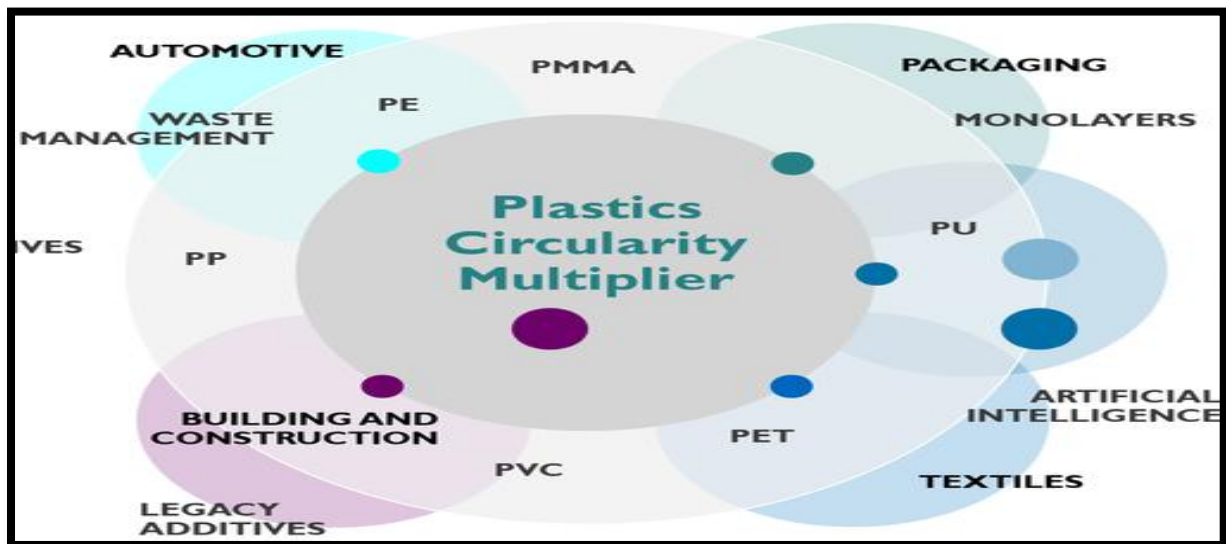
Atmosphere in the initial stage. Here, the system needs an additional impulse for proper orbit maneuvering and the proposed fuel type will actuate the process. We can also use the fuel in the third stage of the propulsion process but in that case there can be a possibility that traces of the burnt fuel may re-enter the Earth's atmosphere in the fourth stage and we must avoid this in order to promise a pollution free process. Hence, the second stage is the best zone of application. The main reason for this precautionary measure is because our main component of fuel is low sulfur and HCl containing 'Thermoplastic Gas' which can be toxic for Earth's Ozone layer creating ozone holes. So, in order to completely avoid this, we choose the 2nd stage as the apt one. So, the safest area of application is after leaving the Earth. In the 2nd stage, after completion of the Jet Propulsion process, the ejected impurities (mostly in gaseous state) get diffused in Space, "without harming the Earth by any means". So, in this way, the proposed Jet Propulsion procedure can become a major success as it surpasses all the constraints and can execute the purpose in an eco-friendly way without hampering the Earth's environment and reducing its pollution by utilizing plastic trash.

X. CONCLUSION

Pyrolysis of hydrocarbon polymers which are generated from waste plastics is a very complex process, which consists of hundreds of reactions and products. Several factors have significant effects on the reactions and the products. Therefore, in this new and modified pyrolysis process, when consumption of non-biodegradable polymeric materials has become formidable and their generated wastes too, together with the growing concern of depleting non-renewable

energy sources such as fossil fuels and rising demand of petroleum oil as well as natural gas, the improved technological approach towards pyrolysis for energy recovery from polymeric wastes appears unambiguously attractive along with being effective. In addition to the utilization of the contained energy and the raw materials in the polymeric wastes by conversion into valuable gas, tar and char, there is also efficient management of the environmental impacts. The Fig.16 below gives a depiction of the circularity of plastic wastes.

FIGURE 16: CIRCULARITY OF PLASTIC WASTE



REFERENCES

- [1]. A. K. Panda, R. K. Singh, and D. K. Mishra, "Thermolysis of waste plastics to liquid fuel: a suitable method for plastic waste management and manufacture of value added products: a world prospective," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 1, pp. 233–248, 2010. View at: [Publisher Site](#) | [Google Scholar](#)
- [2]. M. A. Uddin, K. Koizumi, K. Murata, and Y. Sakata, "Thermal and catalytic degradation of structurally different types of polyethylene into fuel oil," *Polymer Degradation and Stability*, vol. 56, no. 1, pp. 37–44, 1997. View at: [Google Scholar](#)
- [3]. H. Gulab, M. R. Jan, J. Shah, and G. Manos, "Plastic catalytic pyrolysis to fuels as tertiary polymer recycling method: effect of process conditions," *Journal of Environmental Science and Health*, vol. 45, no. 7, pp. 908–915, 2010. View at: [Publisher Site](#) | [Google Scholar](#)
- [4]. Anuar S., Shafferina D., Abnisa F., Wan Daud W.M.A., Aroua M.K.A **review on pyrolysis of plastic wastes** *Energy Convers. Manag.*, 115 (2016), pp. 308-326 , 10.1016/j.enconman. 2016.02.037 : Google Scholar
- [5]. Thahir, R., Altway, A. and Juliastuti, S.R., 2019. Production of liquid fuel from plastic waste using integrated pyrolysis method with refinery distillation bubble cap plate column. *Energy Reports*, 5, pp.70-77.
- [6]. Abd Rahman, N.A., Feroso, J. and Sanna, A., 2020. Stability of Li-LSX Zeolite in the Catalytic Pyrolysis of Non-Treated and Acid Pre-Treated Isochrysis sp. Microalgae. *Energies*, 13(4), p.959.
- [7]. Cleetus, C., Thomas, S. and Varghese, S., 2013. Synthesis of petroleum-based fuel from waste plastics and performance analysis in a CI engine. *Journal of Energy*, 2013.
- [8]. Google Search (Rocket fuel composition)
- [9]. <https://history.nasa.gov/in>

- [10]. Williams, P.T., J. Scheirs and W. Kaminsky, Editors. 2006, John Wiley & Sons, Ltd: Leeds. Yield and composition of gases and oils/waxes from the feedstock recycling of waste plastic, in Feedstock Recycling and pyrolysis of waste plastics.
- [11]. Oluwafunmilayo A. Aworanti, Samuel E. Agarry, Ayobami O. Ajani. Advances in Chemical Engineering and Science, 2012 <http://dx.doi.org/10.4236/aces.2012.24054> Published Online October 2012 (<http://www.SciRP.org/journal/aces>)
- [12]. Plastics Recyclers Europe, How to boost plastics recycling and increase resource efficiency – Strategy Paper, 2012.
- [13]. Preliminary study on the conversion of different waste plastics into fuel oil, Munich, GRIN Verlag, <http://www.grin.com/en/ebook/206451/preliminary-study-on-the-conversion-of-different-waste-plastics-into-fuel>.
- [14]. CONVERTING WASTE PLASTICS INTO A RESOURCE (Compendium of Technologies) United Nations Environmental Programme Division of Technology, Industry and Economics International Environmental Technology Centre Osaka/Shiga, Japan.
- [15]. RECOUP, Recycling of Used Plastics webpage: <http://www.recoup.org/>
- [16]. Scrubbing of HCl Gas from Synthesis Gas in a Multistage Dual-Flow Sieve Plate Wet Scrubber by Alkaline Solution Swamy Kurella1, Mounika Ballal, Pavan Kishan Bhukya1 and Meikap BC1,2* 1 Department of Chemical Engineering, Indian Institute of Technology Kharagpur, India 2 Department of Chemical Engineering, School of Chemical Engineering, Howard College Campus, University of Kwazulu-Natal (UKZN), Durban, South Africa
- [17]. K. Murata, K. Sato, Y. Sakata, Effect of pressure on thermal degradation of polyethylene, Journal Analysis Application of Pyrolysis, 71: 569–589 (2004)
- [18]. Catalytic pyrolysis of plastic waste for the production of liquid fuels for engines- Supattra Budsareechai, Andrew J. Hunt and Yuvarat Ngernyen
- [19]. <https://newenergyandfuel.com/http://newenergyandfuel.com/2010/12/03/pyrolysis-oil-gets-more-practical-refining/>
- [20]. Plastics Europe-**An Analysis of European Plastics Production, Demand and Waste Data for 2011, Plastics - the Facts 2012** (2012)
- [21]. (2012)
- [22]. L.A. Utracki, International Abbreviations for Polymers and Polymer Processing, National Research Council Canada, Industrial Materials Institute, Boucherville, QC, Canada
- [23]. A. Demirbas-**Pyrolysis of municipal of plastic wastes for recovery of gasoline-range hydrocarbons** -J. Anal. Appl. Pyrolysis, 72 (2004), pp. 97-102
- [24]. M. Motevasel, B. Roozbehani, A. Shahi**Catalytic degradation of mixed polymers into environmental friendly and useful products** -Am. J. Oil Chem. Technol., 2 (2014), pp. 360-367
- [25]. M. Syamsiro, H. Saptoadi, T. Norsujianto, P. Noviasri, S. Cheng, Z. Alimuddin, and K. Yoshikawa, Fuel Oil Production from Municipal Plastic Wastes in Sequential Pyrolysis and Catalytic Reforming Reactors, Energy Procedia. 47, pp. 180-188, Jakarta: Elsevier (2014)
- [26]. R. Bagri, PT. Williams, Catalytic pyrolysis of polyethylene, Journal Analysis Application of Pyrolysis, 63: 29–41 (2001)
- [27]. S. Kumar, R.K. Singh**Recovery of hydrocarbon liquid from waste high density polyethylene by thermal pyrolysis**-Braz J Chem Eng, 28 (04) (2011), pp. 659-667
- [28]. Association of Plastic Manufacturers Europe, **Plastics – the Facts 2016An analysis of the European plastics production, demand and waste data**-European Association of Plastics Recycling and Recovery Organisations (2016), pp. 1-38
- [29]. **Experimental study of catalytic pyrolysis of polyethylene and polypropylene over USY zeolite and separation to gasoline and diesel-like fuels**-J. Anal. Appl. Pyrolysis, 127 (2017), pp. 31-37, [10.1016/j.jaap.2017.09.005](https://doi.org/10.1016/j.jaap.2017.09.005)
- [30]. Yuliansyah et al., 2015 - Yuliansyah T.A., Agus P., Ramadhan A.A. M., Laksono1 R.**Pyrolysis of plastic waste to produce pyrolytic oil as an alternative fuel**, Int. J. Technol., 7 (2015), pp. 1076-1083
- [31]. Moinuddin et al., 2012- Moinuddin S., Mamunor Mohammad, Rashid Mohammed M., Muhammad S.R **A new technology proposed to recycle waste plastics into hydrocarbon fuel in USA**, Int. J. Energy Environ., 3 (2012), pp. 749-760



**International Journal of Advances in
Engineering and Management**
ISSN: 2395-5252



IJAEM

Volume: 02

Issue: 01

DOI: 10.35629/5252

www.ijaem.net

Email id: ijaem.paper@gmail.com