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Reactivity Controlled Compression Ignition Engine Powered with Plastic Oil and B20 Karanja Oil Methyl Ester

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Abstract

In the early stages of the investigation, plastic oil was mixed with conventional fuel in various proportions, revealing that a 30% volume fraction of plastic oil was optimal when combined with diesel. Building on this, the current study incorporated biodiesel in a 30% volume fraction into the test sample (30PO+70D) at different blending ratios of 10%, 20%, 30%, and 40%. The experimental effects implied B20 blend, representing 20% biodiesel in the test sample, led to reduced emissions compared to the baseline test sample blend. Although there was a slight decrease in performance and fuel consumption, particularly at larger loads, the addition of biodiesel showed a trend of reducing emissions. The power of the diesel locomotive tended to increase with higher biodiesel concentrations, despite biodiesel blends exhibiting delayed combustion. Notably, biodiesel blends demonstrated a reduction in smoke, nitrogen oxides (NOx), and carbon monoxide (CO) levels at maximum brake power. Considering these results, the B20 blend, consisting of plastic oil and diesel, presents itself as a shows potential applicant for future studies because of favorable performance, combustion characteristics, and cleaner emissions.

Keywords: *Biodiesel, Combustion, Emissions, Plastic Oil*

1.0 Introduction

Amidst upward apprehensions stopped ecological issues arising from fossil fuel emissions, the depletion of fossil fuel resources, and the escalating global demand for energy, the search for another fuel has become imperative[1]. Plastic oil, derived through pyrolysis of plastic waste, has emerged as a noteworthy alternative fuel. While plastic serves crucial roles in domestic and industrial applications, its non-biodegradable nature leads to environmental pollution and landfill concerns. Pyrolysis, identified as an effective method, facilitates the recovery of energy from plastic in the form of liquid products with properties akin to petroleum fuels. Previous investigations indicated that diesel engines can efficiently operate using plastic oil, albeit with higher emissions compared to traditional diesel[2,3]. The primary challenge with plastic fuel lies in incomplete combustion due to

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specific properties. To address this issue, the current study explores the enhancement of plastic oil quality through blending with biodiesel. Biodiesel, characterized by its oxygen content, is known to improve combustion rates in diesel engines. The results of these findings establish that the B20 blend, comprising plastic oil and diesel, leads to decreased exhaust related with plastic oil-diesel blends, albeit with a minor reduction in performance and fuel consumption[4,5]. The focus of the current investigation lies in understanding the impact of biodiesel on plastic oil-diesel blends across different loading conditions, including a comprehensive combustion analysis.

The characteristics of plastic oil acquired throughout pyrolysis is dependent on raw material and pyrolysis conditions, with the oil primarily composed of naphthenes and olefins, which have suboptimal ignition quality. In experimental studies, a 20% blend of biodiesel with plastic oil-diesel was chosen as viable in an unmodified diesel engine. Waste polymer cracking using thermal and catalytic methods demonstrated a 95% conversion efficiency[6-8]. However, at highest operating conditions, emissions such as nitrogen oxides, carbon monoxide, hydrocarbons, smog, and exhaust gas temperatures increased compared to diesel, while synthetic oil exhibited higher thermal efficiency at 80% load. The reaction temperature during plastic oil production influenced its quality, with lower temperatures resulting in higher thermal efficiency, shorter ignition delays, and lower emissions. The use of waste polyethylene pyrolysis oil in diesel engines, particularly at a 5% volume blend, was suggested as an alternative fuel due to performance and environmental reasons[8-12]. Tests with HDPE-derived plastic oil revealed that it met specifications and had a low boiling range, suggesting potential efficiency as a fuel. Blends of plastic oil with diesel showed similar pressure characteristics to diesel, with lower emissions of hydrocarbons and nitrogen oxides. Blending plastic oil with biodiesel was explored as a substitute for diesel engines, with studies focusing on blends of biodiesel derived from palm oil and castor oil with plastic oil[13-15]. The addition of biodiesel generally reduced hydrocarbons and nitrogen oxides but increased smoke and carbon monoxide emissions. Lastly, an engine powered by simarouba seed oil demonstrated enhanced performance at an injection timing of 27 degrees bTDC, which is 4 degrees advanced compared to the base mode of operation. These findings collectively contribute to the understanding of plastic oil as a possible petroleum-based energy fuel and highlight the importance of considering various factors, including blend ratios and production methods, for optimizing engine performance and emissions[15].

2.0 Materials and Methods

In the ongoing research, waste plastic High-Density Polyethylene (HDPE) is gathered and mechanically reduced into smaller pieces. These crushed plastic fragments, along with 5% fly ash acting as a catalyst, are introduced into a reactor for the pyrolysis reaction, which involves heating. The pyrolysis unit is equipped with a temperature indicator to monitor and note down the reaction temperature. The mixture is heated to a temperature of 350°C. As the reaction progresses, the vapors emerging from the reactor undergo condensation to form a liquid fraction. This process aims to convert waste HDPE plastic into a usable liquid product through controlled pyrolysis, with the inclusion of fly ash as a catalyst to facilitate the reaction. The temperature control and condensation steps are essential elements in optimizing the pyrolysis process for the efficient transformation of discarded polymers keen on a liquid fuel.

2.1 Experimental Setup

The investigational arrangement involved a single-cylinder diesel engine with a rated power of 5.2 kW at a speed of 1500 rpm, and it operated as an electrically loaded engine. Crank angle information was recorded using a Top Dead Center (TDC) encoder. The exhaust composition was measured using an AVL gas analyzer, while smoke density was determined using an AVL 437 smoke meter. The experiments encompassed the use of diesel as a neat fuel and blends of plastic oil diesel with biodiesel at varying proportions: 10%, 20%, 30%, and 40%. The biodiesel employed in the blends was derived from pongamia oil. This setup allowed for a comprehensive investigation into the performance, emissions, and combustion features of the apparatus running on different fuel blends, contributing valuable insights into the feasibility and environmental impact of utilizing plastic oil diesel blends with biodiesel in a diesel engine (Figure 1 and Table 1-3).

Table 1. Specification of IC engine

Engine	Make Kirloskar, Model TV1, Type 1
Cylinder power	5.2 kW
Number of cylinders	4 stroke Diesel, water cooled
Speed	1500 rpm
Stroke	110 mm
Bore	87.5 mm
Compression ratio	17.5

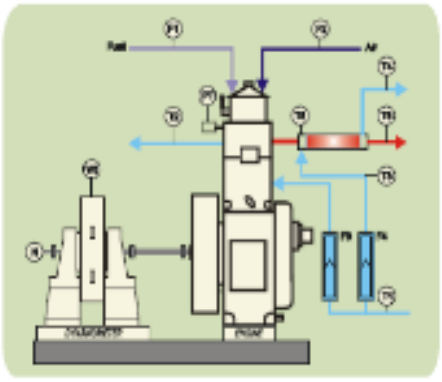


Figure 1. Schematic representation of experimental set up.

Table 2. Properties of plastic oil and diesel

Property	Method	Diesel	Plastic Oil	Biodiesel
Density kg/m^3	IS1448	830	870	820
Kinematic viscosity at 400C, cst	IS1448	3.78	2.77	6.2
Flash point, ^{0}C	IS:1448	53	>25	160
Heating value, kJ/kg	IS1448	42.46	35400	35246.12

Table 3. Analytical instruments used

Gas Analyzer	Range	Accuracy
CO	0-15%	5%
CO_2	0-20%	3%
HC	0-30000 ppm	3%
NOx	0-5000 ppm	1%
Crank angle encoder	720 x 10	10

3.0 Results and Discussions

3.1 Brake Thermal Efficiency

Figure 2 depicts the relationship between brake thermal efficiency and load, revealing that both diesel and a blend of plastic oil and diesel exhibit the highest efficiency. The presence of an aromatic bond in plastic oil necessitates more energy for bond breaking, influencing the overall efficiency. Notably, the addition of biodiesel to the plastic oil diesel blend enhances thermal efficiency due to the favorable properties of biodiesel, including high oxygen content, low viscosity, and a high cetane number. These attributes are identified as catalysts for improved combustion efficiency. The provided information is sourced from reference [13], indicating a comprehensive study underpinning the findings. In essence, the study underscores the role of biodiesel in augmenting thermal efficiency and elucidates the impact of specific

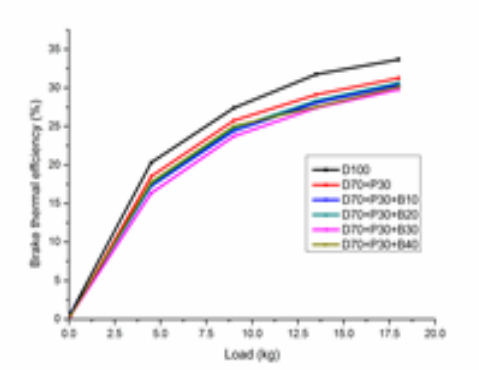


Figure 2. Load vs. brake thermal efficiency.

fuel properties on combustion in the context of engine performance.

3.2 In Cylinder Pressure

In Figure 3, the relationship between crank angle and pressure rise is illustrated, with a notable increase in pressure for plastic oil and diesel attributed to their high density and low viscosity, which promotes the early onset of ignition. However, the incorporation of biodiesel in the plastic oil diesel blend leads to a reduction in pressure rise. This is attributed to the lower calorific value and enhanced latent heat of evaporation associated with biodiesel. Alongside the decrease in pressure rise, the introduction of biodiesel also extends ignition delay. These observations are in line with findings referenced in [11], suggesting that the addition of biodiesel not only mitigates pressure rise but also influences ignition characteristics, emphasizing the complex interplay of fuel properties in the combustion process.

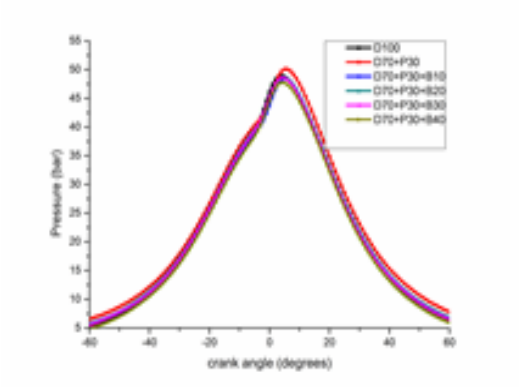


Figure 3. Crank angle vs. pressure.

3.3 Heat Release Rate

In Figure 4, the relationship between crank angle and heat output is depicted, revealing an elevated intensity discharge rate for the plastic oil and diesel blend. This heightened discharge rate is attributed to the blend's high heat content and low atomization. The negative trend observed at the beginning of ignition signifies fuel dissipation through heat absorption from the combustion chamber. The initiation of burning is delayed in the plastic oil diesel blend, a delay that multiplies with the increased addition of biodiesel. This heightened ignition delay is ascribed to the elevated latent heat vaporization associated with biodiesel. Studies referenced in [12] indicate that the addition of biodiesel prolongs ignition delay due to the breakdown of aromatic compounds. Notably, higher heat release rates for all biodiesel blends indicate enhanced atomization, and the oxygen content of biodiesel is credited with accelerating the combustion rate. The heat release curves align closely with the B20 blend, suggesting a noteworthy impact of biodiesel concentration on combustion characteristics.

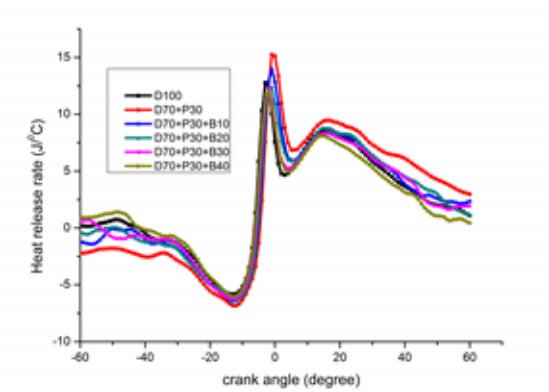


Figure 4. Crank angles vs. heat release.

3.4 Oxides of Nitrogen

Figure 5 illustrates the relationship between load and Nitrogen Oxides (NOx) emissions in a diesel engine. NOx emissions are a significant component of diesel engine exhaust. The formation of NOx is influenced by factors such as chamber temperature, oxygen concentration, and the duration of exposure. The temperature increase in the Plastic Oil (PO) is more pronounced than in diesel due to higher heat releases and a longer ignition

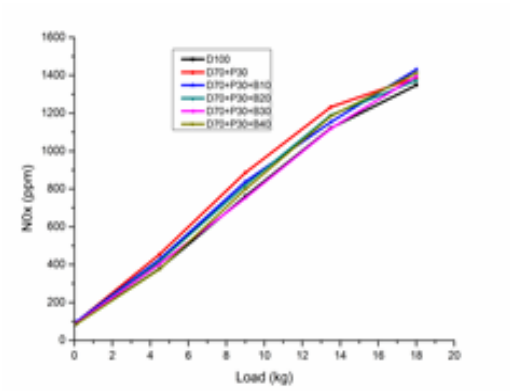


Figure 5. Load vs. nox emission.

delay period, resulting in elevated NOx emissions. However, as the proportion of biodiesel in the plastic oil diesel blend increases, NOx emissions decrease. This reduction is attributed to lower cylinder pressure and reduced heat release associated with biodiesel addition, as discussed in reference [14]. The findings underscore the potential of biodiesel to mitigate NOx emissions in diesel engines, offering insights into the interplay between fuel composition and environmental impact.

3.5 Hydrocarbon

In Figure 6, the relationship between load and Hydro Carbon (HC) emissions is presented, revealing an increase in unburnt hydrocarbon emissions for biodiesel blends. This rise in HC is attributed to a reduction in density resulting from the addition of biodiesel. Additionally, the high latent heat of vaporization associated with biodiesel is identified as a contributing factor to the increased HC emissions. The B20 blend aligns with diesel emissions

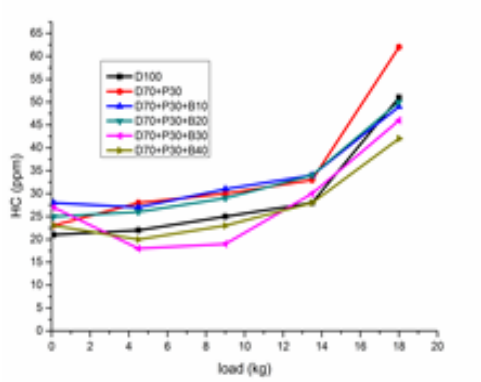


Figure 6. Load vs. HC emission.

at 100% load, indicating a comparable performance to conventional diesel in terms of hydrocarbon emissions. The findings suggest that while biodiesel blends may lead to an increase in unburnt hydrocarbons, the specific blend composition, such as B20, can offer performance similarities to traditional diesel under certain load conditions.

3.6 Carbon Monoxide

In Figure 7, the relationship between load and Carbon monoxide (CO) emissions is depicted, demonstrating the evolution of carbon monoxide in a diesel engine as part of the exhaust byproduct resulting from incomplete combustion due to limited oxygen availability. The creation of carbon monoxide also depends on the characteristics of the sample. The incidence of oxygen in biodiesel is noted to facilitate more complete combustion of the fuel, leading to lower carbon monoxide emissions. Specifically, CO emissions are found to be less for the B20 blend, suggesting blend with 20% biodiesel content performs favorably in relation to reducing carbon monoxide releases contrasted to normal straight fuel. These findings highlight the role of biodiesel in influencing combustion completeness and emissions characteristics in compressed ignition engines.

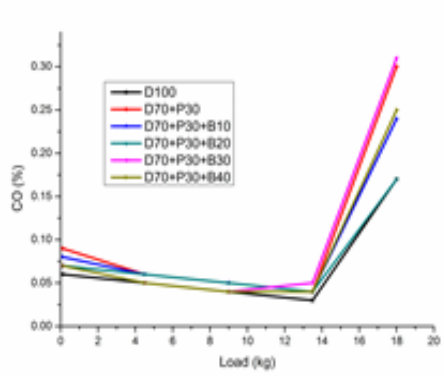


Figure 7. Load vs. CO emissions.

3.7 Carbon Dioxide

The release of Carbon dioxide (CO_2) is a result of complete combustion, where carbon molecules in the fuel are fully oxidized. Unlike some other emissions, CO_2 is typically not regulated due to its non-toxic nature. In the context of using plastic oil, the release of carbon dioxide has been observed to increase linearly. This is

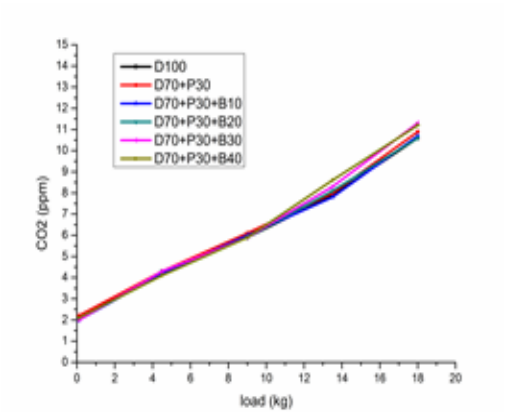


Figure 8. Load vs. CO_2 emissions.

recognized to the higher presence of carbon molecules in plastic oil compared to straight fuel. The linear increase in CO_2 emissions indicates an exact connection link of the carbon matter present in the test sample and the amount of carbon dioxide released during combustion (Figure 8). While CO_2 itself is not considered a harmful gas considering its harmfulness, it is a significant greenhouse gas contributing to climate change when released into the atmosphere. The findings underscore the value of comprehending the specific emissions associated with different fuel types to address environmental concerns.

4.0 Conclusion

The following conclusions are drawn from the experiment results.

The experimental findings reveal several key insights into the performance of biodiesel blends compared to plastic oil diesel blends. Firstly, it is noted that the thermal efficiency of biodiesel blends is lower than that of plastic oil diesel blends. From the pressure rise, the B20 blend closely mirrors diesel fuel, reaching around 48 bar. With a rise in biodiesel blend in plastic oil, there is a corresponding decrease in the heat release rate, attributed to a reduction in calorific value compared to P30 and diesel blends. Importantly, Nitrogen Oxide (NOx) emissions show a considerable reduction with an increasing biodiesel blend, linked to a decrease in the heat release rate. Carbon monoxide (CO) emissions at 75% load decrease for the B20 blend, aligning closely with diesel fuel at 100% load. Conversely, Carbon dioxide (CO_2) emissions increase with a higher biodiesel blend, indicative of complete combustion. Considering these findings, the experimental results suggest that the B20 blend could be considered an optimum fuel blend based on the observed characteristics, highlighting the intricate interplay of fuel composition on engine performance and emissions.

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6.0 References

1. Lee S, Yoshida K, Yoshikawa K. Application of waste plastic pyrolysis oil in a direct injection diesel engine: For a small-scale non-grid electrification. Energy Environ Res. 2015; 5(1):18–32. https://doi.org/10.5539/eer.v5n1p18
2. Mani M, Nagarajan G, Sampath S. Characterisation and effect of using waste plastic oil and diesel fuel blends in compression ignition engine. Energy. 2011; 36(1):212–9. https://doi.org/10.1016/j.energy.2010.10.049
3. Kalargaris I, Tian G, and Gu S. The utilization of oils produced from plastic waste at different pyrolysis temperatures in a DI diesel engine. Energy. 2017; 131:179-85. https://doi.org/10.1016/j.energy.2017.05.024
4. Kalargaris I, Tian G, Gu S. Combustion, performance and emission analysis of a DI diesel engine using plastic pyrolysis oil. Fuel Process Technol. 2017; 157:108-15. https://doi.org/10.1016/j.fuproc.2016.11.016
5. Gungor C, Serin H, Özcanl M, Serin S, Aydin K. Engine performance and emission characteristics of plastic oil produced from waste polyethylene and its blends with diesel fuel. Int J Green Energy. 2015; 12(1):98–105. https://doi.org/10.1080/15435075.2014.893873
6. Syamsiro M, Saptoadi H, Kismurtono M, Mufrodi Z, Yoshikawa K. Utilization of waste polyethylene pyrolysis oil as partial substitute for diesel fuel in a DI diesel engine. Int J Smart Grid Clean Energy. 2019; 8(1):38–47. https://doi.org/10.12720/sgce.8.1.38-47
7. Khan MZH, Sultana M, Al-Mamun MR, Hasan MR. Pyrolytic waste plastic oil and its diesel blend: Fuel characterization. J Environ Public Health. 2016. https://doi.org/10.1155/2016/7869080
8. Kumar R, Mishra MK, Singh SK, Kumar A. Experimental evaluation of waste plastic oil and its blends on a sin-

gle cylinder diesel engine. J Mech Sci Technol. 2016; 30(10):4781-9. https://doi.org/10.1007/s12206-016-0950-7
9. Singh TS, Verma TN, Singh HN. A lab scale waste to energy conversion study for pyrolysis of plastic with and without catalyst: Engine emissions testing study. Fuel. 2020; 277:118176. https://doi.org/10.1016/j.fuel.2020.118176
10. Nagesh SB, Banapurmath NR, Chandrashekhar TK, Khandal SV. Biodiesels powered in-cylinder Common Rail Direct injection (CRDi) assisted Homogeneous Charge Compression Ignition (HCCI) engine. Int J Sustain Eng. 2021; 14(2):147-61. https://doi.org/10.1080/19397038.2020.1811012
11. Kaimal VK, Vijayabalan P. An investigation on the effects of using DEE additive in a di diesel engine fuelled with waste plastic oil. Fuel. 2016; 180:90–6. https://doi.org/10.1016/j.fuel.2016.04.030
12. Selvam MAJ, Sambandam P, Sujeesh KJ. Investigation of performance and emission characteristics of single-cylinder DI diesel engine with plastic pyrolysis oil and diethyl ether blends. Int J Ambient Energy. 2020; 43(1): 3810-4. https://doi.org/10.1080/01430750.2020.1860127
13. Kaimal VK, Vijayabalan P. An investigation on the effects of using DEE additive in a DI diesel engine fuelled with waste plastic oil. Fuel. 2016; 180:90–6. https://doi.org/10.1016/j.fuel.2016.04.030
14. Wathakit K, Sukjit E, Kaewbuddee C, Maithomklang S, Klinkaew N, Liplap P, et al. Characterization and impact of waste plastic oil in a variable compression ratio diesel engine. Energies. 2021; 14(8). https://doi.org/10.3390/en14082230
15. Singh RK, Ruj B, Sadhukhan AK, Gupta P, Tigga VP. Waste plastic to pyrolytic oil and its utilization in CI engine: Performance analysis and combustion characteristics. Fuel. 2020; 262:116539. https://doi.org/10.1016/j.fuel.2019.116539

List of Abbreviations

PO - Plastic oil
WPO - Waste plastic oil
PPO - Pyrolysis plastic oil
30PO - 30% plastic oil + 70% Diesel
B10 - 30% plastic oil + 60% Diesel+B10
B20 - 30% plastic oil + 50% Diesel+B20
B30 - 30% plastic oil + 40% Diesel+B30
B40 - 30% plastic oil + 30% Diesel+B40