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Recycle of Waste Plastic into Alternate Fuel

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ABSTRACT

This research presents an innovative approach to plastic waste management by converting it into alternative energy sources. The study focuses on transforming recyclable plastics like LDPE, HDPE, and PP into various types of oils through processes like pyrolysis, catalytic cracking, and hydrothermal liquefaction. Emphasizing the selection of high-quality, flammable plastics with low moisture content, the research highlights the importance of avoiding harmful substances to ensure health and environmental safety. The methodology includes the use of essential machinery for cleaning and processing plastics, such as reactor vessels and condensers. Results show that different plastics yield varying amounts of liquid fuel, with higher temperatures favouring the production of lighter oils. The conclusion underscores the potential of this technology to not only manage plastic waste sustainably but also to produce valuable fuels that can supplement or replace conventional diesel, thereby contributing to a circular economy.

Keywords: Plastic waste, Alternate fuel, Pyrolysis, Liquid fuel, Compact fuel, Refuse derived fuel, Fuel production.

INTRODUCTION

To address the serious issue of plastic waste, researchers have developed a method to transform plastics into alternative energy sources. This process involves converting plastics like LDPE, HDPE, and PP into various types of oils. The study focuses on two categories of plastics: thermoplastics, which soften upon heating and can be reshaped, and thermosetting polymers, which cannot be reshaped once set. Specifically, the research targets recyclable thermoplastics such as polyethylene (C_2H_4), polystyrene (C_8H_8), and polyvinyl chloride (C_2H_3Cl) for their potential energy content. The selection of plastics for conversion is critical, with preference given to those that are flammable and have low moisture content, as these characteristics are conducive to fuel production. The study emphasizes the importance of choosing high-quality plastics that do not contain harmful substances like bromine or sulphur, which can negatively impact health and the environment. The recycling process itself is influenced by the physical properties of the plastic, dictating the necessary pretreatment steps, the temperature at which the plastic is processed, and the intended final use of the product. The research also sheds light on challenges such as emissions, residual ash, and the potential for equipment corrosion. It underscores the need for sustainable plastic waste management practices and the adaptation of technology to effectively facilitate the conversion process. The study concludes by stressing the importance of matching the type and quality of the produced fuel to the specifications of the stoves used, in order to maximize energy recovery and minimize the environmental impact of emissions and ash.

Methodology

Materials for Processing

1. Discarded tires and rubber.
2. Plastic bags no longer in use.
3. Abandoned buckets.
4. Household plastic waste, including toys and bottles.
5. Hospital waste, such as used injections and plastic bottles.
6. Any other form of plastic waste is also acceptable.

Essential Machinery

1. Reactor vessel
2. Reboiler
3. Condenser-vessel
4. Hydrocarbon-oil

Machine for Plastic Cleaning(Purification)

This machine is used to remove water, soil, dust, and other unwanted substances from the plastic. It ensures the plastic is thoroughly dried and cleaned before it is introduced into the reactor vessel.

Overview of the Fuel Production Line from Waste Tire Pyrolysis

1. Old tires or rubber items are turned into useful things through a special process. First, they are sorted and broken down. Next, they are mixed with a special material in a machine that heats them up and breaks them down further. After that, a process is used to take out the black carbon, which can involve cleaning out sulphur or nitrogen. Finally, the material is cut into small pieces and goes through a cleaning process in a tall tower to make oil from tires.
2. The tire oil is heated for degumming and dehydration, and sulfuric acid is added at a Temperature of 30-50°C for acidification. The process involves separating precipitation and removing acid sludge and gum.
3. To clean something using this method, you need to wash it several times, about three to five times. After that, you add a chemical called sodium hydroxide to make the solution neutral. Then, the used cleaning liquid is treated, and clay is added to the mix to take away any colour, finishing up the process.
4. The crude bio-diesel is filtered by a frame filter, followed by catalytic-distillation. Other oils and catalysts are added to produce high quality bio-diesel.

Processing Unit

1. The processing unit necessitates 4,600 sq. ft. of operational area.
2. The height requirement is approximately 18 to 22 ft.
3. The unit is highly automated, resulting in a very low operator-to-processor ratio.
4. The system is made with parts that fit together easily, so it can be set up quickly and work well without any hassle.

Liquid Fuel Production

Method of Production

The transformation of plastic waste into fluid(liquid) fuel is achieved through a process where plastics undergo pyrolysis, resulting in the production of hydrocarbons which are then condensed. Pyrolysis refers to the breakdown of materials at high temperatures in the absence of oxygen(O_2), often using inert gases such as nitrogen. During this process, plastics that are amenable to conversion are placed in a reactor and subjected to temperatures ranging from 450 to 550 degrees Celsius. The type of plastic and the specific conditions of pyrolysis influence the formation of carbon deposits within the reactor, which must be cleared post-pyrolysis to ensure efficient heat transfer. The oil produced, a composite of various liquid hydrocarbons, is then distilled continuously as the plastics reach a vaporizable state at the reaction temperature. This vaporized oil is further refined using a catalyst to crack it into simpler forms. The boiling range of the resultant oil is determined by the operational settings of the reactor, the cracking unit, and the condenser. Fractional distillation may be employed in certain setups to tailor the output to specific requirements. Once distilled, heavier hydrocarbons like diesel fuel, kerosene-oil, and gasoline are condensed using a water-cooled system, while lighter gaseous hydrocarbons such as methane (CH_4), ethane (C_2H_6), propylene (C_3H_6), and butane (C_4H_{10}) are typically burned off in a flare stack, especially when the reactor produces a substantial volume of exhaust gas.

Feeding Methods and Reactor Types

The processing of waste plastics can differ based on their characteristics. Typically, waste plastics are fed into the reactor without pre-treatment. However, flexible plastics such as films and bags may be shredded and melted to reduce their volume before introduction into the reactor. Various reactor designs and heating methods exist, including kiln and screw types, with some utilizing induction heating as an alternative to burners. Carbonaceous deposits forming in the reactor can insulate heat, thus stirring mechanisms are sometimes employed to facilitate their removal. Post-pyrolysis, these deposits are extracted either by vacuuming or using a screw conveyor system at the reactor's base. Understanding the interplay between the waste plastic's amount and type, alongside the operational parameters, is crucial for operators. Evaluating the efficiency of the process often involves comparing energy usage and plant costs against the capacity for plastic treatment.

Products and By-products

You can use a special kind of fuel, made from things other than normal gasoline, in engines and to start fires. There's a table below (Table 1) that shows how this fuel, made from old plastic, is different from natural gas. You can also mix this plastic fuel with the usual gasoline to make engines work better and more reliably. This method makes the engines more stable and dependable.

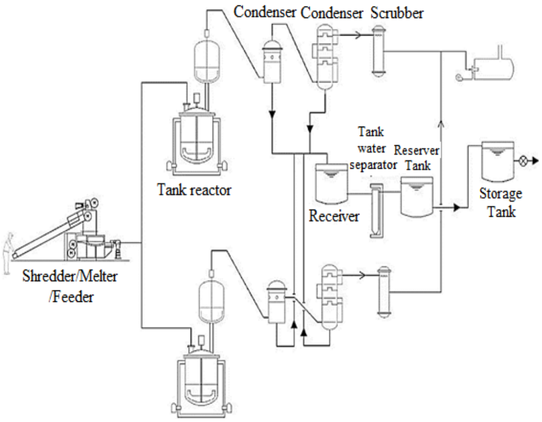

Fig. 1. Liquid Fuel Production Process (Source-Ref. no.-21)

Compact Fuel Production Manufacturing Method

The manufacturing method for compact fuel generally consists of two stages: processing and small rigid structure production: Processing involves shredding and removing non-flammable materials from the plastic. Small rigid production includes minor crushing and small size compact structure (<200°C). However, no pre-treatment is necessary if the compact fuel manufacturer can manage the waste with proper separation.

Large scale factory setup model (36 ton/day)

To process plastic waste, we use a reactor. You can just throw the waste in, but for things like plastic bags, it is better to chop and melt them first so they don't take up too much space. There are different kinds of reactors that heat up in various ways. Some even use electricity instead of fire. Sometimes, the reactor gets coated with a layer of carbon, which keeps the heat in. To get rid of this layer, some reactors have special mixers. After we heat the plastic and turn it into a liquid, we clean out any leftover carbon. This can be done with a vacuum or a moving screw at the bottom of the reactor. It's crucial for the people running the reactor to know how the type and amount of plastic they use can change the process. They also look at how much energy the reactor uses and how much it costs to run compared to how much plastic it can handle.

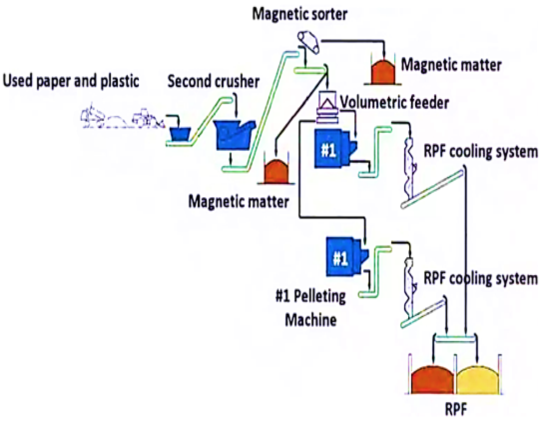

Fig. 2. RPF Production Process (Source-Ref. no. 21)

RESULT AND DISCUSSION

Figure 3 below illustrates the pyrolysis temperatures for converting various municipal waste plastics into fluid(liquid) fuel oils. The types of plastics, including PP, LDPE, HDPE, and a mixed category, demonstrate distinct thermal behaviours, transitioning from solid to liquid and gaseous states below 300°C. Specifically, PP undergoes pyrolysis at an average temperature of 225°C, LDPE at 210°C, HDPE at 213°C, and mixed plastics at 197°C. The duration of pyrolysis also varies, with PP and L.D.P.E requiring 214 and 235 minutes respectively, H.D.P.E 220 min, and mixed plastics 260 minutes. These variations in temperature and time influence the length of the hydrocarbon chains produced during decomposition. For instance, pyrolyzing waste plastic bags at 420-440°C yields a 74% conversion rate to a liquid product, often termed plastic crude oil. The study indicates that higher temperatures favour the production of liquid products with lower boiling points and gaseous outputs. This is attributed to the oxidative degradation process, where atmospheric oxygen reacts with organic materials, initially forming peroxides and ultimately resulting in a substantial fluid(liquid) yield.

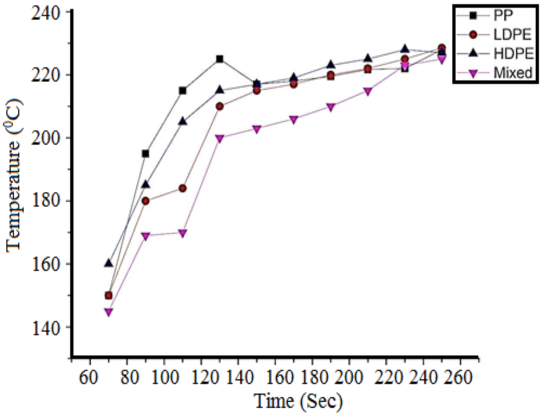

Fig. 3. The impact of varying reaction temperatures on the production of liquid fuel. (Source-Ref. no. 17)

Figure 4 analysis reveals that the yield of liquid fuels derived through pyrolysis of plastics sourced from municipal landfills exhibits variability. Specifically, polypropylene (PP) generates a liquid fuel yield of 4,820 mL, equating to 80% of its weight. Low-density polyethylene (LDPE) produces a yield of 4,400 mL, approximately 73% by weight. High-density polyethylene (HDPE) results in a yield of 4,150 mL, or 70% by weight. Conversely, a mixture of plastics yields 2,700 mL, representing 46% by weight. Notably, the yield correlates with the pyrolysis process's temperature and duration. It is hypothesized that elevating both parameters could enhance the thermal cracking process, potentially increasing the output of the sought-after crude oil fraction from plastics. The effect of varying conditions on the fluid (liquid) yield was systematically evaluated, acknowledging that the thermal decomposition of plastics proceeds via a radical mechanism initiated by heat-induced radicals.

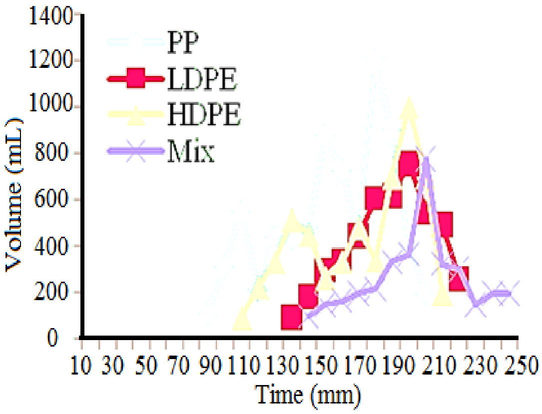

Fig. 4. The Distillation temperature for the pyrolytic oils derived from various municipal waste plastics such as polypropylene (P.P), low density polyethylene(L.D.P.E), high density polyethylene (H.D.P.E), and mixed plastic materials. (Source-Ref. no.18)

From Fig. 5 the process of pyrolysis necessitates careful consideration of both temperature and duration to initiate the necessary chemical reactions. There is a critical interdependence between these two factors. Pyrolysis can occur at varying rates, categorized into rapid and gradual phases. The latter can be further divided into traditional pyrolysis and the carbonization process. The conversion ratios of different plastics sourced from municipal waste (such as PP, LDPE, HDPE, and assorted plastics) into pyrolytic liquid fuel are depicted in the accompanying figure. For instance, PP converts into pyrolytic liquid fuel (PLF) at a rate of 80% by weight, leaving behind 13% as non-condensable gases and 7% as other residues. In the case of LDPE, it transforms into PLF at a rate of 73% by weight, with 15% becoming non-condensable gases and the remaining 12% as other forms of waste. HDPE's conversion into PLF occurs at a rate of 70% by weight, with equal proportions (15%) of non-condensable gases and other residues. The conversion rate for mixed plastics into PLF is 46% by weight, with 40% turning into non-condensable gases and 14% remaining as residue. The study utilized a conventional slow pyrolysis method, operating at temperatures ranging from 250-350°C to facilitate the reaction. The findings indicate that higher temperatures lead to an increased production of liquid products with lower boiling points and gaseous outputs. This is attributed to the oxidative degradation process where atmospheric oxygen binds to organic molecules, leading to the initial formation of peroxides. As the reaction progresses, the oxygen integrated into the organic compounds results in a higher yield of liquid products.

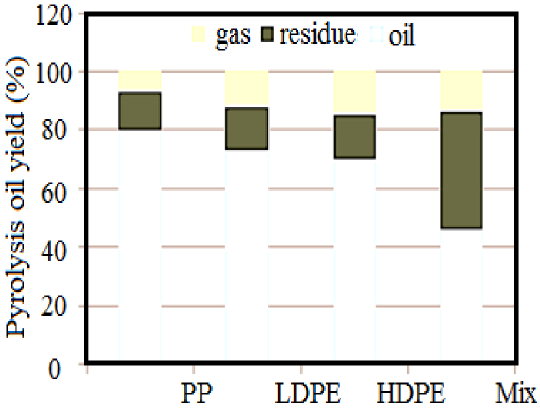

Fig. 5. The proportion of liquid fuel derived through pyrolysis from mixed plastics in municipal landfills, including PP, LDPE, and HDPE. (Source-Ref no. 18)

From Table 1, Research indicates that the energy content of fuel derived from plastic waste is on par with that of conventional petroleum-based diesel when refined through distillation. This process effectively segregates the various oil densities light, medium, and heavy mirroring the separation found in standard diesel. The calorific values, as outlined in Tables 1, demonstrate this similarity. For instance, the calorific value of standard diesel, as per ASTM D240, is 45.50 MJ/kg, while the values for fuels from different plastics range from 40 to 42.50 MJ/kg, with variations based on the distillation temperature. Specifically, fuels distilled below 170°C have a calorific value of 37 MJ/kg. Those distilled between 170°C and 250°C have a value of 40 MJ/kg, and those above 250°C reach 46 MJ/kg. The empirical formula of CH_2 for waste plastic bags, akin to polyethylene, along with a higher ratio of carbon and hydrogen, contributes to the elevated energy content of these fuels. The kinematic viscosity and specific gravity of these fuels also show comparable figures to diesel when measured at 40°C and 15.6°C respectively, according to ASTM standards D445 and D1298. The cetane index, flash point, and distillation temperatures further align with diesel specifications, albeit with some variations across different plastic-derived fuels. In summary, the pyrolysis of mixed plastic waste not only offers an alternative route for feedstock recycling but also produces liquid hydrocarbons that can potentially blend with or replace conventional diesel. The high calorific values surpass those of biomass and low-grade coal, suggesting a viable use as a standalone fuel or in combination with other materials. Moreover, engines running on 100% waste plastic oil have demonstrated increased thermal efficiency, highlighting the potential of converting plastic waste into a valuable energy resource.

Table 1: Characteristics of the liquid fuel derived from plastic waste in relation to conventional diesel fuel from petroleum sources

Fuel Type	PP	LDPE	Mixed	HDPE	Diesel
Gross calorific value	41	41.6	42	42.5	45.5
Kinematic viscosity	1.968	2.311	2.64	2.421	3.2
Specific Gravity	0.749	0.779	0.81	0.81	.835
Flash point	<24	<24	50	40	75
Distillation temperature	100	100	100	100	250
Distillation temperature	161	174	221	211	300
Distillation temperature	272	286	333	325	350
Cetane index	40	40	55	51	64

CONCLUSION

In this research paper we discuss the innovative and developmental utilization of plastic waste, addressing the challenge of finding alternatives to plastic due to its diverse applications and characteristics. As plastic demand rises, so does the corresponding increase in plastic waste, contributing to environmental issues. A compact waste management method gains traction, utilizing byproducts from resin pyrolysis as powders or synthetic substances. Waste plastic undergoes pyrolysis, avoiding costly catalysts, resulting in a mix of gas and oil. Despite a temporary dip in demand growth due to the global financial crisis, current data shows a steady rise in crude oil consumption. Existing gas and oil reserves may be depleted soon. Plastic pyrolysis oil serves as diesel fuel in engines, with adjustable combustion conditions. Chemical recycling reduces landfill and incineration, substituting fossil resources with recycled materials. These recycled raw materials transform plastic waste into secondary materials for new plastics, supplementing existing recycling methods and enhancing the EU's total recycling capability.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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