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Extraction and Performance Analysis of Hydrocarbons from Waste Plastic Using the Pyrolysis Process

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Abstract: Ecosystem destruction is one of today's significant challenges due to fast industrialisation and an increasing population. It takes several years for solid trash, such as plastic bottles and supermarket bags, to decompose in nature. In addition, plastic disposal techniques such as landfilling, reuse, and incineration pose significant threats to human health and the environment. In this paper, we investigated whether the impact of mixing biodiesel with waste oil from recycled plastic on the resulting fuel mixture's yields better physical and chemical properties. Consequently, pyrolysis is one of the most advantageous and practical waste disposal methods as it is both environmentally benign and efficient. Pyrolysis is the high-temperature thermal breakdown of solid waste to produce pyrolytic oil. The pyrolytic (plastic) oil produced is converted to a hydrocarbon-rich pyrolytic fuel. Similar to diesel and gasoline, pyrolytic fuel has the same calorific value. Internal combustion engines may operate on pyrolytic fuel without suffering a performance reduction. Researchers examined engine performance and exhaust pollutants. The research discovered that the engine could operate on plastic pyrolysis fuel at full load, enhance brake thermal efficiency by 6–8%, and lower UBHC and CO emissions; however, nitrous oxide (NOx) emissions were noticeably higher. The findings demonstrated the possibility of using plastic pyrolysis fuel as a diesel substitute.

Keywords: waste plastic; reactor; pyrolysis; biofuel; hydrocarbons

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1. Introduction

Energy demand and consumption are anticipated to rise, particularly for fossil fuels [1–3]. Fossil fuels, often referred to as traditional energy, are extensively used in India's automobiles and industrial facilities [4,5]. Plastic consumption went from 4000 tonnes per year in 1990 to 4 million tonnes per year in 2001 and is projected to escalate by 3.5–4 lakh million tonnes per year by 2022 [6,7]. After they have served their purpose, items made of plastic are thrown away. Biological breakdown is not possible with these materials [8,9].

Consequently, they are either buried or burned [10]. These processes pollute the air and the land, making them not eco-friendly. Tyres and waste plastic are classified as hazardous or solid waste in India [11,12]. About 60% of (retreated) waste tyres are thought to be disposed of in both urban and rural areas via unidentified routes [13,14]. The risks associated with waste tyres include air pollution brought on by the open burning of plastic, aesthetic pollution brought on by the accumulation of waste plastic, illegal waste collection, and additional effects such as changes to hydrological regimes when gullies and watercourses turn into dump sites [15–17], as shown in Figure 1.

Figure 1. Waste plastic on land and water.

Most waste comprises thermoplastic polymers, and this percentage is steadily rising globally [18,19]. Therefore, waste plastics present a severe environmental challenge due to their enormous quantity and disposal issues because thermoplastics take a very long time to biodegrade [20,21]. The conclusion drawn from every line of reasoning and argument in favour of and against plastics is that it is not biodegradable [22]. Several different kinds of research have been done regarding the disposal and decomposition of plastics [23]. Currently, disposal techniques are used in landfills and mechanical, biological, thermal, and chemical recycling. Chemical recycling is one of these methods, and it's a research area that's recently attracted much attention because the products that come from it are beneficial.

This study shows how people are currently utilising energy and looks into ways to improve it by using plastic waste oil. The pyrolysis process produces a fuel with hydrocarbons similar to conventional fuel [24,25]. We collect plastic waste from homes, industries, and other locations. This simple pyrolysis apparatus converts collected plastic waste into a liquid fuel called plastic oil [26,27]. The water washing method was used to clean the waste plastics to avoid contamination in the liquid fuel. Later, various experiments were carried out to identify the characteristics of the obtained liquid fuel.

2. Literature

In India, there are currently no substantial alternative energy sources [28]. Moreover, it imports more than 49% of its energy requirement, owing to its inability to fulfil energy demand in 2017. In 2016 and 2017, the price of imported crude oil and petroleum products climbed by 39.8% and 23.0%, respectively, due to Thailand's growing oil consumption [29,30]. Thailand has purchased chiefly crude oil from countries in the Middle East. It is predicted that the use of renewable energy in Thailand will gradually climb. It has been proposed that oil produced from recycled plastic is utilised as an alternative fuel for automobiles to increase this proportion while decreasing the quantity of primary energy consumed. This programme moves toward fuel diversification via energy conversion technologies, notwithstanding the declining need for energy in the transportation sector. In addition, it focuses on the use of oil derived from discarded plastic in diesel engines.

There is much plastic garbage because factories and homes produce too much waste. These wastes are difficult to handle and take hundreds of years to decompose. Only 2% of chemicals are recycled, compared to the majority of plastic, which is recycled mechanically [31,32]. In general, the landfill method of waste management is currently in vogue [33]. This method typically necessitates a large amount of landfill space and affects the environment, causing soil pollution.

Plastic garbage contains hydrocarbons, the main constituent of conventional fuels [34]. By converting plastic trash into fuel, the possibility of recycling improves. Products may be acquired from the manufacturing process and utilised as an energy source equivalent to traditional fuels. In terms of waste management, it may also improve the environment by minimising the challenge of locating landfill sites, thus reducing the quantity of plastic trash created and lowering the cost of plastic waste disposal. The diverse plastic compositions affect various sorts of plastics as well. Recent research found that the combination of low-density polyethylene (LDPE) and high-density polyethylene (HDPE) in oil products has a higher heating value than the use of LDPE, polypropylene (PP), or HDPE by themselves. The most excellent yields were determined to be LDPE [35]. Oil from recycled plastic-powered engines was also tested, and it was discovered that there was almost no variation between it and diesel fuel [36]. The thermal efficiency of waste plastic oil was significantly higher when compared to that of diesel fuel [37,38].

Kalargaris et al. investigated the exhaust emissions of a diesel engine with 4 cylinders and direct injection. It uses diesel mixed with varying amounts of waste plastic oil, increasing ignition delay and nitrogen oxide emissions [39]. There were more hydrocarbon emissions than with diesel fuel [40]. These findings contradict the findings of another study that observed the exhaust emissions of a diesel engine with 4 cylinders and direct injection.

Biodiesel is expected to become a green energy source in energy mobility. Much research has supported using biodiesel as a viable substitute for diesel fuel. It is envisaged that the presence of oxygen in fuel molecules will result in cleaner biodiesel combustion and lower emissions. On the other hand, there are not an excessive number of reports involving biodiesel that has been combined with used plastic oil. For instance, Ramesha et al. discovered that a B20 mixture of algae biodiesel fuel and waste plastic oil might be utilised as fuel for diesel engines when blended together [41].

The oil from the waste plastic–biodiesel combination displayed 16% greater braking thermal efficiency than diesel engines. Furthermore, nitrogen oxide emissions increased slightly compared to diesel, while hydrocarbon and carbon monoxide emissions decreased. Senthilkumar et al. examined recycled plastic oil in diesel engines in conjunction with Jatropha biodiesel and observed that the waste plastic oil–biodiesel combination had higher brake thermal efficiency and brake-specific fuel consumption than oil from waste plastic [42]. When waste plastic oil and Jatropha biodiesel were combined, the emissions of hydrocarbons and carbon monoxide were reduced [43,44]. Without modifying the engine, waste plastic oil–biodiesel blends were used in the current study as an alternative fuel in a diesel engine. Castor and palm oils were blended with old plastic oil after transesterification and utilised to make the biodiesels that were ultimately selected [45,46]. The palm tree is a critical commercial crop in Thailand and the principal feedstock utilised in biodiesel production. Due to its substantial oxygen content in fuel molecules and outstanding fuel lubricity, castor oil was a viable alternative to edible feedstock [47,48]. Regarding the emissions produced, the oxygen in the fuel molecules assists in boosting the combustion processes. In this paper, we investigated the impact of mixing bio-diesel with oil from recycled plastic on the resulting fuel mixture's fundamental physical and chemical fuel properties. The primary areas of our investigation were the performance, combustion characteristics, and exhaust gas emissions of a diesel engine with a single cylinder. During the engine test for the combustion characteristics part, basic measures such as in-cylinder pressure and crank angle were logged. These data were used to evaluate the engine's performance. The first rule of thermodynamics' mathematical underpinnings was then used to calculate the rate at which the test fuels released heat. The specific heat ratio (SHR) was estimated using the in-cylinder pressure and the combustion chamber volume under the assumption that there was a polytropic process [49].

According to the observations of Machiraju et al., pyrolysis with a catalyst can produce a fuel with chemical properties similar to conventional fuels [50]. Observations indicate that pyrolysis is a feasible and economical process. The processing of one kilogramme of trash plastic results in the production of 0.75 kilogrammes of usable liquid fuel, all without releasing any contaminants and toxins. Along with the reduction in crude oil imports, there is also a reduction in the waste of harmful plastics. The fuel produced is most similar to diesel and can be used directly to start diesel engines. The biofuel generated has a pyrolysis Castrol oil content of 48.6%, a wax content of 40.7%, a pyroplin content of 10.1%, and a carbon black content of 0.6%, which is similar to plastic oil [47].

Brindhadevi et al. illustrated and explored the catalytic degradation of LDPE in a solid reactor using synthetic catalysts, which are expected to produce gasoline, hydrocarbon-rich liquid fuel, coke, and gas [51]. During the initial reaction, the TiO_2 catalyst generates the maximum yield of liquid fuel; as the reaction continues, this yield rapidly decreases. During cracking using the TiO_2/AlSBA-15 catalyst, the gasoline content rose from 45.6% to 85.4%, as did the liquid fuel efficiency (89.1%) and conversion (98.4%). The calorific value of the liquid fuel generated by the composite catalyst is 47.8 MJ/kg, which is higher than that of regular petroleum.

3. Materials, Process, and Characterisation

3.1. Waste Plastic

Although there are a variety of plastics, not all of them can be converted into plastic fuels. They must be segregated and categorised. The bulk of plastic garbage consists of LDPE, HDPE, PP, polyvinyl chloride (PVC), polystyrene (PS), and polyethylene terephthalate (PET). The majority of trash plastic consists of HDPE and PP [52].

3.2. Pyrolysis Process

The process of pyrolysis involves heating organic material in an oxygen-free environment to chemically decompose it. This results in the separation of large molecules into simpler ones. The processing of waste plastic is shown in Figure 2, which demonstrates how electric coils are used to maintain a maximum temperature of up to 400 degrees Celsius within the reactor. We restrict the heating temperature to avoid polymers degrading. The waste plastic is then vaporised, and at this high temperature, the output gas is condensed via the condenser unit. A small quantity of gas that cannot be condensed is then discharged into the atmosphere. This process of recycling used plastic into plastic oil took place nonstop across the whole facility. The collected liquid further purified and served as fuel for the vehicle. The non-condensable gases in our work were given a cooling treatment to lower their temperature, but in the future, we could set up a special system to burn the exhaust gas in the container. The following output products were gathered from the pyrolysis process: oil from recycled plastic (70%), gas (10%), and solid (20%), with values varying according to the weight of the input material. The production of the polymers was somewhere between 400 and 500 millilitres per kilogramme.

Figure 2. Setup for pyrolysis process of waste plastic into plastic oil (hydrocarbons).

3.3. Characterisation of Plastic Oil

Several methods were used to describe the pyrolysis oil, including the flash point, Ph value, engine performance, and emission analysis. The bomb calliper was used to ascertain the flash point together with the fire point of the plastic oil. After purification, a pH test was performed to determine the pH level of the plastic fuel using a pH metre. Fuel is acidic if the pH is less than 7. To raise the pH level to 7, it is necessary to wash with potassium hydroxide or sodium hydroxide dilution. Engine performance and emission analysis were performed on standard engines using blends of plastic oil with diesel in 10% & 90% and 20% & 80%.

4. Results and Discussion

4.1. Flash and Fire Point

A liquid fuel sample's flash and fire points indicate its flammability. It is crucial to understand that the flash point value is not a physical constant but rather the outcome of a flash point test and is based on the tools and techniques employed. The liquid's lowest temperature at which vapour combustion and burning begin may be referred to as its fire point. A fire point is created when an ignition source is used, and the heat generated is self-sustaining because it produces enough vapours to mix with the air and continue to burn even after the ignition source is turned off. The evaluation of fire and flash points using a bomb calorimeter is shown in Figure 3 below. Table 1 makes it very clear.

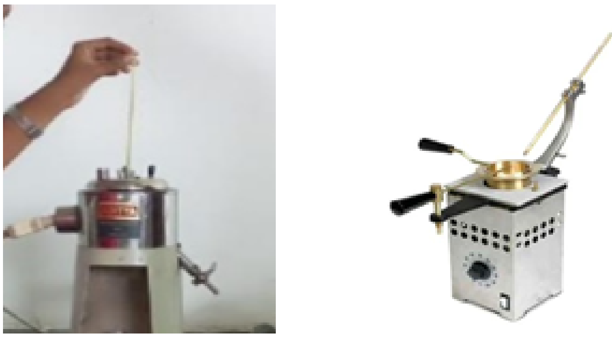

Figure 3. Experimentations of flash and fire point.

Table 1. Plastic oil's flash and fire points.

Sr. No.	Parameter	WPO	Diesel
1	Flash point (°C)	55	45
2	Fire point (°C)	61	56
3	Kinematic viscosity at 40 °C (mm^2/s)	1.98	4.139
4	Density at 40 °C (kg/m^3)	812	875
5	Calorific value (MJ/kg)	40.81	45.39
6	Cetane Number	48	54
7	Carbon (wt%)	81.7	84.7
8	Hydrogen (wt%)	10.7	13.7

4.2. pH Value

The essential characteristic of fuel is its pH level, which determines whether it is acidic or alkaline. The pH of an answer indicates how acidic or alkaline it is. If the pH falls below 7.0, it turns acidic; if it rises above 7.0, it becomes more alkaline. Most water-soluble oils have a pH between 8.5 and 9.0, which is slightly alkaline. We collected 5 mL samples of pure plastic oil to determine the pH level for our research. After purification, the pH value of plastic oil between 25 and 35 °C ranges from 6.5–7, and the resulting plastic oil has a neutral pH value.

4.3. Engine Performance

An experimental investigation was tested to assess and contrast the outcomes of using various test fuel types. This study aimed to find out how a single-cylinder diesel engine's performance and emissions would change when waste plastic oil was mixed with diesel. Here, we looked at examples of pure plastic oil fuels and mixtures of 10% and 20% plastic oil mixed with 90% and 80% of diesel, respectively. A single-cylinder, four-stroke, water-cooled diesel engine (Kirloskar TV1) with direct injection, an unaltered rated output power of 3.5 kW at 1500 RPM, and varied loading situations was used to produce three test fuels for testing. The engine was loaded and placed on a solid flat platform in the research laboratory. Figure 4 depicts the experimental setup.

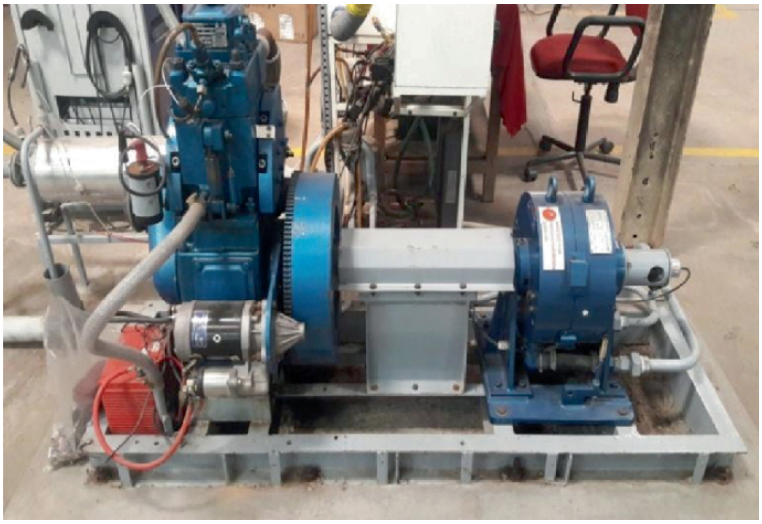

Figure 4. Experimental setups for engine performance on a 4-stroke engine.

The engine's brake-specific fuel consumption (BSFC) results in four different test fuel types under three operating loads. The BSFC increased under low loading (25% of maximum torque) vs. medium loading (50% of maximum torque) and high loading (75% of maximum torque). Moreover, the data suggest that for all fuels, an increase in engine load tends to result in a reduction in fuel consumption precision [53]. For diesel-waste plastic oil, the specific fuel consumption of brakes was marginally enhanced. Due to its lower heating value, diesel often improved BSFC when its proportion in blends was decreased [54]. Diesel increased the combustion efficiency of waste plastic oil, hence enhancing combustion. The lubricating properties of a diesel mix may reduce friction to the extent that waste plastic oil-derived pure brake efficiency is enhanced [55].

Regarding engine performance, an experimental study was conducted using plastic pyrolysis oil and other blend forms in a four-stroke variable compression ratio petrol engine. Regardless of load, the efficiency kept rising. The graph below compares the Brake thermal efficiency of diesel blend and plastic pyrolysis oil. As depicted in Figure 5, the plastic pyrolysis oil's brake thermal efficiency is lower when compared to diesel. A comparison of brake thermal efficiency and brake power is depicted. Pure plastic oil is less effective at braking thermally than blends of 10% and 20% with 90% and 80% diesel, respectively.

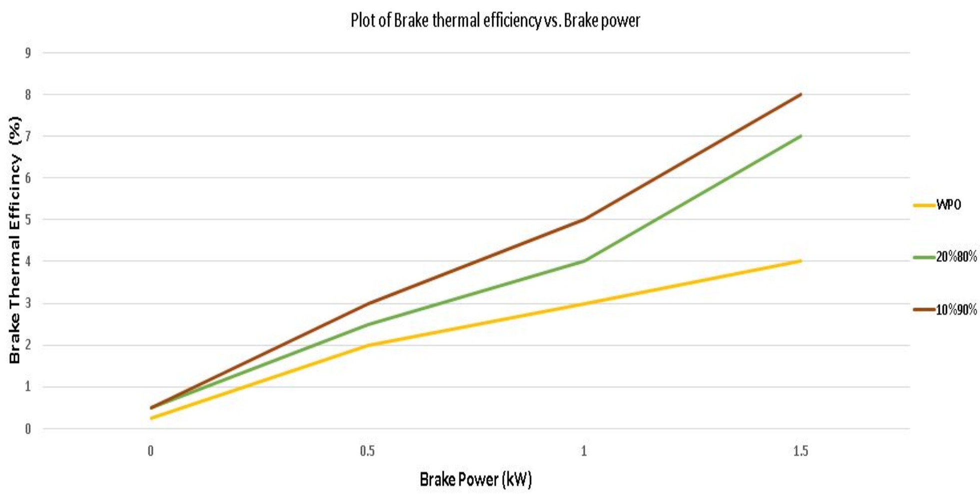

Figure 5. Plot of brake thermal efficiency vs. brake power.

4.4. Emission Analysis

Blends of biodiesel and oil derived from recycled plastic lowered CO emissions due to their higher viscosity and lesser calorific value. Because of the inefficient atomisation of the fuel mixes, the combustion temperature was reduced, which increased carbon monoxide emissions. The waste plastic oil emitted less carbon monoxide than the other two samples examined in this research. When diesel was blended with waste plastic oil, nitrous oxide (NOx) emissions were reduced compared to diesel blends that did not include waste plastic oil. Premixed combustion peak heat release was reduced due to the combustion of plastic oil and diesel mixes, which tended to restrict the increase in combustion temperature and did not encourage NOx formation.

The addition of Castrol oil to diesel fuel resulted in a reduction in NOx, similar to the study by Pumpuang et al. [56]. When plastic oil was added, the 10% mix's NOx emissions were greater than those of the 20% blend. Due to the reduced cetane value caused by adding plastic oil to diesel, there was a longer ignition delay, which may have contributed to the more significant NOx emissions.

4.5. Unburnt Hydro Carbons

Figure 6 depicts the variance of unburned hydrocarbon emissions with load for all mixes. As the amount of plastic oil in the bend increased, emissions of unburned hydrocarbons reduced. The temperature inside the cylinder is a crucial factor in affecting the characteristics of unburned HC and CO emissions. Typically, unburned HCs and CO emissions are more significant at lower temperatures. HC emissions rise while CO emissions decrease at certain temperatures. The threshold temperatures for hot ignition and CO to CO_2 oxidation are essential in determining the characteristics of HC and CO emissions.

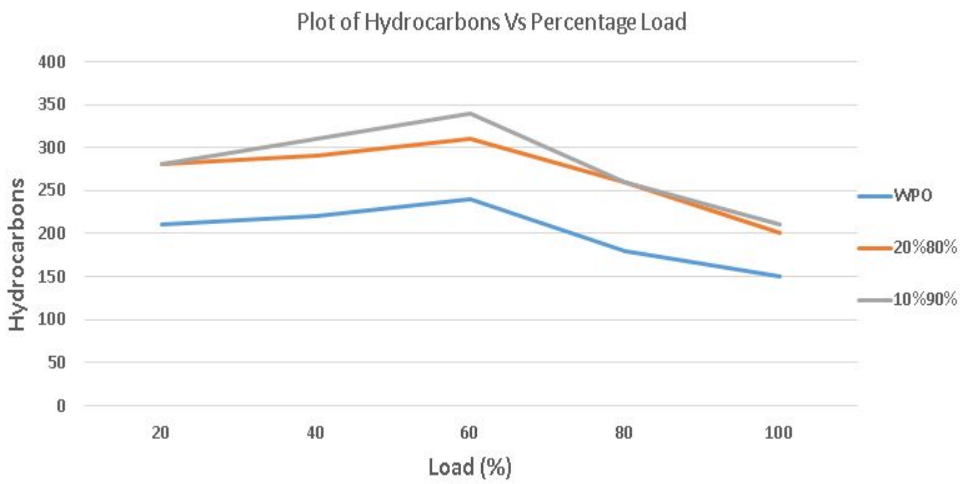

Figure 6. Plot of hydrocarbons vs. percentage Load.

Plastic oil has a more considerable calorific value than diesel mix, which may lead to higher engine temperatures when used in the engine of the present investigation. HC and CO emissions followed a varied pattern as the proportion of plastic oil in the mix increased. This might be because the temperatures within the cylinder are near to or below the temperature at which H_2O_2 decomposes fast, generating radicals that convert HC molecules into CO. When the temperature is near to or below 1000 K, the partial oxidation of HCs into CO does not occur, resulting in more significant HC emissions and reducing CO emissions.

5. Conclusions

This study explored the effects of adding plastic oil to conventional oil on the fuel's blend, which characterised combustion, engine performance, and exhaust pollutants. Two distinct samples were selected for blending with the recycled plastic and diesel. The fol-lowing is a brief summary of the work:

- Pyrolysis, which has been discovered to be the simplest, effective (in terms of cost), and efficient process for turning waste plastic into fuels solves environmental and energy problems. The majority of plastic garbage's energy may be transformed into liquid, gas, or charcoal.
- The technical and economic impacts of utilising this oil in a diesel engine are compared, and it is discovered that this oil can replace diesel oil. This procedure yields a liquid with a substantially greater volume and a narrow boiling range. This method yields cleaner fuel than conventional fuels.
- In terms of fuel lubricity and viscosity, a biodiesel concentration of 10% (v/v) was found to be the most effective for improving oil from recycled plastic.
- Adding biodiesel to used plastic oil slightly increased the engine's thermal braking efficiency.
- Adding biodiesel decreased the amount of hydrocarbon- and oxide-containing nitrogen emissions, whereas carbon monoxide and smoke emissions increased.

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