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# A Review of Plastic-derived Diesel Fuel as a Renewable Fuel for Internal Combustion Engines: Applications, Challenges, and Global Potential

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**Abstract.** Plastics' broad application in a wide range of industries has resulted in an increase in global plastic production rates over time. The continued need for plastic, which can take up a lot of space in landfills due to the accumulation of plastic trash, has contributed to environmental problems. To address the problem of plastic waste, many options, such as recycling and energy recovery technologies, have been created. One possible technique to address landfill issues is to convert plastic waste into diesel fuel. In this review, the potential use of plastic-derived diesel fuel in internal combustion engines as a renewable and sustainable energy source is discussed. It's been found that due to similar properties in plastic-derived diesel fuel, it inherits similar performance in internal combustion engines.

## 1. Introduction

Plastic has risen to become one of the most widely utilized materials. It is less expensive than alternative materials such as paper and fabric. Because of its low cost, plastic is a popular material for a wide range of applications. It has been utilized in a wide range of activities including healthcare, construction, packaging, and engineering [1-3]. Polyethylene Terephthalate (PET or PETE), High-Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low-Density Polyethylene (LDPE), Polypropylene (PP), Polystyrene or Styrofoam (PS), and miscellaneous plastics are the seven types of plastic that are most common in the modern world today [4,5]. The rapid expansion of the world's population has increased the need for commodity plastics. More than 8.3 billion tonnes of plastics were manufactured worldwide between 1950 and 2021 but only 9% of that plastic was recycled, 12% was incinerated, while the remaining 79 % was discarded in the environment [6]. In Malaysia, 19% of the total garbage was made up of plastic in 2007 [7]. Decomposing plastic in landfills might take up to 500 years, and it could release contaminants into surrounding soil and water if not handled properly, which could have adverse











effects on the environment and human health. Previous studies showed that endocrine disruptors, malignancies, developmental disorders, hypertension and reproductive abnormalities have all been linked to plastics' chemical compounds and additives such as phthalates, bisphenol A or polybrominated diphenyl ethers [8-10]. Plastic also breaks down into microscopic plastics that pollute the environment and marine life. Because of their tiny size, microscopic plastics are easily ingested by a wide variety of marine species, ranging from high- to low-trophic level organisms. It impairs their growth, metabolism, reproduction, and cellular response [11-14]. It is essential to properly dispose of plastic waste and transform it into renewable energy sources. Since plastic is mostly made of carbon and hydrogen, it has the same amount of energy as diesel or other traditional fuels. Pyrolysis is a process for converting plastic waste into energy in the form of solid, liquid, and gaseous fuels [15,16]. In pyrolysis, plastic waste is heated to a high temperature in the absence of oxygen to break down it. This study aims to discuss the properties of plastic-derived diesel fuel to determine their suitability as a fuel. Additionally, the application, problems and global potential associated with the utilization of waste plastic diesel fuel in a diesel engine will be examined.

## 2. Physical and chemical properties of plastic-derived diesel fuel relevant to engines

Ashes and volatile matter are the key determinants of liquid oil output in the pyrolysis process. High volatile matter encouraged the production of liquid oil, whereas high ash content reduced it, increasing gaseous yield and char formation [17]. The investigation is performed using a proximate analysis. The proximate analysis refers to the process of determining the ash content, moisture content, volatile matter, and fixed carbon content of a sample. Table 1 shows the proximate analysis of several polymers. Table 2 summarises several of the properties of liquid fuel produced by pyrolysis of mixture/single polymer as reported in the literature.

**Table 1.** Proximate analysis of plastics [18-24].

Types of plastics	Plastic type marks	Moisture (wt%)	Fixed carbon (wt%)	Volatile (wt%)	Ash (wt%)
PET		0.46	7.77	91.75	0.02
HDPE		0.00	0.01	99.81	0.18
PVC		0.80	6.30	93.70	0.00
LDPE		0.30	0.00	99.70	0.00
PP		0.15	1.22	95.08	3.55
PS		0.25	0.12	99.63	0.00
Polyethylene (PE) Acrylonitrile butadiene styrene (ABS)		0.10	0.04	98.87	0.99
Polyamide (PA) or Nylons Polybutylene terephthalate (PBT)		0.00	0.69	99.78	0.00

**Table 2.** Fuel properties

Type of plastic	Mixture of HDPE, LDPE, PP, PS, PET	PE, PS and 70% organic matter	Mainly ABS, PS and clay	Virgin PP	Waste PP	Diesel
Density@15-15.6°C (kg/l)	0.743	0.825	0.9813	0.768	0.769	0.8398
Kinematic viscosity@40°C (cSt)	3.5	3.76	1.918	-	-	2.62
Flash point (°C)	47	41	13	-	-	59.5
Fire point (°C)	53	-	-	-	-	-
Pour point (°C)	-4	-	-	2.7	-4.7	-
Cloud point (°C)	-36	-	-	-	-	-
Calorific Value (MJ/kg)	41.1	40.58	38.3	45.63	46.04	42.9
Aromatic content (%)	29	-	65.5	-	-	29.5
Reference	[25]	[26]	[27]	[28]	[28]	[27]

### 3. Engine performance and emissions using plastic-derived diesel fuel

Engine performance is a measure of the engine's ability to complete its designated function, which is the conversion of the chemical energy contained in the fuel to meaningful mechanical work. The following factors are used to determine an engine's performance: combustion pressure, brake thermal efficiency (BTE), brake specific fuel consumption (BSFC). The pressure is a measure of the power developed by the engine, BTE measures the effectiveness of the conversion from the chemical energy contained in the fuel (input) into mechanical work and BSFC is the measurement of fuel efficiency by an engine that combusts the air-fuel mixture and generates the rotational motion of a crankshaft through combustion. In perfect combustion of a diesel engine, only energy, carbon dioxide (CO<sub>2</sub>), and water vapor (H<sub>2</sub>O) would be produced. However, as a result of several non-ideal combustion processes, diesel engines create nitrogen oxides (NO<sub>x</sub>), unburned hydrocarbons (UHC), carbon monoxide (CO), and hazardous particulates. Table 3 summarizes the performance and exhaust emission characteristics of CI engines fuelled with diesel-derived plastic fuel in comparison with diesel fuel. As shown, the peak pressure of diesel engines with plastic oil is increased or similar to diesel fuel. Plastic oil caused a longer ignition delay in the premixed combustion phase. This is due to the high viscosity of plastic oil. The in-cylinder pressure is increased because of a longer ignition delay in waste plastic oil [29,30]. Additionally, the high viscosity, poor atomization, heavier hydrocarbons, and bigger aromatic bonds resulted in the chain requiring more energy to break down [29-35]. As a result, the BTE decreased and BSFC increased. Exhaust emissions were reported to increase for all types of plastic fuel. The increase in NO<sub>x</sub> might be attributed to the increased exhaust gas temperature of plastic oil, which results in more oxygen atoms combined. This increase is also a result of the high cylinder pressure and ignition delay, which results in a greater amount of heat being released when compared to other test fuels [36]. Another possibility is that the presence of more aromatic compounds in plastic oil raises the adiabatic flame temperature, resulting in a rapid rate of heat release and a high level of NO<sub>x</sub> in the exhaust [37]. The higher CO emission in plastic oil is a result of its increased viscosity, which inhibits fuel vaporization and atomization, hence promoting incomplete combustion of the air-fuel mixture. The higher CO concentration in plastic oil than in diesel is also most likely due to the low oxygen component of the fuel [38]. The increased UHC emission from plastic oil is owing to its high density and viscosity, which prevent it from burning completely throughout the combustion chamber, exiting as an incomplete combustion product [39].

**Table 3.** Summary of performance and exhaust emission characteristic of CI engines fuelled with diesel-derived plastic fuel in comparison with diesel fuel.

Type of plastic fuel	Calorific value Diesel/Plastic Oil (MJ/kg)	Engine type	Peak Pressure	BTE	BSFC	NOx	UHC	CO	Ref.
HDPE	43.5/44.2	Single cylinder, 4-stroke, water-cooled, naturally aspirated DI diesel engine	Increased	Decreased	-	Increased	Increased	Increased	[29]
-	43.9/44.6	Single-cylinder, water-cooled DI diesel engine	-	Decreased	Increased	Increased	Increased	Increased	[30]
HDPE+PE T+LDPR+ PVC+PP+ PS	43.3/44.4	Single-cylinder with 4-stroke DI diesel engine	Increased	Decreased	Increased	Increased	Increased	Increased	[31]
HDPE	43.5/44.2	Single cylinder, 4-stroke, water-cooled, DI diesel engine,	-	Decreased	Increased	Increased	Increased	Increased	[32]
waste plastic	43.5/44.2	Single cylinder, 4-stroke, water-cooled, DI diesel engine	Increased	Decreased	-	-	-	-	[33]
LDPE and polybags	45.5/40.4	Single-cylinder, liquid-cooled, naturally aspirated diesel engine	Similar	Decreased	Increased	Increased	Increased	Increased	[34]
-	46.5/45.2	Single-cylinder, water-cooled, 4 stroke diesel engine	-	Decreased	Increased	Similar	increased	Increased	[35]

#### 4. Global potential and challenges

Pyrolysis is gaining attention as a method of converting plastic to liquid fuel due to its storage and transportation advantages, as well as its applicability to applications such as combustion engines, boilers, and turbines [40, 41]. The calorific value of plastic oil is comparable to that of conventional diesel. As a result, it has the potential to be used as a source of alternative energy and a mode of transportation. Additionally, it can be blended with diesel, biodiesel fuel, and additives to improve performance and efficiency [42]. The global annual production of plastic has been estimated at 300 million tonnes, and this figure is rapidly increasing [43]. Pyrolysis of plastic waste provided a high output of liquid fuel of more than 80% by weight, according to a prior study [44,45]. As a result, the plastic oil sector currently has the potential to produce 240 million tonnes of plastic oil annually. When compared to generating the same amount of polymers from virgin fossil fuel, recycling every additional tonne of plastic reduces emissions by 1.1–3.0 tonnes of CO<sub>2</sub>e [46]. Despite the decreased engine performance of plastic pyrolysis oil, the amount of plastic waste generated is large, and it must be handled to avoid environmental hazards. Not only is converting waste to energy a financially advantageous investment, but it is also an environmentally friendly option.

A major drawback of the pyrolysis process is that it is energy expensive, and the resulting oil requires further energy to refine. Another key issue is the lack of readily available plastic feedstocks for pyrolysis, due to the inefficiency of recycling at the moment, such as mechanical separation, pelletization, and regeneration, including high labor costs and water contamination, particularly in developing countries [47]. The pyrolysis emission treatment technique must be further enhanced to achieve maximum environmental benefits due to harmful gases such as sulfur, created by the pyrolysis of some plastic waste, such as HDPE and mixed plastics [48,49]. To ensure the lowest environmental impact, the pyrolysis oil derived from various plastic types must be cleaned extensively before it is utilized in any application [50]. Aromatic hydrocarbons, some of which are well-known carcinogens, have the potential to do significant harm to human health and the environment [51]. This necessitates serious consideration.

#### 5. Conclusions

Pyrolysis is an innovative method for converting plastic waste to liquid oil. Plastic oil derived from several forms of plastic waste showed comparable heating values to regular diesel, making it appropriate for use in diesel engines. In comparison to traditional diesel, it has lower thermal efficiency and a greater BSFC. Additionally, as compared to diesel fuel, plastic fuel generates greater levels of NO<sub>x</sub>, CO, and UHC. Additionally, the pyrolysis of plastic waste into diesel fuel has some technical, operational, and post-process challenges that must be solved to maximise economic and environmental advantages.

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