Analysis and Design of Pyrolysis Plant for Islampur City

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Abstract: Plastic waste has enduring life and currently, Islampur Municipality does not have any treatment technology for the disposal of plastic waste. 1.2 tonnes of plastic waste are dumped in the dumping yard every day. The 16 acres of dumping yard are filled (85%) with earlier dumped Municipal solid waste. There are 6 technologies invented by researchers for effective plastic waste disposal. In this paper, these methods are compared and the suitability of pyrolysis technology is analysed and designed for Islampur City. The main purpose is to dispose of plastic waste in an eco-friendly way and obtain products that will prove harmless to the environment.
Keywords: Plastic waste, Refused Derived Fuel (RDF), Pyrolysis

1. Introduction

Arun Kumar Dwivedi (2020)), there were several methods for disposal of municipal and industrial plastic waste adopted in the initial days, i.e., landfill, incineration, recycling, and recovery. In Japan in 1980, municipal solid waste (MSW) was landfilled estimated to be 45%, incineration 50%, and the other 5% segregation and recycling. In the USA in 1990, above 15% of the total MSW was incinerated, and nearly as were recycled. In India in 1998, 60% of plastic waste recycling lead. This was the highest recycling in the world. While in Europe is 7%, Japan 12%, China 10%, and South Africa 16%. In Europe, in 2006 disposal and recovery rates of plastic waste were equal. While now, it is 50-50% recycling and disposal. Energy recovery has increased to 30.3% from 29% in 2005, and recycling has improved to 19.7% from 18% in 2005. Out of the 11.5 million recovered tonnes, 7.0 million were recovered as energy, and 4.5 million were recycled as feedstock and material. With mechanical recycling at 19.1% and feedstock recycling at 0.6%, the overall material recycling rate in 2006 was 19.7%. Since 2005, the energy recovery has increased by 1.5% to 3 % indicating the firm legislation on a landfill. From the above data, it is concluded that material recovery and recycling rates are increasing but the problem is still there because the complete elimination of plastic is not yet done. It exists in another form which again becomes a hazard to the environment.

Javeriya Siddiqui (2013), discussed that in India, the infrastructure required for the harmless disposal of municipal solid waste, mainly in urban areas is insufficient to a greater extent. The country, as well as different state government authorities, had undeniably levied restrictions on thin plastic carry bags. However, it is seen that fewer states were not implementing government regulations. This directly increases pressure on the local authorities to handle the plastic waste produced. It is analyzed that a complete ban on plastic carry bags is not the solution. There is a need to take strong steps for the disposal of waste.

Islampur is a city located in Sangli District of Maharashtra state, India with a population of 69,743 holdings a municipal council of over 14,376 houses (according to the 2011 census), and is forecasted to reach 1,15,127 (by incremental increase method) in 2021. The city facing a problem of 1.2 tonnes of plastic waste generated per day does not have proper treatment technology.

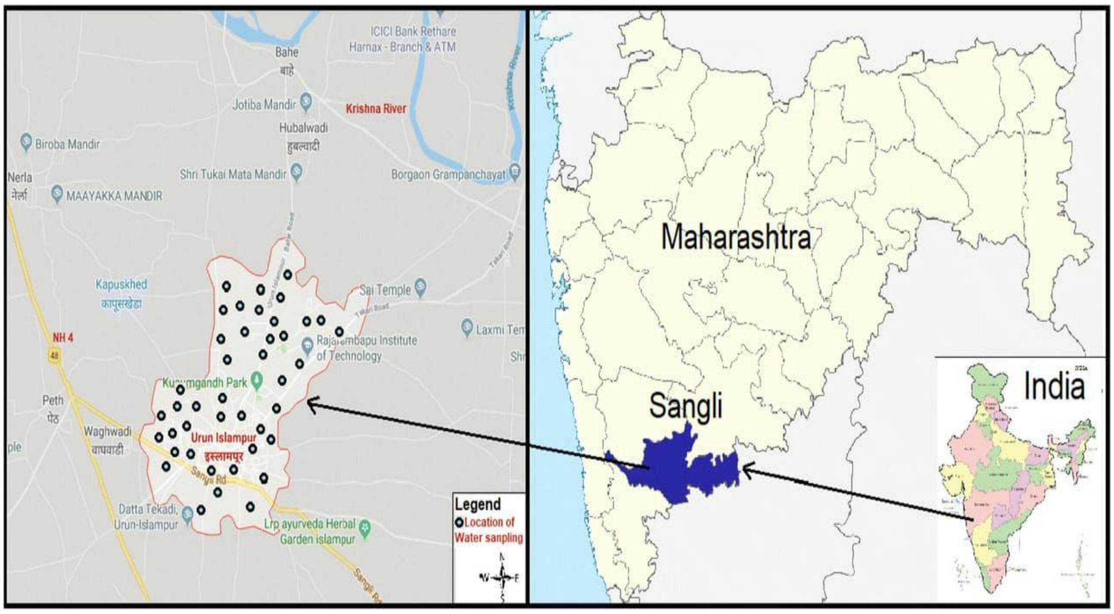


Fig 1: Location of Islampur City

Plastic waste generated is a big question for every developed and developing country. Resulting in areas and volume increase of dumping grounds. Due to landfills, leachate comes out and moves towards the round. Soil pollution and infertility are the problems that arise. Groundwater is also adversely affected by leachate. Open combustion of plastic waste emits hazardous gases which are poisonous to the environment and also affect human health. Correspondingly, these gases are settled on crops and water sources which ultimately end up in nutrition and gather in bodies.

2. Modern Technologies for Disposal of Plastic Waste

Plastic disposal has become the most challenging work for everyone. Despite this, researchers find out several methods listed below. From the listed methods, a suitable method is found by comparing them with each other.

1. Gasification

Arun Kumar Dwivedi (2020), mentioned that gasification facilitates the production of fuels or combustible gases from waste plastic. Air serves as a gasification agent in this process. The utilization of air rather of oxygen and cost savings are the primary benefits. However, there are drawbacks to the gasification process, such as airborne nitrogen. The most effective method for turning plastic trash into energy is gasification. Carbon-containing materials are converted via a thermochemical process to gaseous products such as carbon dioxide, carbon monooxide, hydrogen, and methane gas. These gasses can be used to generate electricity, heat, and light. Although direct gasification is an easy and economical method, the presence of nitrogen in the atmosphere may cause the resultant fuels' calorific value to decrease because of the dilution of fuel gases. The synthetic gas produced can be a raw material to produce chemicals such as hydrogen and methanol.

2. Bioremediation

Wastes are broken down by microorganisms in that process. To support the growth of microorganisms, it requires culture media that includes nutrients, enzymes, pressure, and temperature that must be adjusted to the perfect level. When plastic polymers are exposed to heteroatomic molecules, they can separate and deteriorate biologically. This makes it easier for the trash to begin biodegrading; extracellular enzymes are also used to break up plastic polymers. Enzymes function as chemical catalysts in the bioremediation process by lowering the activation energy and changing the substrate into the product. The enzymes that were employed in the procedure were microbial lipases, microbial oxidoreductase, microbial oxygenase, laccases, peroxidases, lignin peroxidases, hydrolases, and microbial lignin peroxidases. When plastics like polyvinyl chloride naturally degrade, they release dioxins, CFCs, and vinyl monomers, which are monomers of phthalates.

3. Photo-reforming

Mohd. Wasif Quadri (2020), discussed about combining plastic waste with a light-absorbing photocatalyst that absorbs sunlight and transforms it into chemical energy. After being placed in an alkaline solution and exposed to sunshine, the plastic and catalyst combination broke down and released hydrogen gas bubbles. The gas formation amount is not significant.

4. Hydrogenation

Arun Kumar Dwivedi (2020), it is a recycling method. Plastic waste is mixed with hydrogen and coal liquefaction. It converts into naphtha and oil gas. The product undergoes condensation. This condensed mixture, which has a certain chlorine percentage, is introduced into the hydrocracker. Here, hydrochloric acid is removed, producing water. The resultant chlorine-free condensate is then combined with gas and depolymerize for processing in the cascade controller section. Hydrogenating plastic solid waste primarily yields hydrochloric acid, halogenated solid byproducts, and gas.

5. Re-Extrusion:

Lindani Koketso Ncube (2021), is a closed-loop primary recycling method that feeds plastic scrap into the extrusion process. It is used by industries to recycle polymer waste from their production process on plastic waste which is uncontaminated. The recovered plastic is recycled into goods of a similar kind. It is ineffective and inefficient as it demands clean and strict sorting which increases cost of processing.

6. Pyrolysis

In a study by Ram Jatan Yadav (2020), pyrolysis is described as the thermal breakdown of plastics in the absence of oxygen and at elevated temperatures. Plastics primarily derive from petroleum. Through pyrolysis, these polymers transform into hydrocarbon compounds in a permanent and non-reversible manner. The escalating demand for plastics poses significant challenges to environmental equilibrium and the depletion of renewable fossil fuels. It's worth noting that while these fuels are termed "renewable," they can take millions of years to regenerate, or they may never replenish, making their dwindling reserves a pressing concern for the future. The oil resulting from the pyrolysis boasts a high calorific value, positioning it as a potential alternative fuel. Additionally, this process yields other valuable by-products, including specific gases and carbon residues.

Above mentioned methods are modern technologies used worldwide. All have their own limitation as they apply to particular types of plastic, cost-effectiveness, and efficiency like things are involved in that. In the case of pyrolysis, all type of plastic is used in processing. It is a simpler method and is efficient in the complete decomposition of gases. The whole process is carried out in anaerobic conditions, that’s why the whole process is done without hampering the environment.

2.1 Pyrolysis Process:

Akshay Nakate (2017), pyrolysis word is derived from “Greek” where pyro means “fire” and lysis means “Decomposition”. The main benefit of pyrolysis is it can handle easily unsorted and uncleaned plastic. Fundamentally, this process is composed of three main components Reactors, a Condenser, and so storage tank. This technology is a thermal degradation process done in the absence of oxygen. Catalysts are used to fasten the process and achieve a good final product yield. After the pyrolysis process, the distillation process takes place to obtain the pure form of the products.

Pyrolysis stands out as the leading method for recycling plastic waste. This technique breaks down plastic waste thermally at elevated temperatures (ranging from 500-800°C) without the presence of oxygen, yielding fuels. The products from pyrolysis can be categorized into liquid fractions, gaseous fractions, and solid residues. A variety of reactor systems, including batch, semi-batch, and tubular bed, have been devised and employed for this purpose. [4], rotary kiln, fixed bed [3,] and fluidized bed [Yuan Xue]. Fixed bed reactors are widely used. However, this process has major drawbacks wide-ranging products, and high-temperature requirements.

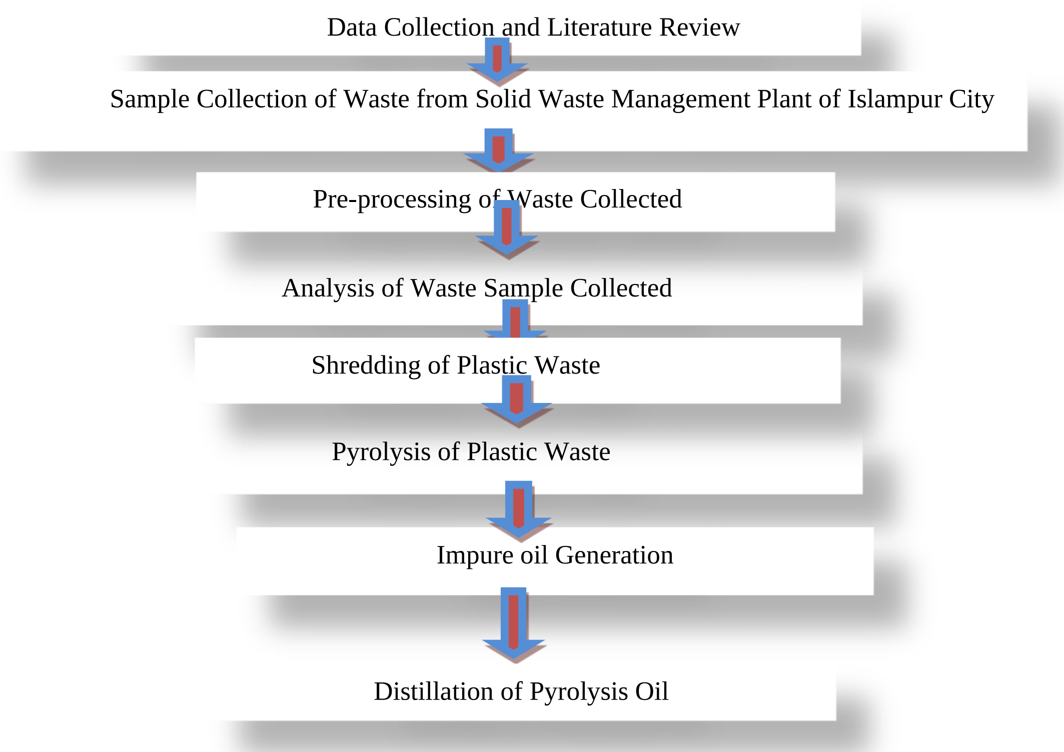
In a study by Mochamad Syamsiroa (2014), catalytic pyrolysis emerges as a solution to various challenges. The incorporation of catalysts in the process can reduce the reaction temperature, foster decomposition reactions, and enhance product quality. The appeal of catalytic pyrolysis largely lies in its energy efficiency, particularly in terms of reactor usage, temperature regulation, and residence time. However, the direct catalytic breakdown of plastic wastes poses challenges that hinder its commercial viability. One primary concern is the challenging recovery of the used catalyst, leading to higher operational costs. Additionally, direct exposure to plastic wastes can cause catalysts to deactivate quickly due to the accumulation of carbon-rich matter and the adverse effects of contaminants like chlorine, sulfur, and nitrogen-containing species present in the waste. To counter these issues, separating the catalytic reforming step from the pyrolysis phase can be effective. Commercially viable catalysts like natural zeolites, found globally, can be employed for this purpose.

Numerous studies have detailed the pyrolysis of plastics, focusing on the treatment of municipal plastic waste (MPW) containing components like polyethylene (PE), polypropylene (PP), and polystyrene (PS). The inclusion of polyethylene terephthalate (PET) in mixed plastics and MPW has been observed to stimulate the formation of new chlorinated hydrocarbons in liquid outputs, while significantly reducing inorganic chlorine content. Additionally, the influence of impurities in MPW cannot be ignored. Such contaminants can be harmful to acidic catalysts, leading to rapid catalyst deactivation during MPW conversion.

This innovative approach suggests utilizing the resulting liquid product either as a standalone fuel for diesel engines or as a blend with standard diesel. This oil can also serve as fuel for pressurized cooking stoves. The produced gas can be leveraged as a heating source for reactors or applied in cooking gas stoves. Concurrently, the solid by-products have potential for co-firing alongside coal and biomass, offering a versatile fuel option for various applications.

3. Methodology

The project aims to design a pyrolysis system for Islampur city. Hence, the methodology is structured along-wise. The data collection and literature review were carried out to find the scope suitable for the city. The hen dry waste sample is collected from Islampur Municipal Corporation Material Recovery Centre. The purpose of sample collection is to analyze the content of the waste sample. In the end, the collected sample is cleaned i.e., removal of dust soil, or other content like food are removed. Then the waste is segregated into papers, plastic, organic dry waste, foam, and clothing waste, and their respective weights are noted. Then shredding of plastic waste i.e., size reduction of plastic waste is done for the pyrolysis process. Then, the pyrolysis process is carried out in a lab-scale model to obtain oil that is in impure form. Then, further distillation is carried out for pure oil generation. The stated methodology is shown in the form of the f flow chart as below:



Flow Chart: Research Methodology

4. Materials and Methods

Experimental Analysis of Dry MSW Sample

The dry waste sample of MSW is collected from the per day household collection of solid waste of Islampur city. The pre-processing involves cleaning and sorting of waste. The weight-wise analysis of the sample was done. The sample consists of paper, cloths, organic dry waste, plastic, and foam. In that, paper 53%, cloths 5%, organic dry waste 14%, plastic 22%, and foam 6%. Plastic content is 22% which is considerable. As municipal corporations do not implement any treatment for collected waste, there is abundant plastic waste present inside the number heaps. By considering a significant amount, there is high scope seen for pyrolysis technology.

Experimental Setup for Pyrolysis Process

M. Z. H. Khan (2016), the plastic used in this study was MPW. A laboratory-scale model is prepared which has a fixed bed reactor schematic diagram shown in fig. 2. The pyrolysis chamber, along with a temperature controller, condenser, temperature sensor, heating coil, insulator, storage tank, valve, and gas exit line, make up the pyrolysis setup.

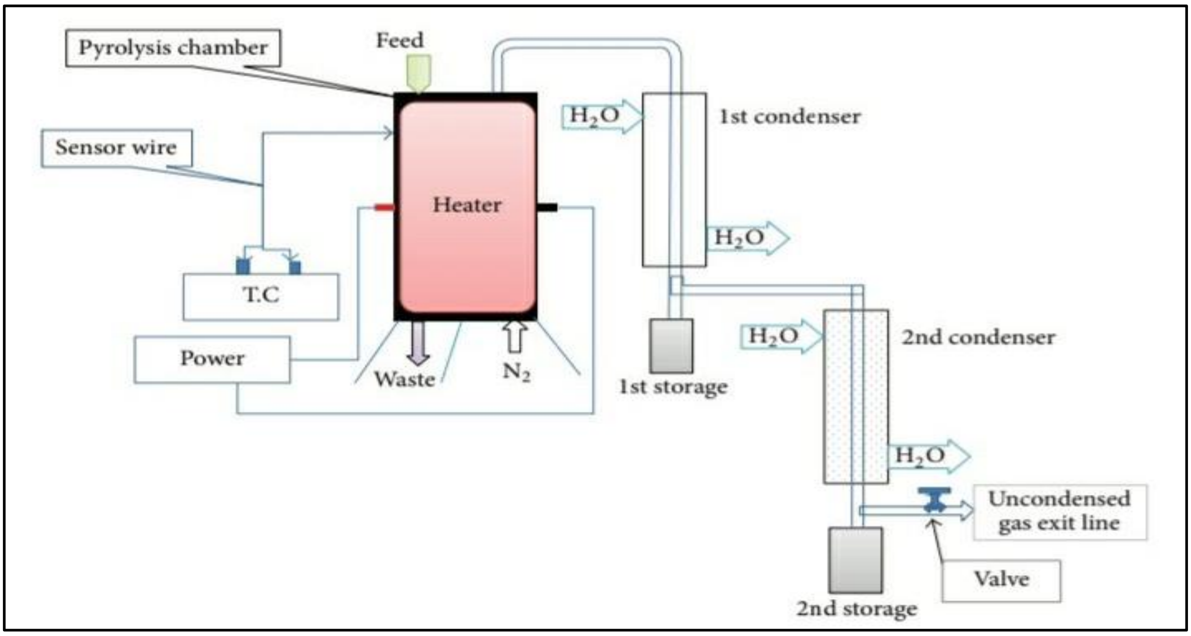


Fig 2: Schematic Diagram of Pyrolysis Setup

Gas Chamber

Reactor

Oil Collector

Fig. 3: Laboratory Scale Model

Plastic waste is cleaned by removing other material stuck to it with normal water and allowing it to sundry. There are four plastic waste samples taken, PE, PP, PS, and MPW. Each waste sample of 1.5 kg was taken for oil for the pyrolysis process. The plastic Waste sample is shredded to obtain a 300-500 mm size of plastic. The effective length is 38 cm and the diameter is 15cm of the stainless steel-made reactor. The reactor with plastic waste is heated with NZ catalyst heated by using CNG gas up to 380◦C. Sensor is placed through the wall of the pyrolysis chamber to measure temperature. The combustion chamber required a 1:1 ratio of catalyst to plastic. In the pyrolysis chamber, a "nitrogen hole" ensures uniform heating throughout the reactor's cross-section and establishes an oxygen-free environment. There wasn't any output at lower temperatures; the procedure was conducted at temperatures between 350°C and 450°C for a duration of 160 minutes. Vapors from pyrolysis were directed to a condenser. This condenser, cooled by water, enabled the collection of condensed oil into designated collectors. Any uncondensed gas was released into the atmosphere, while the resulting char was gathered post the pyrolysis cycle. The produced oil is depicted in Figure 4. The outcomes of the pyrolysis are detailed in Table 1. All the properties of the derived oil were examined. The oil's density was accurately measured to ±0.0005 g/mL, while other parameters like pour point, flash point, and fire point were gauged with an accuracy of ±1°C.

5. Results of Pyrolysis Process

The results of pyrolysis process tabulated in following table no. 1:

Table 1: Product Yield of Pyrolysis Process (by weight in %)

Sr. No.	Sample	Oil (in %)	Gases (in %)	Carbon Residue (in %)
1.	PE	40	47	13
2.	PP	39.88	41.1	19.02
3.	PS	70	14.2	15.8
4.	MPW	60	17.5	22.5

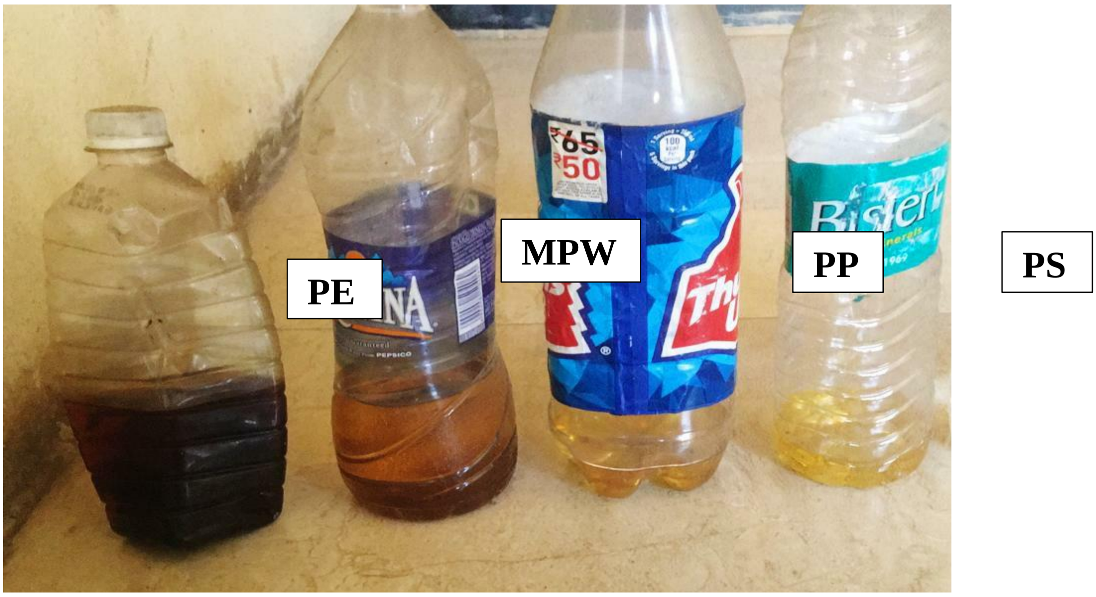


Fig 4: Oil Produced from Sample

The results of the pyrolysis process are stated above in percentage. It is seen that oil yield is comparatively higher in PS and MPW than in PE and PP (both having nearly equal results). Gas yield is significantly higher for PE and PP averagely near 45% while in the case of PS and MPW it is lesser. Carbon residue in all cases average of 17.58% is not much higher showing the lesser yield of production and in all that PP is having 19.02% which is considerable. The motive of the project is to produce oil with the wholesome elimination of plastic and to achieve environmental sustainability. The PE, PP, and PS are individual types of plastic. Hence, most consideration should give to the MPW which contains all types of plastic to achieve motives. The properties of oil produced from MPW are summarised in table no. 2 as follows:

Table 2: Product Yield of Pyrolysis Process (by weight in %)

Properties	**Pyrolyzed Oil**
Colour	Orange to dark brown
Calorific Value	10450
Specific Gravity	0.81
sulphur Content	0.167%
Water Content	0.05%
Flash Point	<40^{0}C

As per the report of tested oil, the oil is the best quality fuel for furnaces, and boilers and it is applicable for all applications which have a requirement of the same with a calorific value. It is also a lower cost. It has a very small amount of sulphur emission and near to zero-carbon residue. Storage and transportation are like other natural fuels but do not require an explosive license for storage. Pyrolysis oil is the best alternative available at a lower cost than natural oil. Pyrolysis oil comparison with light diesel oil (LDO) and furnace oil (FO) is stated in following table no. 3.

Table 3: Comparison Between LDO, FO and Pyroil

Technical Specifications	LDO	FO	Pyroil
Calorific Value (Kcal/ Kg)	10450	9500	10400
Ash (%Wt.)	0.01-0.02	0.02-0.04	0.0028
Carbon Residue (% Wt.)	1.5	2.0	0.0068
Density (g/ml)	0.84	0.92	0.81
Kinematic Viscosity (40 in cSt)	2.5 - 5	80 -125	1.5
Pre-Heating	Not Required	Required	Not required
Sulphur (% Wt.)	1.8	4	0.167
Water Content (% Vol)	0.25	10	0.05

As shown in above table, properties of pyrolytic oil are seen better than LDO and FO. The calorific value of pyrolytic oil (10400) is lesser than LDO (10450). It is not much significant. Other properties are better than other two oils.

Oil Purification Pyrolysis (distillation process):

According to Lee K. (2009), the initial pyrolytic oil derived from the pyrolysis process can comprise compounds ranging from C5 to C25, along with other byproducts. As highlighted by Songchai Wiriyaumpaiwong (2017), distillation can effectively separate lighter components from the denser residues found in pyrolytic oil. This oil, when derived from mixed plastic waste, is clear at 150°C but takes on a yellow tint at 180°C. The rate of distillation isn't uniform, initially accelerating and then slowing down. A higher distillation temperature results in more distillate oil. The distilled pyrolytic oil has both reduced density and viscosity compared to its undistilled counterpart. Notably, both the density and viscosity of the distilled version are akin to gasoline's, though there's a difference in calorific value. Distilled pyrolytic oil, derived from plastic waste, shows promise as an alternative to gasoline for internal combustion engines. Gasoline is conventionally the primary product from crude oil distillation. Undistilled pyrolytic oil can also be apt for internal combustion engines, potentially serving as an alternate fuel source, suggesting that additional distillation might not always be necessary.

6. Design of Pyrolysis Process:

The pyrolysis system will be effective for the city, based on the reviews of plastic, population, trash creation rate in Islampur, and pyrolysis technology that were previously described. Due to covid-19, the census was not done. Hence, population forecasted in 2021 is 1,15,127. As per the Central Pollution Control Board 2019 report plastic waste generated 10.41 grams per capita per day. Hence, the total plastic waste generated by Islampur is 1.2 tonnes/day. Hence, considering the future scope capacity of the pyrolysis plant is 2 tonnes.

Details of Pyrolysis Plant

- Type of Pyrolysis Plant: Continuous Pyrolysis Plant
- Type of Pyrolysis Process: Catalytic Pyrolysis
- Reactor Used: Fixed-bed reactor
- Cycle Time: 12 Hours

Estimation Of Pyrolysis Plant

- Cost of Plant: Rs. 18,750,000/-
- Erection and Installation Charges: Rs. 275000/-

❖ Transportation Charge: At actual
Sub Total = Rs. 19,025,000/-

❖ Pre-processing Machine:
1) Shredding Machine: Rs. 240,000/-
2) Grinding Machine: Rs. 370,000/-
3) Aglow Machine: Rs. 550,000/-
4) Dust Cleaning Machine: Rs 175,00
Sub Total = Rs. 1,335,000/-

❖ Land Required: Rs. 14, 19,500/-
1) Plot: 8500 ft^2
2) Shed: 5500 ft^2

Total Cost = Rs. 19,49,54,500/-

❖ Manpower Requirement:
1) Plant Operators = 4 = 4*15000 Per Month = Rs. 60,000/-
2) Pre-processing Labour = 4*7800 = Rs. 31,200/-
3) Supervisors = 3 = 3* 23000 = Rs. 69,000/-
Sub Total = Rs. 160200/-

❖ Miscellaneous Requirement:
1) Water: 3000liters per month = Rs. 27,000/-
2) Electricity: 35HP per month = Rs. 51,000/-
3) Catalyst: 26000kg = Rs. 520,000/-
Sub Total = Rs. 598,000/-

❖ Cost Estimation Per Liter:

Total Cost Per Month Required = Rs. 7,58,200/-

Oil generated by plant = 1100liters in one cycle (in one day)

Table 2: One Cycle Requirement

Description	Quantity	Cost (Rs.)
Water Required for one cycle	112 liter	1008
Electricity Required for one cycle	1.35HP	1970
Catalyst Required	1000 kg.	20,000
Total Manpower	11	6161.540
Total Cost Required for 1100 liter = Rs. 29,140/-		

Production Cost of One Liter = Rs. 26.49 = Rs. 27/-

7. Impacts of Pyrolysis System on Islampur City

The major issue of plastic waste disposal will be resolved. The disposal treatment results in value-added products i.e., pyrolytic oil, gases, and carbon residue. For 1-year the country facing problems with hikes in oil prices exceeding Rs. 100/-per liter. Here pyrolytic oil is produced in Rs. 27/-. Even considering 20% profit, the cost per liter should not exceed Rs. 40/-. The oil produced can be a replacement for diesel oil. The gases produced are collected in the gas chamber. Hence, air pollution can be prevented. Carbon residue produced can be used as bitumen in road construction or other industrial applications. Mainly, the original form of plastic is eliminated. All in concludingly, plastic is disposed-off without hampering the environment under a controlled system. Hence, environmental sustainability is achieved, and also one step will promote "Swachh-Bharat Abhiyan". There is a employee's requirement, hence unemployment issue can be resolved. Also, the pyrolysis plant contributes to the economic growth of municipal corporations. Therefore, the adoption of this modern technology will prove superior.

8. Conclusion

Islampur City produces 1.2 tonnes of domestic plastic waste. From the analysis of the dry waste sample of MSW, it is seen that plastic content is 22% which is much higher. Hence, it is important to have a prominent technology for its safe and eco-friendly disposal. Recently, refused-derived fuel is a technology arising worldwide. In RDF, electricity generation, palletization, pyrolysis, etc., technologies are involved. Electricity can be generated from wet waste or also it having other renewable sources for production. Palletization involves the production of raw plastic from existing plastic waste for new production. It doesn't achieve complete elimination. Pyrolysis involves combustion in a controlled environment and the resulting products are so much beneficial in maintaining the harmony of the environment and human health.

The designed pyrolysis plant capacity is 2 tonnes per day. It has the efficiency to produce 1100 liter of oil. The production cost of oil is much lesser than naturally producing oil. One liter of oil produced in Rs. 27/- is so much lesser. As stated above, the technology proves best in all ways. The objective of analysis and design of pyrolysis system for complete disposal of plastic waste is achieved.

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