Scientific Inquiry and Review (SIR)
Volume 4, Issue 3, August 2020
ISSN (P): 2521-2427, ISSN (E): 2521-2435
Journal DOI: https://doi.org/10.32350/sir
Issue DOI: https://doi.org/10.32350/sir.43
Homepage: https://journals.umt.edu.pk/index.php/SIR/Home

Journal QR Code:

Article

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Online Published

August 2020

Article DOI

https://doi.org/10.32350/sir.43.01

QR Code of Article

Mohammad Rafiq Khan

To cite this Article

Khan MR, Marat-ul-Ain, Khan RA, et al. Transformation of plastic solid waste into liquid fuel. *Sci Inquiry Rev*. 2020;4(3):01–13.
Crossref

Indexing & Abstracting

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Estd. 1990

A publication of the
School of Science, University of Management and Technology
Lahore, Pakistan.

Transformation of Plastic Solid Waste into Liquid Fuel

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Abstract

The study being reported here was conducted to convert plastic waste, a major source of solid pollution in Pakistan, into liquid fuel by application of Thermal Pyrolysis. A pyrolysis reactor consisting of high strength Pyrex round bottom flask was constructed in the laboratory and used for converting plastic waste into liquid fuel. A 280g sample of plastic waste was pyrolyzed and the resultant products were 120g liquid oil, 100g solid residueand 60g gas.Thus, the yield of liquid fuel from the plastic waste was 43% wt. along with solid mass 36%wt. and gas 21 % wt. The results clearly indicate that there is a significant potential of producing liquid fuel from plastic waste in Pakistan and the world.

Keywords: fuel, liquid, plastic, solid, transformation, waste

Introduction

The management of plastic waste disposal is one of the biggest environmental problems around the globe. About 50 million tons consumed by humans is generated in USA, Europe and Japan alone.The largest producer of plastic waste in the world is Saudi Arabia having a total capacity of six million metric tons per annum [1, 2].There is a decrease in the proportionate number of landfill sites for dumping of waste. Even if available, the practice of landfilling is not commendable. One of the major disadvantages of landfilling is that it can cause pollution in the ground water because of plastic additives such as phthalates and different dyes. There is a disposal process alternative to the current landfill disposal known as incineration. The incineration process has a number of disadvantages because harmful gases such as N_2O, SO_x, dust, dioxins and other toxins are released during the process [3]. According to this research work conducted in

2013, there wasup to 4% increase in plastic production compared to 2012, leading to 299 million tons of plastic production in 2013. The major concern with plastic was that in spite of the recovery and recycling techniques, millions of tons of plastic went to landfills and oceans each year, with approximately 10–20 million tons of plastic wastegoing to the oceans. The studiesreported that approximately 5.25 trillion plastic particles weighing around 268,940 tons were floating in the world's oceans [4].

The plastic processing industry,being one of the useful and well-known industriesof the modern day, is a part of building and construction, transportation, consumer goods, furniture, etc. The plastic business significantly profits by its substitution for different materials including different metals, wood, paper, glass, cardboard and regular fiber items. The plastic is used and will be utilized in future too in many ways.Plastic has found such a broad market due to being lightweight, inexpensive, adaptable, and re-usable. The production of plastic has increased by about10% per annum worldwide since 1950 [5]. Asia has the highest number of plastic usage globally at 36.5% and it has been consistent at being the number onefor many years. The biggest part continues to be packaging, which is responsible for over 35% of the global demand. Unpredictable littering, incompetent reusing/recycling and non-biodegradability of plastic waste have raised the accompanying environmental problems. A few are as under:

- Release of fleeting emissions during the course of polymerization.
- Release of different types of gases in the production of different products.
- Rendering of the land infertile due to indiscriminate dumping of plastic waste.
- Generation of toxic emissions such CO, Cl_2, HCl, dioxin, furans, amines, nitrides, styrene, benzene, 1, 3- butadieneCCl_4, acetaldehyde and others as a result of plastic burning.
- Leaching of toxic substances such as lead and cadmium pigments used in LDPE, HDPE, PP, etc.,as additives.
- Non-recyclable plastic wastes including multilayer, metalized pouches and othersalso raise disposal issues.

The expansion on the rate of plastic use all over the world has prompted the development of an ever-increasing number of measures of plastic waste disposal. Thus, an appropriate treatment plan for plastic waste management has become imperative. According to the report,a major portion of plastic waste has been subjected to landfilling. Such a disposal of waste to landfills is now strictly regulated. The regulations are expected to achieve a reduction of 35% in land filling from 1995 to 2020. Also the rising cost and scarcity of land, the generation of explosive greenhouse gases (such as methane), a high volume to weight ratio of plastics, and the poor biodegradability of commonly used packaging polymers also make it an unattractive option [3].

The reprocessing of used plastic products to make new similar items is called mechanical recycling, in which the remade products claim the same or less performance than the original articles and the technique seems to be “a green operation”. Reprocessingis not cost effective because it demands high energy for cleaning, sorting, transporting, and processing to make a product. Practically it has been observed that reprocessing of contaminated plastic mix leads to mechanically inferior products, which lack in durability as compared to the original products.

Substitution of non-biodegradable plastics by biodegradable plastics is another way of disposal. Biodegradable plastics are those which can be converted back to biomass in a realistic time but a number of difficulties have been encountered in the use of degradable plastic products. Two areas follows:

1. Appropriate conditions,i.e.,the presence of light for the photo-degradation of such plastics is essential.

2. Greenhouse gases such as methane are released if plastics are degraded anaerobically due to catabolization of the molecular structure of the plastic films in the environment to form inert humus-like material that is less harmful.

Incineration of plastic is a widely used method in waste managementwhich has been considerably reviewed. The researchers are of the opinion that“there are four methods for conversion of organic wastes to synthetic fuels: hydrogenation, pyrolysis (thermal and catalytic), gasification and bioconversion” [6, 7].

"As an alternative to combustion and gasification, pyrolysis of plastic waste has gained importance because of having better advantages toward environmental pollution [7, 8]. Because of an inert atmosphere, free from oxygen, it does not form dioxins by reaction of products with oxygen as stated previously and emphasized by others [6, 9,10, 11, 12]".

"The two main competing technologies to pyrolysis are gasification and hydrocracking (i.e. hydrogenation) which both make the other two types of thermo-chemical treatment (TCT) technologies that are typically applied for Plastic Solid Waste (PSW). The gasification process received attention from the early 70s due to its application in various fields including petroleum refining processes and heavy crude treatment;hence, its availability on commercial and industrial scale is more notable than pyrolysis. Gasification is defined as the thermal treatment of plastics in low levels of oxygen to produce a syngas, which can be refined for various applications or directly combusted [6, 13]".

The racking process breaks down the long polymeric chains into smaller molecular weight compounds. The products of pyrolysis are very useful and can be applied as fuels or chemicals in different fields. Moreover, the pyrolysis reaction can be performed in the presence or absence of a catalyst. If accomplished without a catalyst, it is called thermal cracking or thermolysis, and if otherwise, it is called catalytic pyrolysis.

Thermal cracking or pyrolysis is the degradation or cracking of the plasticsby heatingata very high temperature. The heating process needs to be anaerobic and thus it should be carried out in the absence of oxygen to ensure that there is no oxidation of polymer or polymeric products. The recommended temperature isbetween 350^{o}C and 900^{o}C. The products obtained are carbonized char (solid residues) and volatile fraction that can be condensed to produce "paraffins, isoparaffins, olefins, naphthenes, and aromatics". The remainder is a non-condensable high calorific value gas. The formation of products and their composition solely depends on the process conditions and type of plastic wastepyrolyzed. If the process is carried out in the presence of a catalyst, the products may be different despite similarities. The main advantage of the catalyst in this process is that it lowers the temperature and time of reaction. Another advantage may be that in thermal cracking a broad variety of products are formed by the breaking of the polymeric chains, while in catalytic cracking, the product distribution is much narrower in which peak products are the lighter hydrocarbons. If considered in the economic context, reduction in the cost also adds value to its attractiveness.

At the turn of the century, a large number of studies were undertaken onsolid plastic waste's gravity being the cause of extensive solid waste pollution, with an aim to transformplastic waste into useful products such as "fuel gas, hydrocarbons and liquid fuel with regard to increase of their yield using different catalysts and other reagents [14, 15, 16, 17, 18, 19].Some kinetic studies have been also carried to look into the impact of different parameters on process efficiency to produce useful products [20, 21]".

The objective of this study was the identification and optimization of the processes of plastic pyrolysis for maximizing a range of useful products, designing continuous pyrolysis equipment at lab scale, and evaluating the yield of products from plastic waste by the process developed in the laboratory.

2. Materials and Methods

2.1. Sample Plan

The work reported here encompasses quantitative research suggested after reviewing the relevant articles and field observation. Domestic plastic waste from Allama Iqbal Town was collected randomly in a crisscross manner from 10 spots. The waste plastic samples were cleaned to remove dust particles and then air dried to physical dryness. The waste plastic was cut into pieces of about 1×1 cm and mixed well.

2.2. Laboratory Procedure of Pyrolysis for Plastic Waste to Liquid Fuel

About 280g of the plastic stock was pre-weighed. The pyrolysis reactor consisted of a high strength Pyrex round bottom flask of 1L volume equipped with connectors and connected to an inclined condenser attached with cooling water. The waste plastic waste was pushed into the pyrolysis reactor using a glass rod until the reactor was full of the sample. The pyrolysis reactor was heated slowly to melt the filled sample and as the plastic melted, more sample was pushed in until all the pre-weighed waste plastic filled the pyrolysis reactor. The reactor was attached with the condenser using quick-fit connectors and checked for any possible leakage. Then the reactor was heated at maximum flame to completely melt and boil the plastic sample. After a while of boiling at high temperature, the plastic pyrolysis products started to evaporate and reach the condenser. In the condenser, the pyrolysis products in the gaseous form condensed into liquid products. The liquid products were then collected in an air tight glass bottle and weighed for mass balance calculation. During the pyrolysis, in addition to the liquid product, some of the plastic was converted into the gaseous product that was burned off to prevent emission of gaseous hydrocarbons in to the air. The remaining dirty waxy waste was weighed and the weight of gaseous emissions was determined by the mass balance.

2.3. Fractionation of the Raw Liquid Fuel

The raw liquid fuel was taken in a 500 ml round bottom flask, attached with an inclined condenser by quick fit connectors, and finally attached with a collecting flask. The connecter on the flask had a port for fitting the thermometer. The raw fuel was heated on the flame and different fractions were collected in the temperature ranges of 40-70^{o}C, 71-120^{o}C, 121-170^{o}C, and 171-272^{o}C and termed as Naphtha, Gasoline, Kerosene oil, Diesel and Lubricating oil. The weight of each fraction was determined to know the mass balance of the fractions of the raw fuel.

According to protocols, the conceived program was analyzed using:

- Thermal pyrolysis
- Elemental analyzer
- Dispersive X-ray analyzer
- Anhydrous powder

2.4. Analysis

The liquid product was further analyzed by using different temperature ranges.The other properties weredetermined by ASTM methods.

2.5. Pyrolysis Process

The pyrolysis process set upby a researcher [22], and used as a reference here is shown in Figure 1. The liquefaction biomass by pyrolysis is shown in Figure 2.

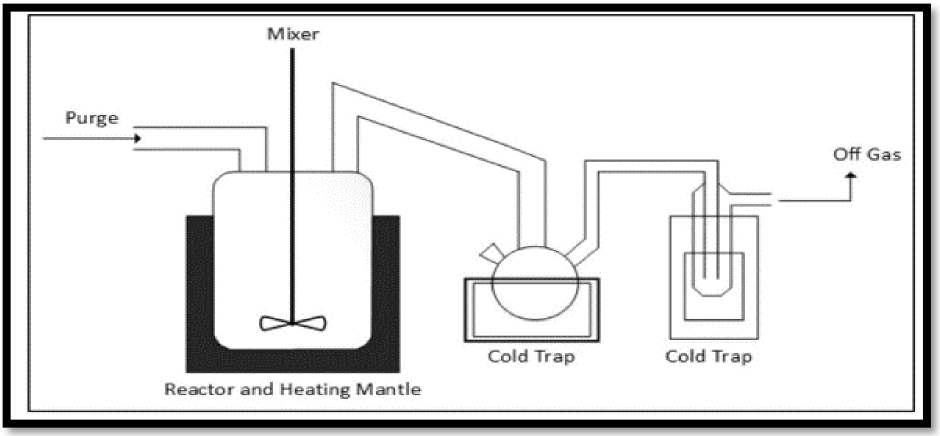

Figure 1. Pyrolysis setup [22]

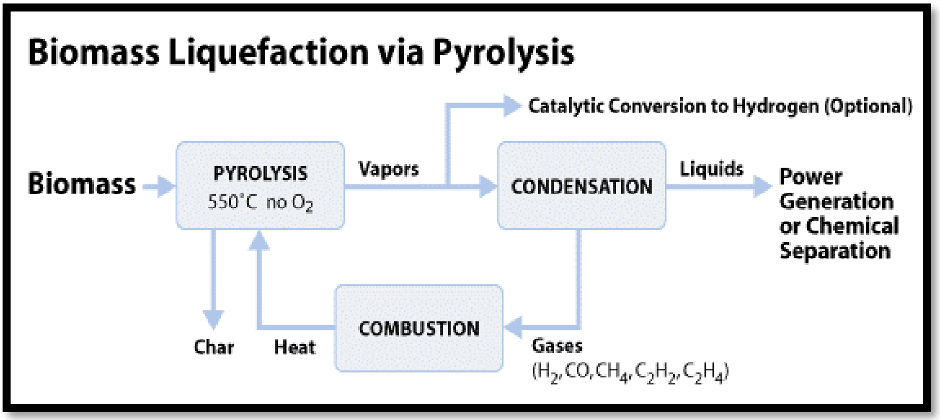

Figure 2. Biomass liquefaction by pyrolysis

3. Results and Discussion

The results of pyrolysis of plastic waste are shown in Table 1. It shows that the yield of liquid fuel is 43% and the solid mass left after pyrolysis is 36%. Gases are 21% which were low carbon pyrolytic gases**.**

Table 1. The Mass Balance of the Waste Plastic Pyrolysis

	G	%
Waste Plastic	280	---
Liquid oil	120	43
Solid	100	36
Gas	60	21

Table 2. Fractions of the Raw Fuel and their Densities

	Temperature	Fraction	Density
	C	%	g/ml
Naphtha	40-70	2.7	0.755
Gasoline	70-120	12.3	0.751
Kerosene oil	120-170	15.9	0.740
Diesel	170-272	52.3	0.779
Lubricating oil	272- ---	16.7	---

Table2 displays the fractions composing raw liquid fuel obtained in different temperature ranges, percentage composition and densities.It further indicates its chemical composition i.e., Naphtha 2.7%, Gasoline 12.3%, Kerosene Oil 15.9%, Diesel 52.3 and lubricating oil 16.7%.Tables1 and 2 show that diesel was produced in high amounts and its density was fairly closer to petroleum diesel. Therefore, this can be used as a fuel substitute if produced at a large-scale commercial level.

Selling price of the products of liquid fuel compared to the fuels present in the market is mentioned in Table3.

Table 3. Selling Cost of the Products of Liquid Fuel

Amount of liquid fuel obtained equal to 120g.			
Products	**Amount of each product in 120g**	**Price per liter in Market Rupee**	**Sale Value**
Naphtha	2.7	75.49(Int.)	0.34
Gasoline	12.3	88.79	1.75
Kerosene oil	15.9	80	2.06
Diesel	52.3	99.56	8.02
Total benefits	12.21		

The results reported in Table 3 show that the disposal of plastics via pyrolysis is highly significant because it ultimately translates into the disposal of a highly polluting solid waste with the extraction of economic benefits in the energy context because there is 43% yield of liquid fuel with 21% yield of fuel gas. The solid mass left after pyrolysis may be investigated further for its techno-economic utilization. Khan et al (2016) conducted a similar research on plastic waste [23]. The research team conducted pyrolysis to get useful fuel fractions from plastic waste. A good number of useful products were produced that included diesel and kerosene oil, which are also a part of our findings. The diesel and kerosene oil had densities of 0.84g/ml and 0.82g/ml respectively. The density results when compared with our results are similar. Hence, this comparison also proves that the objectives were achieved.

While evaluating the benefits of the process, the large tonnage of plastic waste spread in different localities and dump depots as a zero-costmaterial-creating nuisance everywhere should not be overlooked.The benefits turned out to be Rs. 43,607 per ton of plastic waste processed via pyrolysis. Imagine the tonnage at the national level. If updated and benefits calculated, a huge techno-economic value can be expected. Thus, the study strongly recommends the following steps to extend the project toa national level and finally to a global level:

1. Running of the process at a pilot plant level to qualify it for taking it upto the commercial level.
2. Assessment of the total plastic waste produced in Pakistan and calculation of potential of production of liquid fuel and fuel gas at the national level.
3. Designing of the project, "Techno-economic Disposal of Disposal of Plastic Waste in Pakistan to Produce Liquid Fuel and Fuel Gas" to conduct its feasibility andprofitability by applying the Discounted Cash Flow Technique.
4. Assessment of the production potential of liquid fuel and fuel gas in the context of the energy crises and the disposal of plastic waste at the global level.

Why are the recommendations worth accepting? The question may be answered on the basis that the broad audit of pyrolysis as a method has indicated that pyrolysis introduces a manageableand proficient experimental technique to control waste collection that is an imperative problem these days for doing away with disposal area and contamination regulation. This process acts as a flexible strategy that creates scope of helpful hydrogen and carbon compounds conceivably utilized as a concoction feedstock. This process can limit the reliance of non-inexhaustible non-renewable energy sources as well as take care of the landfilling issue. According to theseconditions, pyrolysis is an adaptable procedure in which temperature, weight, time, can be altered to achieve the specific target.

4. Conclusion

The objectives of this research wereto identify and optimize the range of useful products, to conduct the process of pyrolysis of polythene bags at the lab scale and finally,to evaluate the yield of plastic waste products. The research was conducted to answer the question whetherit's possible to conduct an efficient and effective pyrolysis at the lab scale. As plastic is used worldwide in large amounts, it is necessary to find harmless and easy ways to recycle and reuse the plastic waste. Therefore, this research was conducted solely for this purpose. On the basis of results reported in this article it can be said that the goal and objectives of the research have been successfully achieved.

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