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Sustainable Development – Plastic Waste to Fuel

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Abstract

Plastic is a material consisting of a wide range of synthetic or semi-synthetic organic compounds that are malleable and so can be molded into solid objects. Plastic is now common in our day to day activities. In 2017, the global plastic production reached about more than 400 million tonnes. At this time, India produced just 7.6 tonnes of plastic. Most the plastic produced was dumped in landfills or was let in the ocean or is incinerated. All the above technique caused a severe damage to the environment and the human life.

In order to decompose, plastic is treated with corn starch during manufacturing process. This made them biodegradable, the time required to decompose is just 3 to 6 months but at the cost of environmental degradation. Instead of this, plastic could be pyrolysised in order to get fuel.

Keywords: Centane Index, Fire point, Flash point, Plastic waste, Pyrolysis.

Introduction

Plastic was discovered by Leo Hendrik Baekeland in 1907. Plastics is term commonly used to describe a wide range of synthetic or semi-synthetic# materials that are used in a huge and growing range of application. Plastic is organic materials, just like wood, paper or wool. The raw material used for plastic depends upon the purpose for which that plastic is used.*

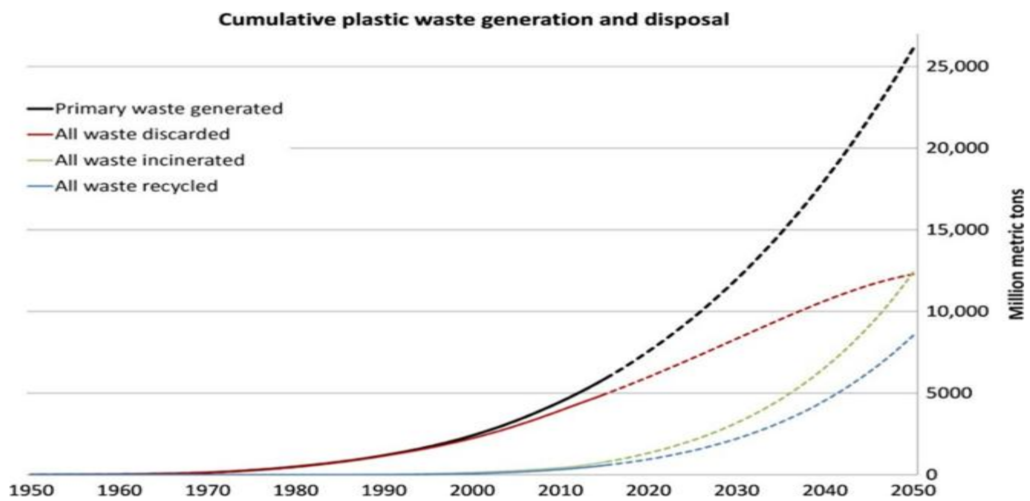

Fig 1. Expected Global plastic waste generation and disposal till 2050.

The different type of plastic, according to their chemical composition are-

1. Polyethylene Terephthalate (PETE or PET)
2. Polyvinyl Chloride (PVC)
3. Low-Density Polyethylene (LDPE)
4. High- Density Polyethylene (HDPE)
5. Polypropylene (PP)
6. Polystyrene or Styrofoam (PS)
7. Miscellaneous plastics (includes polycarbonate, polyactide, acrylic, acrylonitrile and butadiene. [1,

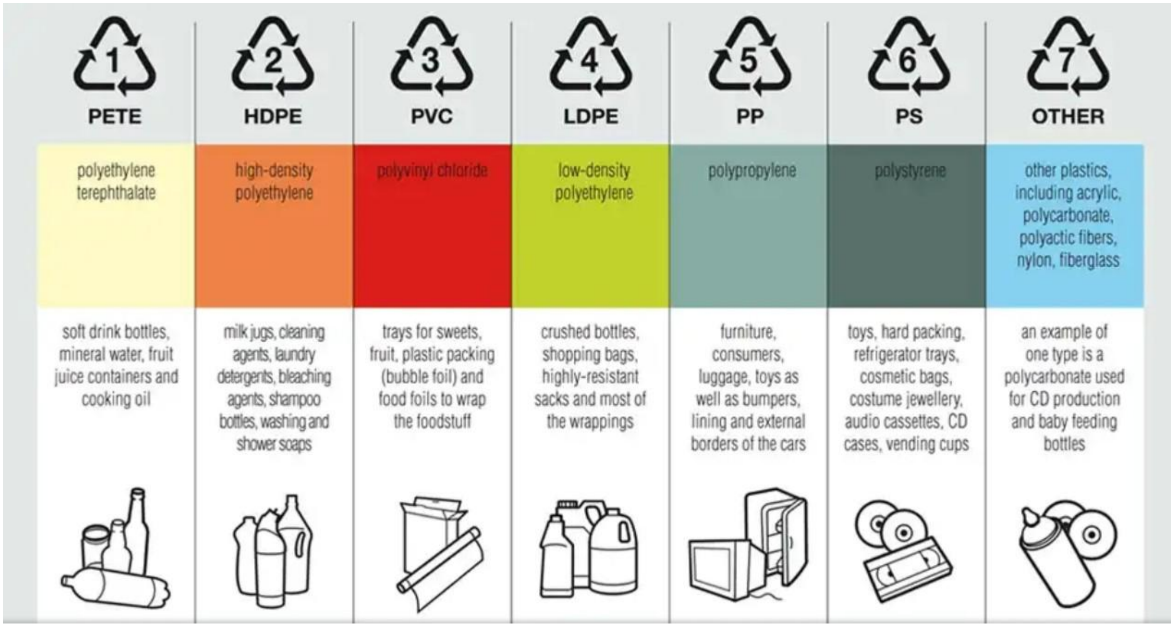

Fig 2. Type of plastic, according to their general numbering.

*Synthetic organic compounds are organic (carbon based) chemicals that are less volatile than volatile organic compounds. \Atrazine, Polychlorinated Biphenyls (PCB) are some synthetic organic compounds

#Semi-synthetic organic compounds that uses chemical compounds isolated from natural sources. Steroids are some of semi-synthetic organic compounds.

Type of plastic on the basis of thermal resistance:-

Thermoplastic: -Plastic that can be soften by heating and can be moulded again. Such plastics are defined as thermoplastic. Acrylic, polypropene, polystyrene, PVC, polythene are some examples. [3]

Thermosets: - Plastic that are formed by heat process and they retain their shape on application of heat. Such plastic are called as thermosets. Melamine, Bakelite, polyester, epoxy resins are few examples.[3]

Methods of recycling plastic are: -

1. Primary Recycling:-

The most popular 3R concept is represented as primary recycling. This is very simple and could be used in day to day life. The major drawback of this technique is the material has its own reuse limit. [2]

2. Secondary Recycling or Mechanical Recycling:-

In this process, only thermoplastic polymer can be used, as they can be re-melted and can be reprocessed into an end product. The mechanical recycling does not involve the alteration of the polymer during the process. The disadvantages of this method refers to the heterogeneity of the solid waste and deterioration of product`s properties. Also, this technique is relatively inexpensive but needs substantial initial investment. [2]

3. Feedstock or Chemical Recycling:-

Chemical recycling is defined as the process in which polymers are chemically converted to monomers or partially depolymerized to oligomers through chemical reaction. This method is able to transform the plastic material into smaller molecules.

The chemical recycling is not fully developed and for this reason, only few companies are working on it because this method needs a lot of investment and expert personnel. [2]

4. Energy Recovery or Quaternary Recycling: -

This method refers to recovery of plastic`s energy components. The most effective way to reduce the volume of organic materials which involves the recovery of energy from polymers, but it`s not ecologically acceptable because of the health risk from air-borne toxic substances. [2]

Among the above recycling techniques, the only one acceptable according to the principle of sustainable development is chemical recycling, because this method leads to the formation of the monomers which the polymer is made.

Technique	Advantages	Disadvantages
Primary	**Simplicity**	**Number of recycles are less**
Mechanical	**Cost-effective, efficiency, well-known**	**Deterioration of product's properties, pretreatment**
Chemical	**Operational for PET, simple technology**	**Mainly limited for condensation polymer**
Energy Recovery	**Generates considerable energy from polymer**	**Not ecologically accepted**

Table 1. Challenges and advantages of various recycling techniques of plastic. [2]

Chemical Recycling- Pyrolysis

Pyrolysis is the process of thermally degrading long chain polymer molecules into smaller, less complex molecules through heat and pressure. The process requires intense heat with shorter duration and in absence of oxygen. The three major products that are produced during pyrolysis are oil, gas and char which are valuable for industries especially production and refineries. Pyrolysis process is able to produce high amount of liquid oil up to 80 wt% at moderate temperature around 500^{0}C. In addition, pyrolysis is also very flexible since the process parameters can be manipulated to optimize the product yield based on preferences. The liquid oil produced can be used in multiple applications such as furnaces, boilers, turbines and diesel engines without the needs of upgrading or treatment. [6]

Unlike recycling, pyrolysis does not cause water contamination and is considered as green technology when even the pyrolysis byproduct which is gaseous has substantial calorific value that it can be reused to compensate the overall energy requirement of the pyrolysis plant. The process handling is also much easier and flexible than the common recycling method since it does not need an intense sorting process, thus less labor intensive.[6]

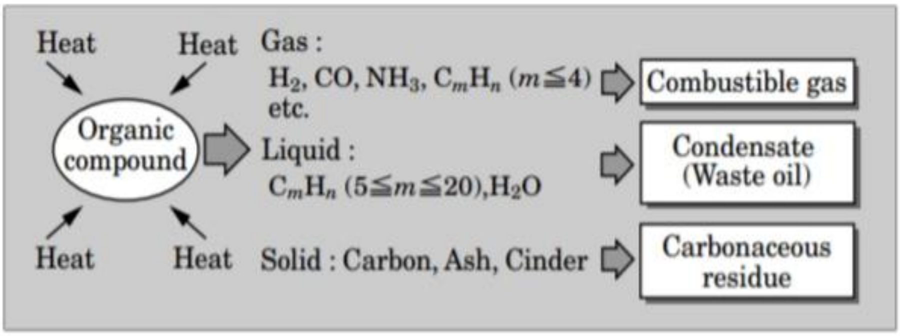

Fig 3. Expected products obtained after doing pyrolysis of any organic compound.

Comparison between pyrolysis oil and commercial gasoline and diesel, according to their physical properties:-

Physical properties	PET*	HDPE*	PVC*	LDPE*	PP*	PS*	Diesel#	Gasoline#
Calorific value(MJ/kg)	28.2	40.5	21	39.5	40.8	43.0	43.0	42.5
API gravity at 60^{0}F	n.a	27.48	38.98	47.75	33.03	n.a	38	55
Viscosity (mm^2/s)	n.a	5.08[a]	6.36[b]	5.56[c]	4.09[a]	1.4[d]	1.9-4.1	1.17

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Density at 15^0C (g/cm^3)	**0.90**	**0.89**	**0.84**	**0.78**	**0.86**	**0.85**	**0.807**	**0.780**
Ash (wt %)	**n.a**	**-**	**n.a**	**0.02**	**-**	**0.006**	**0.01**	**-**
Octane number MON (min)	**n.a5**	**85.3**	**n.a**	**n.a**	**87.6**	**n.a**	**-**	**81-85**
Octane number RON (min)	**n.a**	**95.3**	**n.a**	**n.a**	**97.8**	**90-98**	**-**	**91-95**
Flash point (^{0}C)	**n.a**	**48**	**40**	**41**	**30**	**26.1**	**52**	**42**
Cetane index	**n.a**	**31.05**	**n.a**	**n.a**	**34.35**	**n.a**	**40**	**-**
Pour point(^{0}C)	**n.a**	**~5**	**n.a**	**n.a**	**~9**	**~67**	**6**	**-**
Aniline point(^{0}C)	**n.a**	**45**	**n.a**	**n.a**	**40**	**n.a**	**77.5**	**71**

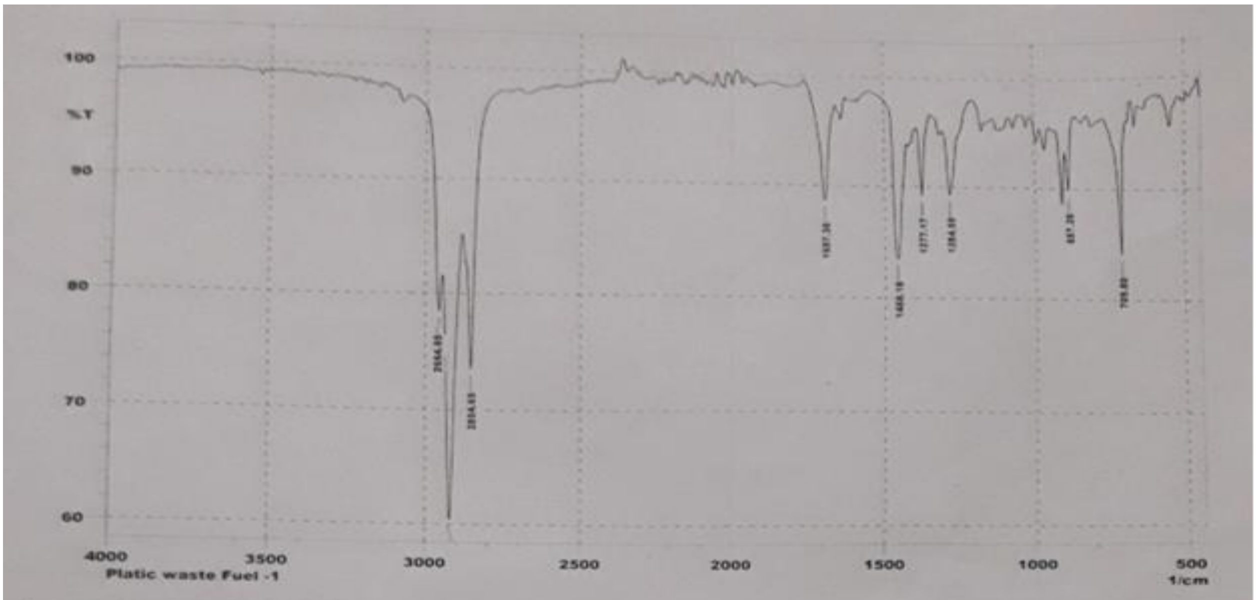
Table 2. Fuel properties of plastic pyrolysis oil [6]

*-Fuel obtained from the source (experimentally obtained)$^\#$-Commercial standard value

^{a}-Viscosity at 40^0C ^{c}-Viscosity at 25^0C

^{b}-Viscosity at 30^0C ^{d}- Viscosity at 20^0C

The pyrolysis oil obtained from plastic has significantly low amount of sulphur content. It was found to be in the range of 0.038% to 0.028%. The commercial diesel had sulphur content of about 0.038%. The fire point of this oil was found to be in the range of 56^0C to 46^0C. This temperature of fire point makes it suitable to be used as fuel.



No.	Peak	Intensity	Corr. Intensity	Base (H)	Base (L)	Area	Corr. Area
1	709.8	84.069	12.229	767.67	690.52	2.423	1.184
2	887.26	89.81	4.613	898.83	860.25	1.066	0.22
3	1284.59	89.263	6.617	1307.74	1215.15	2.452	1.052
4	1377.17	89.184	6.686	1392.61	1346.31	1.301	0.494
5	1458.18	83.462	12.187	1500.62	1427.32	3.005	1.69
6	1697.36	88.65	9.56	1762.94	1662.64	2.221	1.59
7	2854.65	73.52	14.427	2881.65	2754.35	5.478	0.523
8	2924.09	60.432	22.3	2943.37	2881.65	8.552	3.683
9	2954.95	78.437	5.214	3032.1	2943.37	3.712	-0.733

Fig 4. Infrared Spectroscopy of the pyrolysis oil using zeolite catalyst($NaAlSi_2O_6.xH_2O$).

Main components found from the above IR Graph are Benzoic Acid (C_6H_5COOH), C-Cl bond, C-O bond, C-F bond, C=C bond, C=O bond, C-H bond, N-H bond, O-H bond and presence of functional groups -CN and alkynes.

Table 3. Main oil composition from the pyrolysis of plastic [6]

PET	HDPE	PVC	LDPE	PP	PS
1-Propanone, Benzoic Acid, Biphenyl, Diphenylmethane, 4-Ethylbenzoic	**Benzene and its substituted derivates, Toluene, Xylene,**	**Azulene, Naphthalene and its substituted derivates, Phenanthren**	**Benzene and its substituted derivates, Toluene, Xylene,**	**Benzene and its substituted derivates, Toluene, Xylene,**	**Benzene and its substituted derivates, Toluene, Xylene,**

Acid, 4-Vinylbenzoic Acid, Fluorene, Benzophenone, 4-Acetylbenzoic Acid, Anthracene, 1-Butanone, m-Terphenyl	**C4-C13 hydrocarbon, Over C14 hydrocarbon, Cyclopentene and its substituted derivates.**	**e and its subituted derivates.**	**Indane, Indene, Naphthalene and its substituted derivates, Fluorene.**	**C4-C13 hydrocarbon, Over C14 hydrocarbon.**	**Naphthalene and its substituted derivates.**

By-products of plastic pyrolysis

Due to continuous heating in the pyrolysis process, there is formation of a solid mass that renders the thermal conductivity of the container. This solid residue mass is called char. Char is composed of volatile matter and fixed carbon, while moisture and ash are found in minor traces. The calorific value of char is experimentally found to be about 18.84 MJ/kg. Due to low sulphur content, it is suitable to be used as fuel. The char obtained from PP and PE contains significantly high amount of inorganic content, making it difficult to be used as fuel. This type of char is used in road surfacing and as adsorbent in water treatment to remove heavy metal through an upgrading treatment. Other application of this char is feedstock for activated charcoal and as solid fuel in boilers. [6]

The other by-product formed are the gases. The main component of these gases are hydrogen, methane, ethane, ethene, propane, propene, butane and butene. The other additional gases obtained are carbon dioxide, carbon monoxide and hydrogen chloride. The calorific value of these gases is very high. The calorific range from 42 to 50 MJ/kg. These gases can be used in gas turbines to generate electricity. [6]

Issues related to pyrolysis of plastic

In domestic plastic waste, plastic includes many stabilizers and colorants added to it. These colorants include Ti, Cd, Cr, and Fe and carbon pigments. When plastic is pyrolysised, these are converted into vapour state and mix with the environment. Ti reacts with oxygen present in atmosphere to form TiO_2, Titanium oxide is carcinogenic in nature. Exposure to Cd vapours leads to Cadmium poisoning. Cr vapours causes irritation to nose, throat and lungs. When the concentration of these vapours is high, it causes serious damage to eyes and nose. Fe vapours are carcinogenic in nature. It can also cause asthma and increase in risk of heart attack. Carbon pigment converts into carbon particles of very small size. These particles might trigger the increase in risk of cancer. Due to the emission of these gases, there might be a decrease in health quality of people.

Conclusion

From experimentation, we can conclude the fuel obtained by pyrolysis of plastic can be used as fuel. Due to ever increasing demand of fuel and increasing plastic waste, we can solve the problem of fuel shortage. According to the experimentation by using various catalyst like Sodium bentonite ($Al_2H_2Na_2O_{13}Si_4$), Sodium zeolite ($NaAlSi_2O_6.xH_2O$), Silica (SiO_2) and Alumina (Al_2O_3), we can increase the yield of the fuel that is to be obtained. Since pyrolysis is less polluting, it decrease the risk of land pollution caused by landfill dumping. Also the pollution caused by the convention pyrolysis can be overcome by replacing it with electrolytic pyrolysis. [1]

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