A study of Pyrolysis as a plastic waste management technique

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Abstract: The demand for plastics is increasing exponentially with the growing population. Plastics are indispensable due to their versatility, flexibility, manufacturability and lower cost. The same molecular structure that makes them such a stable and versatile material also makes them impervious to the forces of nature that help in degrading waste. This non-biodegradability of plastics has created a dire situation in which neither its use can be limited nor can the waste generated by its use be managed properly. The current methods of plastic waste management like incineration and landfilling are not only inefficient but they merely pass the buck around. Incineration turns land and water pollution into air pollution and dumping into landfills is not only wasteful but can be harmful to groundwater reserves. Fortunately, the solution to this problem also lies in the structure of plastics. They are essentially very long chain hydrocarbons which are synthesized from petroleum products and can hence be broken down in the absence of oxygen (pyrolysis) into smaller chains of fuel range like petrol, diesel or fuel oil in general which then can be used as a substitute for traditional fuels. Pyrolysis as a method of plastic waste management is a three-pronged solution of the plastic waste crisis as it removes plastic waste from the environment, provides an alternative source of fuel and gives people a monetary incentive to participate. It was concluded from the experimental data that varying control parameters like type of plastic, use of catalyst and condenser temperature affected the oil yield in terms of quality and quantity, so the new updated apparatus has been designed considering that information. This will help us in increasing the efficiency of the process.

***Index Terms* - Plastic Waste, Energy Recovery, Pyrolysis, Fuel Oil**

I. Introduction

In the last century, plastics have revolutionized the material industry and have become ubiquitous in most of the industrial sectors. Due to their excellent machinability, low-density, low cost, imperviousness to water, durability and design flexibility, plastics can be found right from the household industry to the aerospace industry. Considering the current consumer culture of throw away products, rapid growth of population and advent of manufacturing techniques like 3D Printing, which is pivoted around polymers, the rate of plastic production will only keep on increasing. However, plastics have their own shortcomings, the primary one being non-biodegradability which cannot be overlooked as their disposal becomes an ever-increasing threat to the environment. Disposing plastics into landfills has proven to be both ineffective and harmful. The chemical additives present in the plastic turn soil as well as ground water reserves underneath them toxic [1]. Each year, a considerable portion of the plastic waste ends up in the oceans and water bodies, endangering the aquatic life and causing an imbalance in the ecosystem [2].

348 million tons of plastics were produced in 2017, representing a 4 per cent increase over 2016 [3]. A recent study conservatively estimated that 5.25 trillion plastic particles weighing a total of 268,940 tons are currently floating in the world's oceans. In India, out of 25940 tons of plastic waste generated daily, less than 10% is recycled [4]. The traditional methods like incineration and mechanical recycling have proven to be ineffective considering the magnitude of the problem [5]. Mechanical recycling demands an intensive work force to segregate the plastic on basis of their grade, colour and type [6]. Incineration is the burning of plastics in open air as secondary fuels, which generates toxic gases and hence poses a threat to the environment as well as human health. Thus, the lack of effective waste management technologies at present has reduced plastic waste to an uncontrollable necessary evil.

Therefore, there is a need to look beyond the conventional techniques of plastic waste management. Pyrolysis presents one such alternative which has shown promising results.

II. Related Work

Extensive research work was carried out in the domain over the past couple of decades. Several published materials were studied to understand the current trends in the field and crucial aspects of the technology. In [7] and [8], the authors have investigated the potential of different plastic types found in Municipal Solid Waste (MSW) for pyrolysis. Also, the effect of process parameters like temperature, residence time, catalysts, pressure and reactor type on qualitative and quantitative efficiency of the system was analysed. In [9], the use of different acidic catalysts like Zeolites, Aluminium Silicate and MCM-41 has been tested and, their respective effect on the process efficiency and fuel quality has been analysed. In [10], using a laboratory scale plant non-catalyst conventional slow pyrolysis was performed on plastic wastes procured from landfills and accordingly the relative proportion of fuel oil yield obtained for different plastic types and mixture was reviewed. The feasibility of technology for processing plastic waste in urban cities was investigated in [11] and a rudimentary setup was developed to demonstrate the process. This setup was acquired and used to carry out experiments which have been presented in the later section of this paper.

III. Problem Statement

To provide an effective and economical solution for processing plastic waste by designing an efficient Pyrolysis setup which could recover the energy content of the discarded plastics in the form of readily usable fuel oil. In addition to the effective management of waste plastics, this process would not only cater to the energy demands of the masses but also would provide a monetary incentive for plastic waste management.

IV. Methodology

Plastics are basically hydrocarbon polymers of chain length ranging from C>50000 and C<1000000, chemically synthesized from petroleum. So, they inherently possess significant energy content which could be harnessed. Pyrolysis is the thermo-chemical process of decomposing long-chain organic matter into simpler chemical compounds in the absence of oxygen. When plastics are pyrolyzed, they crack down from long hydrocarbon chains to smaller chain lengths of fuel range which can be condensed, distilled and processed to be utilized for numerous industrial and domestic applications. A proportion of the plastic vapours of very short chain length (<C4) remain uncondensed at the end of process. This gaseous fuel can be used for supplementary heating in the plant furnace, thus enhancing the net energy efficiency.

Our paper is aimed at comprehending this process through repeated experimentation by tweaking a few influencing process parameters. The parameters that have considerable effect on overall process efficiency and fuel quality are:

a) Type of plastic used
b) Reactor temperature
c) Condenser temperature
d) Type of catalyst used
e) System pressure
f) Fluidizing gas used

Fig. 1 depicts the flow of plastic waste through the system:

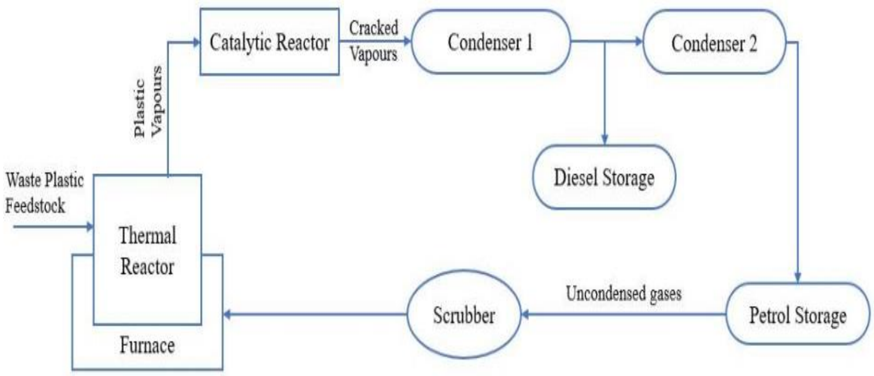

Fig. 1. Pyrolysis process flow chart

The laboratory scale apparatus used for experimentation comprises of a batch-type Mild Steel reactor of 1kg capacity, with a removable cone shaped top head for feeding waste plastics. The reactor is provided with an insulation layer of glass wool around its surface to reduce convection losses. An electric resistance heater made from Nichrome wire coil is provided at the base of reactor with no control provision for temperature or rate of heating. A coil type condenser made of copper tube wound in the form helix is used. One end of the copper tube is securely brazed at the top of the reactor from where the pyrolyzed plastic vapours are transmitted to the condenser. The condenser tank holds water, which surrounds the copper tube spiral coil, at atmospheric conditions. Condensed fuel oil at the output is collected in a PET plastic bottle. A picture of the setup showing its different components can be viewed in Fig. 2.

Fig. 2. Apparatus

V. Experimentation

Seven experiments were performed on the aforementioned setup with the primary objective of validating the theoretical findings on the influential extent of the various process parameters. Since, the setup had no provision for control of temperature, heating rate, pressure and fluidizing gas, the experiments were performed with different permutations of the remaining parameters. The other objective for carrying out experimentation was to understand the operational intricacies, establish design specifications and considerations for an enhanced system through analysis of the results.

Initially, 3 experiments were carried out with single Polyolefin plastic type at feed. The objectives of these experiments were to investigate relative oil yield for different materials under similar process conditions. The test results are presented in the table 1.

Table 1

Sr. No.	Plastic Type	Weight (in gms)	Oil Yield (in gms)	Gas Output	Conversion Efficiency
1)	HDPE	1000	100	Low	10%
2)	PP	320	80	Low	25%
3)	LDPE	300	30	Low	10%

Further, to investigate the effects of catalysts on the process efficiency, two experiments were performed with LDPE milk bags procured from garbage bins as feed material. Different catalysts were used during both the experiments. The catalysts used were Zeolite and Aluminium Silicate in pulverized form which was fed along with the waste plastics into the reactor.

Table 2

Sr. No.	Plastic Type	Weight (in gms)	Oil Yield (in gms)	Gas Output	Conversion Efficiency
1)	LDPE (with Zeolite)	340	90	Moderate	26.5%
2)	LDPE (with Al_2SiO_5)	350	85	Moderate	24.29%

To demonstrate the quality of oil obtained when LDPE Milk pouches were pyrolyzed in the presence of Zeolite, a picture of the same has been provided below.

Fig. 3. Oil Sample obtained from LDPE Milk bags

As PET and PVC are two polymer types undesirable for Pyrolysis due to their chemical structure, experiments were performed with both to investigate their effect and analyse the yield obtained. The test results obtained are presented in table 3.

Table 3

Sr. No.	Plastic Type	Weight (in gms)	Oil Yield (in gms)	Gas Output	Conversion Efficiency
1)	HDPE, PVC & PE	500	140	High	28%
2)	PET	250	-	Very High	Nil

VI. Results and Discussion

The following conclusions about various sections of the process were drawn from the experiments. Electrical heating which was inefficient in itself combined with a limited area under its effect and a lack of temperature control mechanism drastically reduced the efficiency of the process. There was no provision for storing or reintroducing the Syngas generated at the end into the system and is hence a waste of energy. The apparatus was not designed in accordance with the principles of chemical, manufacturing engineering and was therefore prone to leaks and energy loss. The design had no separate provisions for introducing the catalyst into the system so it was mixed with the plastic which did increase the yield but was still sizeably lower than the theoretically expected value. It was concluded that the method of introducing the pulverized form of catalyst directly into the plastic was not as suitable as the standard practice of using crystalline catalyst in a separate chamber as it was costlier due to its perishable nature. It was found that PVC and PET were not suitable for pyrolysis as their output is harmful and unusable. These plastics can be separated from the useable plastic types by floatation separation method [12] and then processed using other suitable methods. After these limitations of the current setup came to light, design considerations and standards were established for an enhanced setup to remediate these shortcomings and further improve the efficiency by controlling input energy, catalyst introduction, and raw material parameters.

VII. Conclusion

Plastics have revolutionized several industrial sectors since they were introduced and an alternative for it, which offers the same convenient properties at a comparable cost, has not been worked out. The demand for plastics is increasing exponentially in tandem with the growing population and as they continue to replace many traditional materials in different sectors thus, the consequent waste generation has also been increasing. Also, the energy demand has been increasing which needs to be taken care of to ensure unhindered progress. Through the scope of this research we have found pyrolysis to be an effective solution to address plastic waste predicament and, in the process, generate an alternate fuel source. The implementation of this project can create numerous socio-economic opportunities in the city, and this could help to consequently lower the burden of fuel imports. Also, the other significant feature of this technology is its flexibility and thus, it could be designed for varying capacity ranging from 10 kg per day to tonnes per day. A Pyrolysis plant could be specifically designed and developed considering region's waste generation trends. This plant could be set-up near the source of waste generation, lowering the associated logistic costs. The fuel oil derived through pyrolysis can be further chemically processed to replace transport grade fuels or to be blended with them for use in conventional IC engines.

It is imperative at the present to take conclusive steps to address the problem of plastic pollution. Also, increase in energy demand due to urbanization, population growth, industrialization and increased price of fuel makes this technology even more significant.

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