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A Comparative Study of Plasto Oil Blends with Diesel in Diesel Engines: Performance, Emissions, and Future Prospects

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Abstract

The rising environmental issues stemming from plastic waste generation and dwindling fossil fuel reserves have created urgency in the quest for alternative, sustainable sources of energy. Plasto oil, obtained by the thermal breakdown of plastic wastes, presents itself as a suitable alternative. The present review investigates the production technologies, physicochemical characteristics, blending practices, engine performance results, emission patterns, merits, demerits, and future directions involved with the application of Plasto oil as an alternative in CI engines. This assessment emphasises the potential of Plasto oil as a sustainable fuel and its role as an alternative to conventional fuels, as well as the advancements necessary for commercial feasibility.

Major Findings: *NOx and particulate matter emissions remain a persistent issue. Low-percentage Plasto oil blends, ranging from 10% to 30%, can reduce Carbon Dioxide (CO) and Hydrocarbon (HC) emissions while achieving brake thermal efficiency comparable to that of pure diesel.*

Keywords: *Alternative Fuel, Brake Thermal Efficiency, Plasto Oil, Pyrolysis*

Nomenclature

BTE - Brake Thermal Efficiency
BSFC - Brake Specific Fuel Consumption
EGT - Exhaust Gas Temperature
HRR - Heat Release Rate
CR - Compression Ratio
CI Engine - Compressed Ignition Engine
HDPE - High Density Polyethylene
PP - Polypropylene
PS - Polystyrene
$TiCl_3$ - Titanium Trichloride
$TiCl_4$ - Titanium Tetrachloride
$AlCl_3$ - Aluminium Chloride
$FeCl_3$ - Ferric Chloride
HZSM-5 - High Silica Zeolite
HY - Y zeolite
HUSY - Hierarchical Ultra Stable Y Zeolite
Y - Y zeolite
β - Beta Zeolite

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1.0 Introduction

1.1 Background and Importance

The demand for plastic is increasing because of its beneficial properties like lightweight durability and huge production rate applicable to various industries like automotive, electronics, electrical and packaging. The worldwide increase in the use of plastics has created a massive accumulation of plastic waste. The global consumption of plastic has been increasing by five per cent every year[1]. According to a recent study, there is an astounding 4.9 billion tonnes of plastic waste produced worldwide, of which only 9% is recycled, and as of 2015, 79% of it is still in landfills in the natural environment[2]. Also, plastic has a rapid growth, increasing from 1.5MT to 359MT in 2021[3] and also quadruples by 2050[4]. Appropriate waste plastic handling is an urgent issue in our society. Scientists are searching for processes to produce a fuel resource for transportation using waste plastics.

1.2 Pyrolysis as a Promising Waste-to-Fuel Technology

Various studies have been carried out to find a solution for waste plastics by converting them and using them in several ways, but it signifies that the chemical decomposition method is one of the most dependable solutions. One significant thermochemical conversion process is pyrolysis, which produces oils, gases, and solid carbon black by heating plastic waste to moderate temperatures between 573 and 823 K in an inert atmosphere[5,6].

Waste-to-fuel technologies, particularly pyrolysis, offer a compelling pathway to simultaneously address both environmental pollution and growing energy demand. Waste plastics are a desirable feedstock for pyrolysis, which produces plastic oil, because they are free and only require collection, sorting, cleaning, cutting, grinding, and other expenses. Waste plastics can be pyrolysed to create a wide range of products, such as char, flammable gas, and liquid oil, all of which have numerous uses. The pyrolysis process yields a liquid with a higher heating value, so that is an available option for alternative fuel.

The pyrolysis is a method in which thermally decomposing waste plastics in the absence of oxygen, providing a large amount of heat and pressure to recycle plastic waste into a usable liquid fuel called plastic pyrolysis oil[7,8]. At the same time, an increasing cost and decreasing supply of diesel fuel necessitate other energy sources for use in transportation and industry. Mixture of Plasto oil with diesel to fuel Compression Engines (CI) has gained interest because of its two-way advantages, one controlling plastic waste and as well as compensating the diesel fuel demand. The finite nature of fossil fuels, with crude oil reserves estimated to last only a few decades at current consumption rates, underscores the critical need for alternative energy solutions.

Plastic pyrolysis oil, often referred to as Plasto oil, has garnered significant attention as a potential pick for conventional fuel due to its equivalent heating value and hydrocarbon composition. The ability of Plasto oil to be used in existing CI engines without substantial modifications is a major advantage, facilitating its integration into the current energy infrastructure[9]. The capability of Plasto oil to transition from fossil diesel to Plasto oil blends does not necessitate a massive overhaul of existing engine fleets or fuel infrastructure, thereby significantly reducing adoption barriers and capital expenditure for end users. This represents a major economic and logistical advantage over alternative fuels that might require dedicated engine designs or extensive infrastructural changes.

1.3 Objectives

This review critically evaluates the influence of Plasto oil performance and emission of diesel engines based on major studies that proved the engine's feasibility under different engine conditions[10]. Systematically analyse the impact of Plasto oil compositions on diesel engine performance factors like Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC), Brake power, Exhaust Gas Temperature (EGT) and combustion variables like In-cylinder pressure, Heat Release Rate (HRR) and combustion delay period. Various pyrolysis methods and mixing proportions employed during the production of Plasto oil, investigated by Gollakota R[11], demonstrate the outcome of manufacturing processes on fuel characteristics and engine performance. Engine performance tests with stable operation at medium to high engine loads. However, higher PPO content is associated with extended ignition delay, elevated peak pressure, and increased heat release due to its lower cetane number. While thermal efficiency showed only a modest reduction

of about 3 to 4% compared with diesel, the emission levels of NOx, CO, CO_2, and unburned hydrocarbons generally increased with rising plasto oil blend ratios[12]. Also, a thorough analysis of the physicochemical features of Plasto oil is made to compare its suitability with standard diesel fuel. This review uncovers essential research gaps, especially in long-term engine durability, real-world driving cycle emissions, and lifecycle environmental performance and suggests avenues of future research to optimise the applied adoption of Plasto oil utilisation with diesel blend in compression ignition engines.

2.0 Plasto Oil Production and Properties

Plasto oil is produced from pyrolysis, a method that has received much attention due to its capability to convert into useful resources. The nature of the pyrolysis method is the process of degrading complex plastic waste into lower hydrocarbon molecules through the application of heat[13,14]. This method provides a viable means of solving both the growing problem of plastic waste and the increased need for alternative fuels. Table 1 depicts the analytical categories for various plastic behaviours under heat.

2.1 Pyrolysis Techniques

In this technique, plastic materials are heated up in an environment where there is no oxygen. This causes the plastics to decompose into a mix of liquid hydrocarbons in Plasto oil, non-condensable gases, and solid remains as carbon black. There are specific conditions and methods employed in pyrolysis that significantly influence the yield and properties of the final products. Researchers like *chintala*[10] have highlighted pyrolysis as an attractive waste management technique that offers solutions to both energy shortages and environmental pollution.

Table 1. Proximate analysis of types of plastics[12]

Plastic Type	Moisture (wt.%)	Fixed Carbon (wt.%)	Volatile Matter (wt.%)	Ash (wt.%)
PET	<0.7	6–14	85–92	<0.1
HDPE	<0.3	~0	94–99.8	<1.5
PVC	<0.8	5–7	58–94.8	<0.1
LDPE	<0.3	~0	99–99.8	<0.4
PP	<0.4	<1.2	95–99.6	1–4
PS	<0.3	<0.2	99–99.8	<0.5
Other	<0.2	<3	97–99.8	1

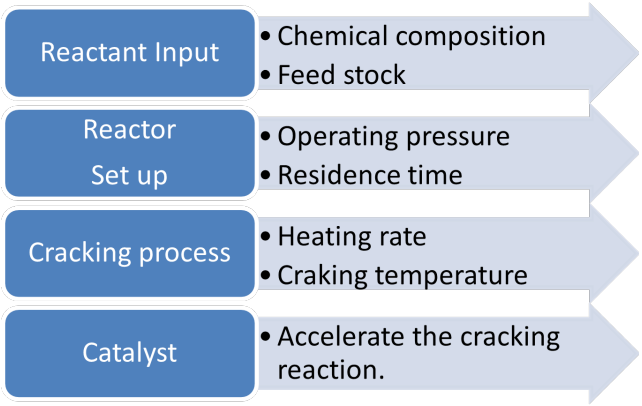


Figure 1. Plasto oil production steps.

2.1.1 Thermal Pyrolysis

This is the most basic and widely applied method to generate Plasto oil by applying heat alone to dissolve the plastic polymers. Plastic waste is melted in a reactor at high temperature, usually from 350°C to 500°C, in an inert environment to avoid combustion. As the *Fulgencio Medrano L.*[15] suggest, temperatures within this range are more conducive for the conversion of synthetic polymer waste to liquid products.

Simplified manner to represent a process:

Plastic Waste + Heat (No Oxygen) → Plasto oil + Non Condensable Gases + Carbon Black

There are a couple of key factors applied to determine what is obtained from this process:

Temperature: When increasing the heat, the bigger molecules of the plastic will start to break down into smaller ones. This can make the liquid volume greater, but only to a certain extent. As research shows, higher temperatures tend to favour the degradation of plastic waste into a liquid or gaseous state.

Residence Time: This is the duration that the plastic waste is subjected to high temperatures. If exposed for a longer time, more gas and liquid are obtained, but the composition of the oil is also altered.

Heating Rate: How fast the plastic is heated is also important. If it is heated slowly, more of the solid material

carbon black is obtained, whereas rapid heating can provide more liquid and gas.

In a research work by Damodharan[16] identified that thermal pyrolysis of plastic refuse and observed liquid yields between 60-80% under the temperature of 350-500°C. They highlighted how crucial it is to achieve just the right temperature and residence time to obtain the maximum liquid fuel.

2.1.2 Catalytic Pyrolysis

There are some improvements in catalytic pyrolysis compared to thermal pyrolysis. Heat is applied for the pyrolysis, but also includes catalysts that facilitate the process of breaking down the plastic trash and enhance the quality of Plasto oil. Catalysts are a sort of helpers that facilitate chemical reactions to take place more comfortably and at reduced temperatures. The research article explains that the usage of catalysts enhances the oil quality and yield[17].

A simplified manner to represent a process with a catalyst:

Plastic Waste + Heat (No Oxygen) + Catalyst → Plasto Oil + Non-Condensable Gases + Carbon Black

Mainly, there are homogeneous and heterogeneous two types of catalyst. In contrast to heterogeneous catalysts, which usually remain in a distinct phase as solids, homogeneous catalysts dissolve entirely in the reactants and solvent. One major drawback of homogeneous catalysts is their inability to be readily separated from the reaction mixture following the process, in contrast to heterogeneous catalysts, which are easily separated because of their solid nature[18].

Compounds such as $TiCl_4$, $AlCl_3$, $FeCl_3$, and $TiCl_3$ are strong Lewis acids that function as electron pair acceptors. These catalysts can change the charge distribution along polymer chains by dissolving in molten polymers. They can take up hydride ions as a result of this change in charge dispersion, which creates carbonium ions. Because it can withstand extreme reactions up to 1300°C and 35MPa and because it is relatively easy to separate from the final product, the heterogeneous catalyst is superior to the homogeneous one. Traditional heterogeneous catalysts include mesostructured and typical acid solid catalysts, as well as nanocrystalline Zeolites like Y zeolite (HY), Hierarchical Ultra Stable Y Zeolite (HUSY), High Silica Zeolite (HZSM-5), Y, and β. Additionally, increasing attention has been paid to zeolites, Fluid Catalytic Cracking (FCC) catalysts, Silica-Alumina (SiO_2-Al_2O_3), and Alumina (Al_2O_3)[17].

Advantages of using the catalysts are lower operating temperatures, as the catalysts assist the reactions, and less energy is required to warm up the plastic. The chemical structure of Plasto oil, which provides more hydrocarbons like gasoline or diesel and fewer aromatics, may be affected by improved oil quality.

2.2 Plasto Oil Properties

The comparison of pyrolysis plastic oil fuel properties with diesel shows comparable heating values and kinematic viscosity, but a higher incombustible residue ash and lower cetane values in the plastic oil than diesel fuel[13].

Research has indicated that post-treatment techniques like hydrotreatment and distillation can improve the fuel qualities of Plasto oil. Hydro treatment is particularly effective in lowering the sulphur content, while distillation, although it increases the sulphur level, significantly raises the flash point. Both treatment processes contribute to a reduction in the water content of Plasto oil. Furthermore, the cetane index of the oil improves after undergoing either of these treatment methods[19]. Table 2 depicts the

Table 2. A comparison of the physicochemical characteristics of diesel and plastic oil[13]

Properties	Standard Diesel	Plasto Oil	Hydrogenated Plasto Oil
Calorific value (MJ/kg)	42	41	45
Kinematic viscosity (cSt)	3.05	2.9	3.5
Density (Kg/m_3)	820-850	734	851
Sulphur content (ppm)	<0.035	<0.001	2.48
Cetane index	55	49	62
Pour point	-15	-3	-20
Cloud point	-25	-27	-
Fire point	56	51	72
Flashpoint(°C)	50	46	65
Carbon residue (wt.%)	0.002	0.01	0.1
Ash content (wt.%)	0.04	1	0.01

comparative analysis of fuels like diesel, Plasto oil and Hydrogenated Plasto oil properties for use in the CI engine.

3.0 Engine Performance and Emission Studies with Plasto Oil

3.1 Performance Analysis

Research into the utilisation of plastic oil from plastic debris through pyrolysis as a diesel alternative in CI engines reveals a promising but complex picture. Most studies confirm that blending plastic derived oils with diesel, particularly in ratios up to 30% can sustain engine performance reasonably near to that of pure diesel fuel. For instance, some blends even showed slightly higher BTE or minimal value of BSFC, especially at mid-range loads. However, emissions remain a key concern. Nitrogen Oxides (NO_x) tend to increase due to higher combustion temperatures, while Carbon Monoxide (CO) and Hydrocarbons (HC) are generally elevated at low engine loads. Feedstock type and blending ratios significantly influence both performance and emissions. Notably, oils from High Density Polyethylene (HDPE) and Polypropylene (PP) show better compatibility than those from Polystyrene (PS), which suffers from poor lubricity. While additives like zeolite catalysts and techniques like Exhaust Gas Recirculation (EGR) help mitigate some emission issues, challenges such as high viscosity and inconsistent combustion behaviour still limit large scale adoption. Overall, plastic pyrolysis oil shows strong potential as a supplementary fuel, especially with further refinement in blending strategies and emission controls.

3.2 Major Findings of Plasto Oil in CI Engine from Various Literature

Figure 2 shows the flow chart of the technical summary of various researchers on Plasto oil utilisation in CI engines.

The experimental studies reviewed provide a comprehensive evaluation of the behaviour and effects of Plasto oil derived from various waste plastic sources when used in CI engine configurations. Across multiple references, a range of engine types and blend ratios were tested, highlighting the diversity in both fuel formulation and engine operating strategies.

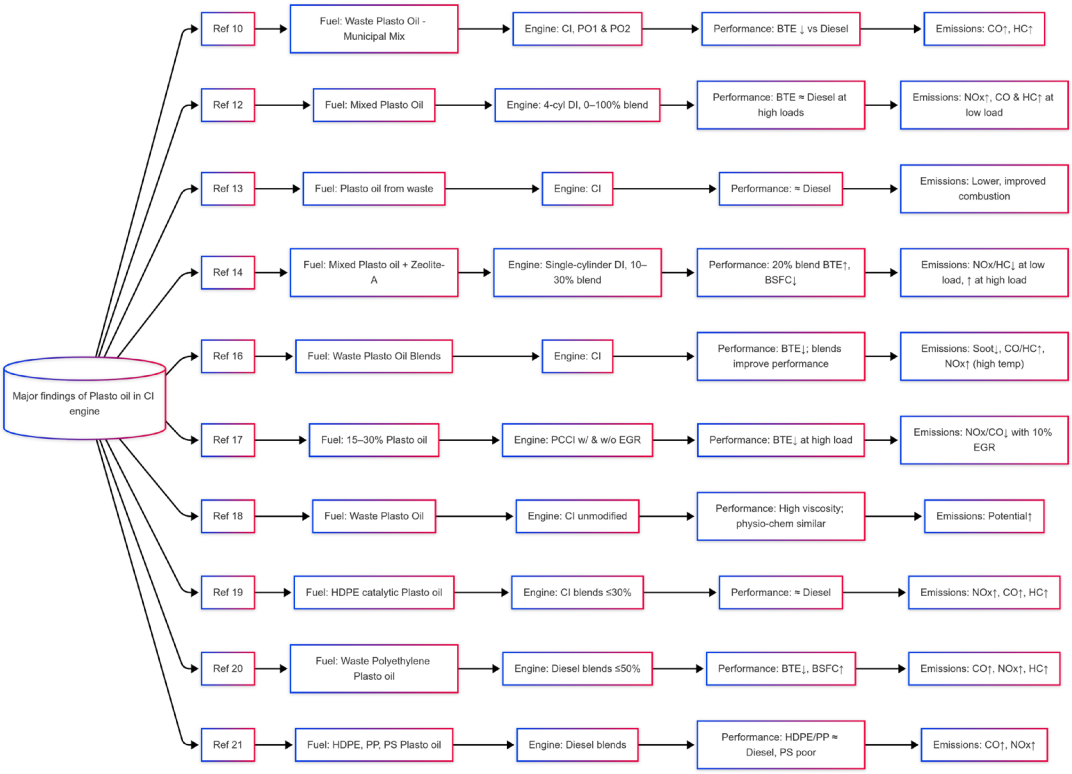


Figure 2. Major findings of Plasto oil in CI engine.

Studies such as[10,13] reveal that waste Plasto oil and its derivatives offer performance metrics such as BTE that are comparable to conventional diesel fuel. Notably, emissions of CO_2 and HC are observed, but combustion characteristics tend to improve due to the oil's inherent volatility. Similarly, Study[12], using a four-cylinder Direct Injection (DI) engine with up to 100% Plasto oil, demonstrates that performance remains consistent with diesel at high loads, albeit with noticeable emissions of NO_x, CO, and HC at lower loads.

More refined blends, including those catalysed with Zeolite A[14], show enhanced thermal performance at 20-30 % blends, with a marked reduction in NO_x and HC emissions under low load. Studies in[16,20] delve into the implications of catalytically improved blends, suggesting a boost in BTE and reduced particulate formation under optimised conditions.

Interestingly, study in[21] explores the application of Plasto oil in Premixed Charge Compression Ignition (PCCI) engines with and without EGR. The results indicate that with 10% EGR, NO_x and CO emissions drop while maintaining high load efficiency. On the other hand, study in[22] identifies the fuel's high viscosity and its similar physicochemical properties to diesel, underlining the necessity for blend optimisation to enhance engine compatibility.

Lastly, polymer specific studies in[20,23], such as those involving HDPE, PP, and PS based oils, confirm that HDPE/PP derived fuels mimic diesel like performance, whereas PS based oils underperform, particularly in terms of combustion and emissions.

Figure 3 indicates the brake specific fuel consumption and brake thermal efficiency of different fuel mixes under varying engine loads. Even at the lowest Plasto oil blending percentage, a discernible rise in brake specific fuel consumption was noted for the blends under all operating conditions.

Figure 4 represents the emission characteristics of the fuels, suggesting Plasto oil 2 has a more balanced CO and NO_x emission characteristics than Plasto oil 1. PO1 has higher CO and lower NO_x emissions, but

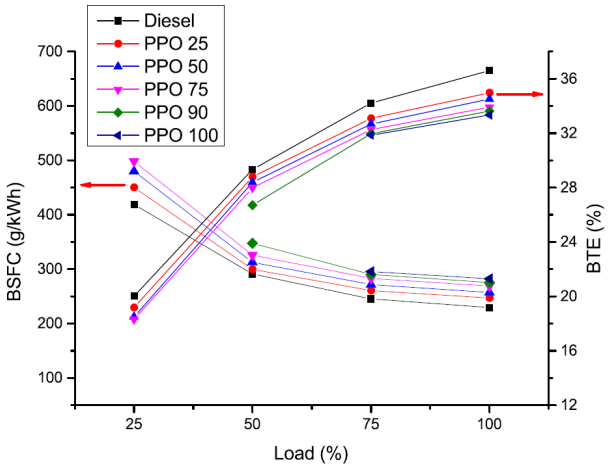


Figure 3. Variation of load vs BSFC and BTE[12].

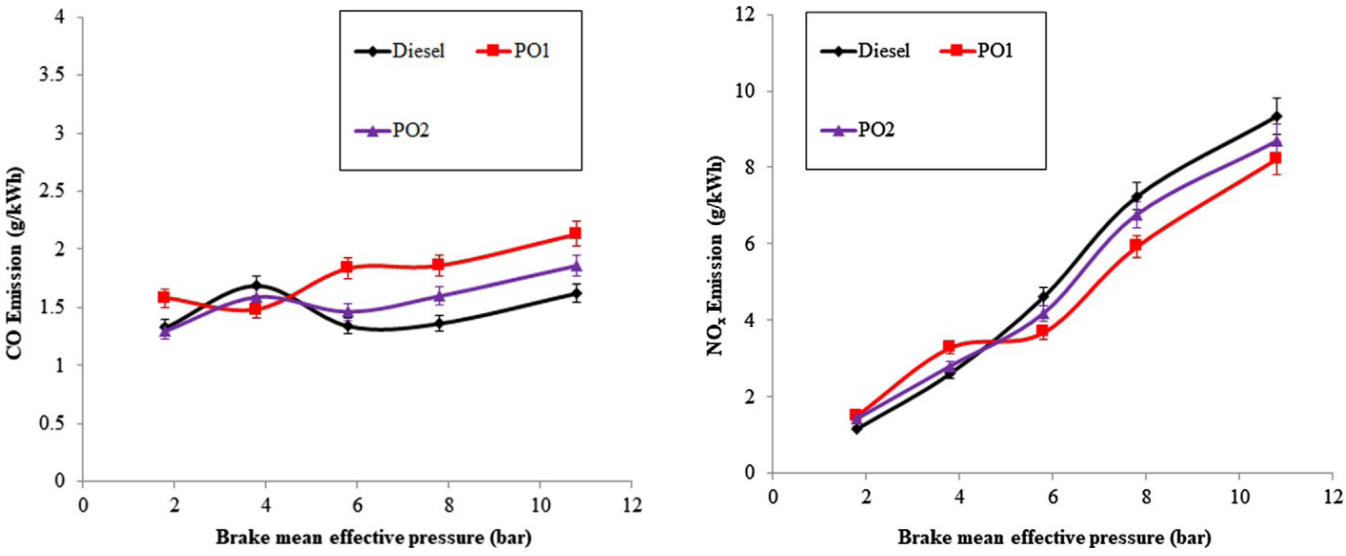


Figure 4. Variation of BMEP vs CO and NOx emission[10].

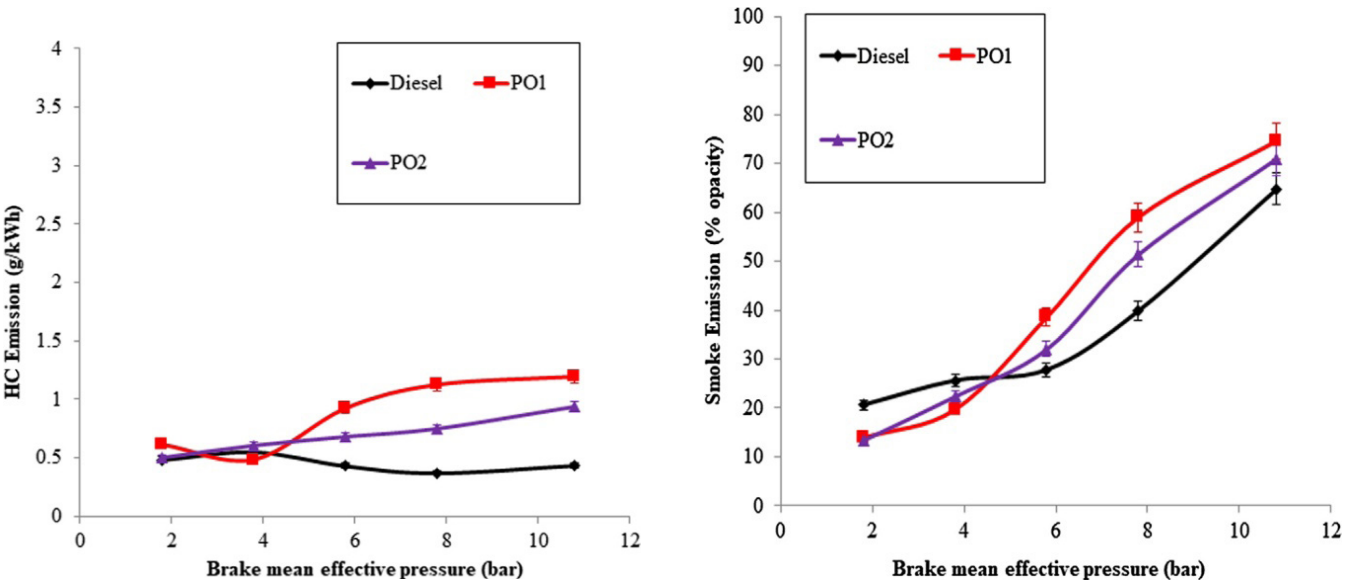


Figure 5. Variation of BMEP vs HC and smoke emission[10].

can be improved upon for more complete combustion. Diesel shows cleaner emissions of CO, but at higher loads produces higher NO_x emissions. In conclusion, PO2 appears to be more favourable as an alternative fuel blend for emission reductions without highly decreased combustion performance.

Figure 5 shows that using Plasto oil resulted in slightly higher engine exhaust emissions, including hydrocarbons, carbon monoxide, and smoke emissions, when compared to using regular diesel fuel at moderate to high BMEPs, especially between 5.8 and 10.8 bar. However, the variations in emission levels were insignificant at lower BMEPs (1.8 to 3.8 bar)[10].

3.2 Combustion Analysis

The combustion analysis examines the combustion parameters of Plasto oil derived from plastic disposal and also blends with conventional diesel. The researchers demonstrate innovative approaches to waste to energy conversion while investigating critical combustion parameters, including peak pressure in cylinder dynamics, HRR patterns, exhaust gas temperatures, and ignition delay characteristics.

3.2.1. Cylinder Peak Pressure

The cylinder peak pressure is a robust indicator of combustion strength and energy release inside the engine. Across most studies, the application of pyrolysis plastic oil blended with diesel leads to an increase in peak pressure of the cylinder, in contrast with pure diesel. This phenomenon is mainly attributed to the extended ignition delay associated with Plasto oil, allowing a larger quantity of fuel to mix with air before ignition, which in turn causes a more vigorous combustion once ignition takes place.

Rajendra Kumar[21] tested a PCCI engine fueled with diesel Plasto oil and found that in cylinder pressure and combustion temperature rose with engine load. Rajan Kumar[20] tested 100% waste plastic fuel and blends in a CI engine. The results of the experimentation indicated WPF100 ran with longer ignition delay, richer aromatic content, and lower cetane number than diesel, which also increases EGT.

Pumpuang[23] observed that HDPE-derived Plasto oil produced cylinder pressure patterns similar to diesel, while PP oil resulted in delayed and elevated peak pressures because of high viscosity and a lower amount of oxygen. On the contrary, Chintala[10] observed peak cylinder pressures with Plasto oil were slightly lower than diesel, especially at low loads, attributing it to advanced combustion phasing and incomplete combustion at lower operating temperatures.

From Figure 6, Singh[13] reported that a 50% blend of Plasto oil with diesel reached a maximum pressure of 67.9 bar, more than 62.5 bar observed with pure diesel, with the peak occurring 3°CA later, emphasising the delayed but more forceful combustion. Similarly, Pakiya

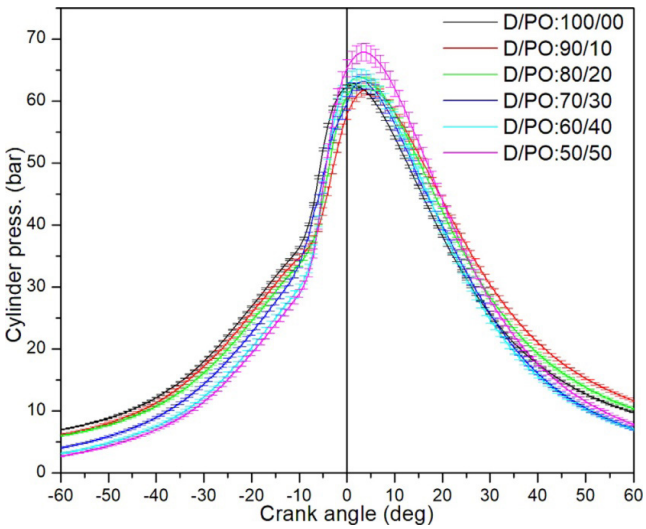


Figure 6. Variation of crank angle vs engine peak pressure at full load[13].

Pradeep[22] in their review highlighted that in several cases, peak pressures of up to 75 bar were recorded with high Plasto oil concentrations, compared to typical diesel pressures of around 65 bar.

Overall, the trend suggests that Plasto oil increases cylinder pressure under most conditions, but variations depend on engine setup, load, and the specific plastic type used in the Plasto oil.

3.2.2 Heat Release Rate

HRR typically shows a more prominent premixed combustion spike, especially at higher blend ratios when utilised in a CI engine. This is largely due to longer ignition delays associated with Plasto oil, allowing a larger quantity of fuel to mix with air before ignition.

According to Singh[13], Plasto oil blends produced higher HRR compared to diesel, with a notable shift in the peak location indicating delayed ignition. In the work by Pumpuang[23], HDPE derived PPO demonstrated a similar HRR curve to diesel, while PP oil caused significantly delayed but higher HRR peaks, indicating more aggressive combustion. In other studies, Pakiya Pradeep[22] and Gowthaman[16], the HRR for 100% plastic oil reached as high as 147 J/°CA, while diesel remained around 85 J/°CA. HRR analysis in Kalargaris[12] showed that higher Plasto oil content prolonged ignition delay and greatly increased the premixed heat release. According to Chintala[10] plastics oils tended to ignite slightly earlier advanced start of combustion, but then produced lower pressures during

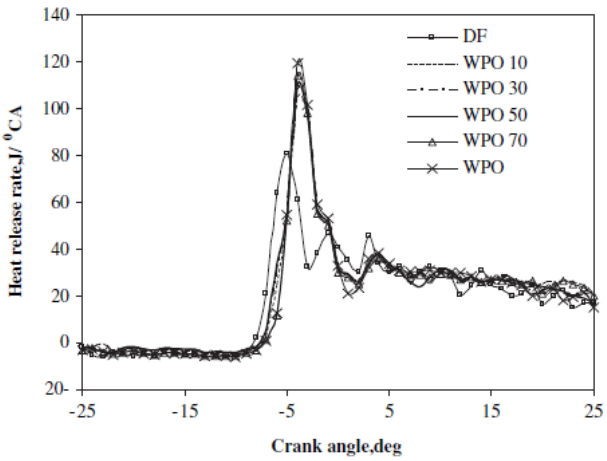


Figure 7. Variation of crank angle vs. heat release rate[22].

the expansion stroke. The authors explained this by noting that Plasto oil 1/ Plasto oil 2 combusted earlier, so part of the pressure rise counteracted the compression work, reducing the later pressure peak. In addition to that, peak flame temperatures were lower with Plasto oil 1/ Plasto oil 2, ranging from 1783 K versus 1963 K for diesel at full load conditions. The final study concluded that plastic oils gave longer ignition delays and slightly lower cylinder pressures in contrast with diesel fuel.

Overall, Figure 7 shows that net heat release increases due to high calorific value, low cetane number, and longer ignition delays associated with Plasto oil, allowing a larger quantity of fuel to mix with air before ignition.

3.2.3 Exhaust Gas Temperature (EGT)

Exhaust gas temperatures followed a predictable pattern that shows higher temperatures with plastic fuel blends than with diesel, especially under load. Ignition delay led by a rapid burn raises in cylinder temperatures, and those carry over to the exhaust. For example, Singh[13] found exhaust gas temperature as high as 370 °C with plastic oil blends, compared to 347 °C for diesel. Rajendra Kumar[21] also saw similar results that at full load, EGT with Plasto oil reached 307 °C with 15% Plasto oil vapour and no EGR. It is also worth noting that EGTs did not increase linearly. Some blends peaked around mid-loads, likely due to improved mixing and burn quality at those conditions.

As illustrated in Figure 8, across all braking power levels, the reported exhaust gas temperature for pure diesel is consistently higher than that for Plasto oil. This

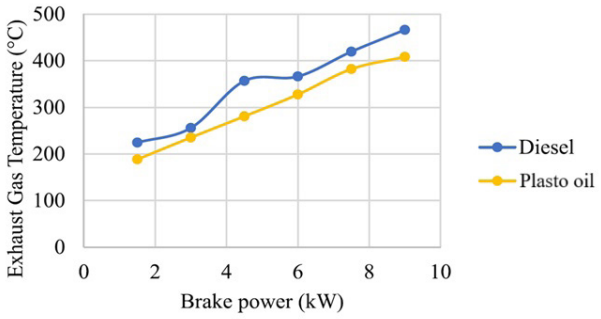


Figure 8. Exhaust gas temperature vs. brake power[24].

suggests that Plasto oil improves combustion efficiency inside the engine cylinder, most likely as a result of better atomisation and improved combustion. Even though Plasto oil and regular diesel fuel can be mixed in different ratios, the exhaust gas temperatures of these mixtures are usually greater than those of pure diesel. The main cause of this is the prolonged ignition delay that blended fuels frequently exhibit. Despite the prolonged ignition delay, these blends tend to combust more rapidly due to improved combustion characteristics, although this often comes at the cost of reduced thermal efficiency compared to diesel fuel[13,23-25]. Less energy is transformed into productive activity when an engine runs inefficiently. Ramesha[26], the Plasto oil biodiesel blend's higher heat release rate and reduced volatility cause combustion to occur more slowly, raising the temperature of the exhaust gases. Additionally, Kumar[25] suggests that waste plastic oil's greater oxygen content, along with the presence of higher boiling point components compared to conventional diesel, contributes to the rise in exhaust gas temperature when using Plasto oil.

In essence, EGT increases with Plasto oil usage are closely linked to delayed ignition and the aggressive nature of premixed combustion, especially under higher load conditions. However, these benefits come with challenges in low load efficiency.

4.0 Discussions and Conclusions

The consolidated analysis from Figure 2 highlights that Plasto oil, especially when blended below 50% or catalytically enhanced, holds substantial promise as an alternative CI engine fuel. While engine performance generally aligns with diesel benchmarks, emissions remain a key concern and vary significantly with blend type, engine configuration, and the presence of EGR or catalysts. Continued refinement of blending strategies and after treatment technologies could enable more sustainable and cleaner combustion of plastic derived fuels.

When Plasto oil is employed, engine efficiency decreases as indicated by the decreased BTE across all blending ratios, as shown in Figure 3. Given that aromatic molecules need more energy to break their chemical bonds, Plasto oil's high aromatic content could be one factor contributing to this decline[27]. Additionally, Plasto oil tends to combust at higher temperatures, potentially resulting in greater heat losses through thermal transfer. Nevertheless, Figure 3 shows that the impact on fuel consumption and thermal efficiency is not drastically negative at higher blending ratios at medium load, the thermal efficiency remains only slightly below that of pure diesel. These findings suggest that Plasto oil and diesel blends can be considered viable under certain operating conditions[12]. Blends with 10-75 % waste Plasto oil by volume were tested in diesel engines, demonstrating stable operation. Only one study reported engine vibrations when Plasto oil content exceeded 30%[28].

Some studies reported that CO emissions decreased, and the largest decrease in emissions was documented as a 47.47% emission reduction by utilising Plasto oil blends[25]. Moreover, challenges remain in managing emissions, especially NO_x and particulates, ensuring consistent feedstock supply, and integrating the process into economic and policy frameworks.

Plasto oil blends demonstrate promise as a renewable alternative to diesel fuel, offering a prominent result for both waste plastic management and the reduction of fossil fuel consumption. While Plasto oil can be successfully mixed into diesel fuel and applied in diesel engines with acceptable performance, particularly at low blend ratios, several challenges remain. These challenges include the variability in fuel properties, the potential for increased emissions, and concerns about long-term engine compatibility and durability.

Future studies should concentrate on the following areas to fully realise Plasto oil's promise as a feasible alternative fuel:

- Developing cost-effective and efficient methods for upgrading the properties of Plasto oil.
- Examining how Plasto oil mixtures affect engine wear and durability over the long run.

- Optimising engine and emission control systems for use with Plasto oil blends.
- Conducting comprehensive economic and lifecycle assessments.
- Exploring advanced blending strategies and novel combustion modes.

Addressing these challenges through continued research and development will pave the way for the wider adoption of Plasto oil as a sustainable and environmentally friendly alternative to diesel fuel, contributing to both waste management and energy security goals.

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