SSRG International Journal of Mechanical Engineering
ISSN: 2348-8360/ https://doi.org/10.14445/23488360/IJME-V11I7P103

Volume 11 Issue 7, 26-33, July 2024

Original Article

Performance, Emission and Combustion of CRDI Diesel Engine While Using Post Hospital Waste Plastic Oil as Fuel

S. Arulselvan[1], K. Kumaravel[2]

[1,2]*Faculty of Engineering and Technology, Annamalai University, Tamilnadu, India.*

[1]*Corresponding Author : sarulselvan74@gmail.com*

Received: 05 May 2024 Revised: 06 June 2024 Accepted: 04 July 2024 Published: 30 July 2024

Abstract - *This study investigates the effects of Common Rail Direct Injection (CRDI) diesel engine performance by utilizing Post Hospital Waste Plastic (PHWP) oil blends as an alternative fuel. With growing environmental concerns and depleting fossil fuel resources, exploring sustainable fuel options becomes imperative. Waste plastic oil, derived from plastic waste, presents a viable alternative. The research focuses on understanding the impact of PHWP oil blends on engine performance parameters such as brake-specific fuel consumption, thermal efficiency, and exhaust emissions, including Carbon monoxide, nitrogen oxides, and smoke. Additionally, combustion analysis techniques such as in-cylinder pressure measurement and heat release rate analysis are employed to gain insights into the combustion process with PHWP oil blends. The findings of this study contribute to the understanding of the feasibility and challenges associated with utilizing waste plastic oil as an alternative fuel in CRDI diesel engines, providing valuable insights for sustainable energy strategies in the transportation sector.*

Keywords - *Common rail direct injection, Diesel engine, Post hospital waste plastic oil, Combustion, Emission.*

1. Introduction

The management of plastic waste has emerged as a critical environmental challenge in recent years, with the healthcare sector contributing significantly to the generation of specific types of plastic waste, notably post-hospital waste plastics [1]. This waste stream, comprising a diverse array of single-use medical devices, packaging materials, and other disposable items, poses unique challenges due to its potential biohazardous nature and the need for specialized disposal methods.

Pyrolysis, a thermochemical conversion process, has gained attention as a promising approach for valorizing post-hospital waste plastics by converting them into valuable products such as liquid fuels. In particular, the pyrolysis of Post-Hospital Waste Plastic (PHWP) oil presents an opportunity to not only mitigate the environmental impact of plastic waste but also generate alternative energy sources [2-4]. However, despite its potential, the pyrolysis of PHWP remains relatively underexplored in the literature, especially concerning its technical feasibility, product characteristics, and environmental implications.

This paper aims to address this research gap by providing a comprehensive investigation into the pyrolysis of post-hospital waste plastic oil. Through experimental analysis and theoretical modelling, the study seeks to elucidate the pyrolysis kinetics, product distribution, and process parameters influencing the quality and yield of pyrolysis products. Furthermore, the environmental implications, including the potential for reducing greenhouse gas emissions and addressing plastic pollution, will be assessed. The utilization of post-hospital waste plastic oil as a feedstock for pyrolysis offers several potential advantages. Firstly, it provides a sustainable solution for managing healthcare-related plastic waste, which is typically challenging to recycle due to contamination and regulatory constraints.

Secondly, the conversion of PHWP into liquid fuels, such as diesel and gasoline substitutes, can contribute to reducing dependence on fossil fuels and mitigating carbon emissions. By advancing our understanding of the pyrolysis process for post-hospital waste plastic oil, this research aims to provide valuable insights into the technical, economic, and environmental feasibility of this waste-to-energy conversion pathway. Ultimately, the findings of this study have the potential to inform policy decisions, guide technological development, and contribute to the transition towards a circular economy paradigm in the healthcare sector.

One of the key advantages of using catalysts in pyrolysis is the ability to tailor the composition and properties of pyrolysis products according to specific applications [5-8]. By optimizing catalyst composition and operating conditions, researchers can fine-tune the pyrolysis process to yield higher proportions of desired liquid fuels while minimizing undesirable by-products such as char and gases [9-12]. This level of control opens up new possibilities for utilizing pyrolysis oil as a sustainable alternative to fossil fuels in various industries. Moreover, the incorporation of catalysts in pyrolysis processes holds promise for addressing some of the challenges associated with conventional plastic waste management [13]. By converting hospital waste plastics into valuable products such as liquid fuels, pyrolysis with catalysts offers a viable solution for reducing plastic pollution and dependency on finite fossil fuel resources [14]. Additionally, the potential for valorizing hospital waste plastics through pyrolysis aligns with broader efforts to transition towards a circular economy model, where waste materials are recycled and reused in a closed-loop system.

However, despite the promising results, further research is needed to fully understand the mechanisms underlying catalytic pyrolysis processes and optimize catalyst formulations for practical applications. Additionally, considerations regarding the scalability, economic viability, and environmental impact of catalytic pyrolysis technologies must be addressed to realize their full potential in sustainable waste management. The production of hospital waste plastic oil through pyrolysis with catalysts represents a promising avenue for addressing the dual challenges of plastic waste pollution and energy sustainability [15]. By harnessing the synergistic effects of zeolite, aluminum, and silica catalysts, researchers are paving the way for more efficient and environmentally friendly approaches to converting hospital waste plastics into valuable resources. As efforts in this field continue to advance, catalytic pyrolysis holds immense promise for contributing to a more sustainable future [16].

In recent decades, the global automotive industry has faced increasing pressure to address environmental concerns while simultaneously striving for improved performance and efficiency. Among the various propulsion technologies, diesel engines have long been favored for their superior fuel efficiency and torque characteristics, particularly in heavy-duty applications [17]. However, the widespread use of diesel engines has also been associated with significant emissions of pollutants such as carbon monoxide (CO) and nitrogen oxides (NOx), contributing to air pollution and climate change [18].

To mitigate these environmental impacts, researchers and engineers have been exploring alternative fuels and advanced engine technologies. One promising avenue is the utilization of waste plastics as a source of fuel. Plastic waste, a ubiquitous environmental pollutant, poses a significant challenge due to its persistence in the environment and limited recycling options. Converting waste plastics into usable fuel not only addresses the issue of waste management but also offers a potential solution to reduce reliance on conventional fossil fuels [19].

In this context, the present study focuses on augmenting the performance of Common Rail Direct Injection (CRDI) diesel engines by employing Post Hospital Waste Plastic oil (PHWP) blend as a substitute for conventional diesel fuel. CRDI technology, known for its precise control over fuel injection, offers a platform for optimizing the combustion process and enhancing engine efficiency. By investigating the effects of higher injection pressures on engine performance while using PHWP oil blends, this research aims to explore the feasibility of integrating waste plastic-derived fuel into diesel engine systems. The utilization of waste plastic oil presents several potential advantages. Firstly, it offers a sustainable solution for managing plastic waste by converting it into a valuable energy resource. Secondly, PHWP oil blends have the potential to cut greenhouse gas emissions and dependence on finite fossil fuel reserves. However, the successful integration of PHWP oil blends into diesel engines requires careful consideration of combustion characteristics, emissions, and engine performance parameters. By addressing these objectives, this research aims to contribute to the advancement of sustainable transportation solutions while simultaneously addressing the challenges of plastic waste management and environmental pollution.

2. Production of Hospital Waste Plastic Oil Through Pyrolysis

Pyrolysis, a thermal decomposition process, offers a promising avenue for converting hospital waste plastics to liquid fuel. Pyrolysis, the process of breaking down waste plastics at higher temperatures in the absenteeism of oxygen, holds immense promise for transforming hospital waste plastics into valuable resources. However, the efficiency and quality of pyrolysis oil can be significantly improved through the use of catalysts. The pyrolysis reactor schematic is shown in Figure 1. A water pump, an oil collector, an electric heater, a reactor, a condenser, a temperature controller, a K-type thermocouple, a pressure gauge, and an inert gas source comprise the setup. It was possible to feed the reactor with three kilograms of spent plastic at once. A 1500 W electric heater is positioned beneath the reactor configuration to make up the reactor. Measuring 25 cm in length and 26 cm in diameter, the condenser was a counter-flow heat exchanger. Cooled water, about 20°C, is used as the coolant. Recycled plastic is placed inside a steel container that measures 15 cm in diameter by 20 cm in height. At last, the electric heater is situated above this container. The bottom of the reactor was constructed with a manhole to facilitate the removal of the converted sludge. For safety, a safety valve is mounted on top of the reactor. A portable weighing scale is used to determine the weights of the polymers and the catalyst. The waste plastic and catalyst were properly mixed before being sent to the reactor. Nitrogen gas was injected into the reactor through a manhole due to its vertical configuration. The pyrolysis reaction can take place in an anaerobic atmosphere by substituting nitrogen for the air in the reactor.

A temperature controller controlled the temperature of the pyrolysis reactor. The power supply for the heating coil is connected to the temperature controller. A K-type thermocouple was installed at the reactor's top to monitor temperature; a temperature controller was connected to the thermocouple's other end. The temperature controller maintains the reactor at the predetermined temperature by cutting off the power to the heating coil once the input temperature is reached. A pressure gauge that measures the pressure is located at the top of the reactor. A power meter is installed to find out how much power is used in this setup. Before starting the heating process, the heater unit is allowed to be filled with nitrogen gas in order to remove any initial oxygen. The temperature controller is then adjusted to the required operating temperature, and the heater is turned on. The gas mixture cools in the condenser. The temperature of the water that is sent to the condenser for cooling is 10°C. A low temperature is produced in a bucket of water by adding ice cubes. Of the remaining uncondensed part, a small amount escapes into the atmosphere.

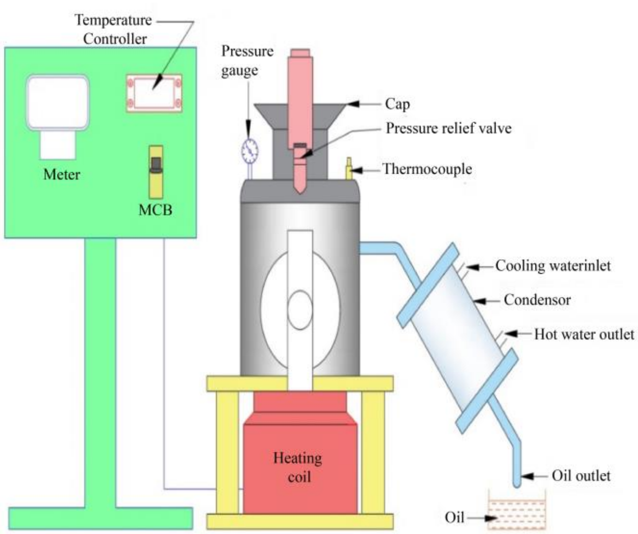

Fig. 1 Schematic diagram of the waste plastic pyrolysis reactor

3. Analysis of the Properties of Waste Plastic Oil

The thermos-physical properties were analyzed as per ASTM standards in the ETA laboratory in Chennai. The flash point of post-hospital waste plastic oil extracted through pyrolysis refers to the temperature at which it emits enough vapor to form a flammable mixture with air near its surface. Essentially, it is the temperature at which the substance can ignite momentarily if interpreted as an open flame or spark. In the case of PHWP oil extracted through pyrolysis, the flash point is found as 79°C. The fire point is at which the vapor being emitted from a substance can sustain combustion for at least 6 seconds after the ignition source is removed. It is a step beyond the flash point and indicates the substance can continue burning. The fire point of PHWP oil extracted through pyrolysis was found as 85°C.

The Cetane index is a measure used to assess the ignition quality of diesel fuels during compression ignition in internal combustion engines. It is often utilized as an indicator of the combustion performance of diesel fuels. Higher cetane index values generally indicate better ignition quality and more efficient combustion. However, the cetane index may not be directly applicable to waste plastic oil extracted through pyrolysis, as its composition can be quite different from conventional diesel fuels. The cetane index of PHWP oil was calculated as 51.

The gross calorific value, also known as the higher heating value, is the amount of heat released when a fuel undergoes complete combustion in an oxygen-rich environment. It represents the maximum potential energy available from the combustion of a substance and is typically expressed in units of energy per unit mass (kcal/kg). Determining the Gross Calorific Value (GCV) of PHWP oil extracted through pyrolysis is essential for assessing its energy content and potential applications as a fuel. From the analysis report, the GCV of PHWP oil was 10291 kcal/kg. Viscosity is a measure of a fluid's resistance to flow. In the context of PHWP oil extracted through pyrolysis, viscosity refers to how easily the oil can flow at a given temperature. The viscosity of this PHWP oil is 2.11. Density refers to the mass of a substance per unit volume. For PHWP oil extracted through pyrolysis, density is a crucial parameter that influences its handling, storage, and transportation. The density of PHWP oil is 0.8354.

Table 1. Properties of PHWP oil

Parameter Name	Unit	Method	PHWP
Flash Point by PMCC Method	°C	IS:1448 (PART21)	79
Fire Point by PMCC Method	°C	IS:1448 (PART21)	85
Calculated Cetene Index	-	ASTM D-976-91	51.01
Gross Calorific Value	Kcals/kg	IS:1448 (PART6)	10291
Viscosity @ 40°C	cst	IS:1448 (PART25)	2.11
Density @ 15°C	Gm/ml	IS:1448 (PART32)	0.8354

4. CRDI Engine Setup

Converting a single-cylinder mechanical injected diesel engine into a CRDI diesel engine involves several steps: Initially, the mechanical injection pump, injector lines, and associated components are removed from the engine. Then, the engine is fitted with a common rail, high-pressure fuel pump, CRDI injectors, and necessary sensors. Modifications to the cylinder head and fuel delivery system may be required to accommodate CRDI components. Wiring harnesses are installed to connect the CRDI components to the ECU. The ECU is mounted and programmed to control fuel injection parameters based on engine requirements. The converted engine is calibrated and tested to ensure proper functionality, fuel delivery, and combustion characteristics. Adjustments made to optimize fuel injection timing, quantity, and duration for optimal performance and emissions control. Figure 2 shows the schematic diagram of the CRDI diesel engine.

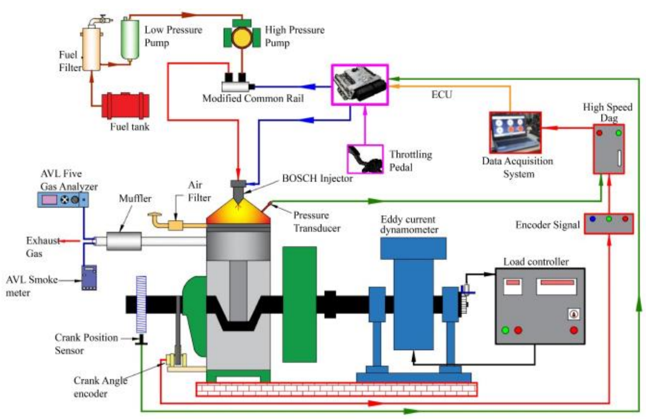

Fig. 2 Schematic diagram of CRDI diesel engine setup

5. Results and Discussion

Post Hospital Waste Plastic (PHWP) oil, also known as pyrolysis oil derived from hospital plastic wastes, has gained attention as a potential alternative fuel source. The utilization of PHWP oil blends in CRDI diesel engines has significant inferences for performance, emission and combustion characteristics. The variation in Brake Specific Fuel Consumption (BSFC) of diesel, PHWP10, PHWP20 and PHWP30 while using fuel in CRDI diesel engines are shown in Figure 3. The BSFC of diesel fuel was found to be 0.348kg/kW-hr. Where it was 0.366, 0.38 and 0.394 kg/kW-hr for PHWP10, PHWP20 and PHWP30, respectively. From the results, it is clear that the BSFC of PHWP fuel blends are higher than diesel fuel. It is also clear that the BSFC increased with an increase in the percentage of PHWP in diesel fuel. PHWP30 shows a higher BSFC than the other two fuel blends at higher engine load conditions.

The variation in Brake Thermal Efficiency (BTE) with respect to brake power of diesel, PHWP10, PHWP20 and PHWP30 while using fuel in CRDI diesel engine were shown in Figure 4. BTE in a diesel engine is a measure of how effectively the fuel energy is converted into useful work. It is typically expressed as a percentage and represents the proportion of the brake power output to the fuel energy input. The calorific value of PHWP is lower than that of diesel fuel. The lower calorific value has resulted in reduced brake power output for the same amount of fuel consumed, thereby affecting the BTE. From the results, the BTE of diesel was found to be 24.9 %, whereas it was 24.5, 23.8 and 23.6 % for PHWP10, PHWP20 and PHWP30 blends, respectively.

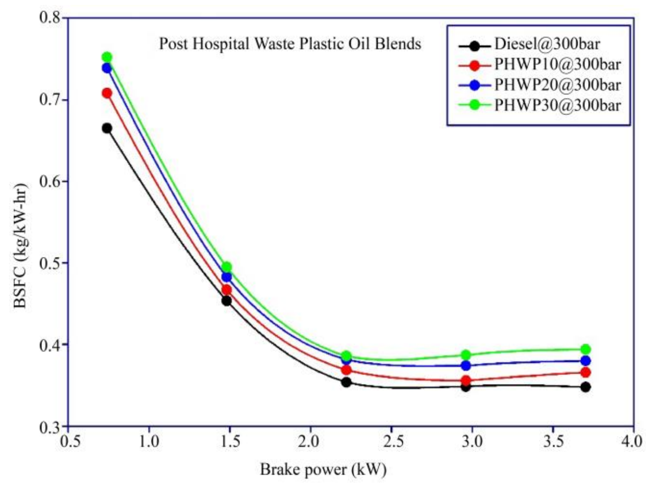

Fig. 3 Impact of PHWP blends on BSFC

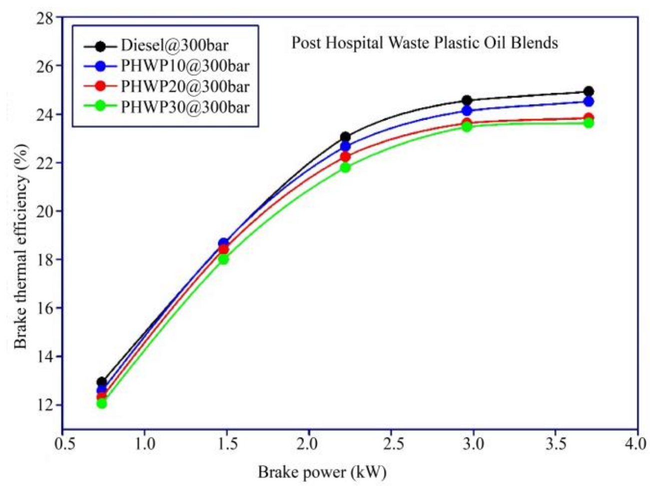

Fig. 4 Impact of PHWP blends on BTE

The variation in CO emission with respect to brake power when PHWP blends are used as fuel in CRDI diesel engines is shown in Figure 5. The PHWP blends do not combust as efficiently as conventional diesel fuel due to their different chemical composition and physical properties. Incomplete combustion can result in the production of carbon monoxide [20]. When PHWP blends do not fully mix with air or do not combust completely, carbon monoxide is formed as a byproduct of the combustion process. From the figure, it is found that the CO emission of diesel fuel is 0.58 % by volume. At the same time, it was 0.6, 0.63 and 0.67 % by volume for

PHWP10, PHWP20 and PHWP30 blends, respectively. The HC emission with respect to brake power is shown in Figure 6. The combustion of PHWP oil blends also affects the hydrocarbon emissions from the engine. Hydrocarbons are organic compounds present in fuel and are emitted during incomplete combustion [21]. The composition of PHWP oil, along with combustion characteristics, influences the HC emissions. From the figure, it is found that the HC emission of diesel fuel is 113 ppm. At the same time, it was 117, 122 and 126 ppm for PHWP10, PHWP20 and PHWP30 blends, respectively. The amount of HC emission is gradually increased with the increase of the percentage of PHWP oil in diesel fuel.

Waste plastic oil often contains complex hydrocarbon molecules that may not combust completely in the engine. When these molecules are incompletely burned, they can form soot particles, which contribute to smoke emissions [22]. Unlike conventional diesel fuel, waste plastic oil may have higher levels of impurities and contaminants, which can further exacerbate incomplete combustion and increase smoke production [22]. The viscosity and density of waste plastic oil differ from those of conventional diesel fuel. This can affect fuel atomization and mixing with air inside the combustion chamber. Poor atomization and mixing can result in localized areas of rich mixture, where incomplete combustion occurs, increasing the likelihood of soot formation and smoke emissions [23]. The smoke density with respect to the brake power of PHWP oil blends is shown in Figure 7. The smoke density increased with an increase in the amount of PHWP in diesel fuel. The smoke density of diesel was found to be 58.5HSU. The smoke density of PHWP10 was 3.07% higher than the diesel fuel. At the same time, it was 6.7% and 8.9% higher compared to diesel fuel for PHWP20 and PHWP30, respectively.

The NOx emission with respect to brake power of PHWP oil blends is shown in Figure 8. The NOx emission decreased with the rise in the percentage of PHWP oil with diesel. Changes in combustion behaviour, such as altered ignition delay and flame propagation, can affect NOx formation [24]. The proportion of hospital waste plastic oil can significantly influence emissions. Hospital waste plastic oil blends have lower nitrogen content compared to diesel. If the nitrogen content in the fuel blend is reduced, there will be fewer nitrogen-containing compounds available for NOx formation during combustion, leading to decreased emissions [20]. Hospital waste plastic oil blends can sometimes lead to lower combustion temperatures compared to pure diesel fuel. Lower combustion temperatures can inhibit the formation of thermal NOx, which is formed at high temperatures during combustion [25]. The NOx emissions of 758, 730, 701, and 681 ppm were found in the cases of diesel, PHWP10, PHWP20 and PHWP30 blends, respectively at maximum load.

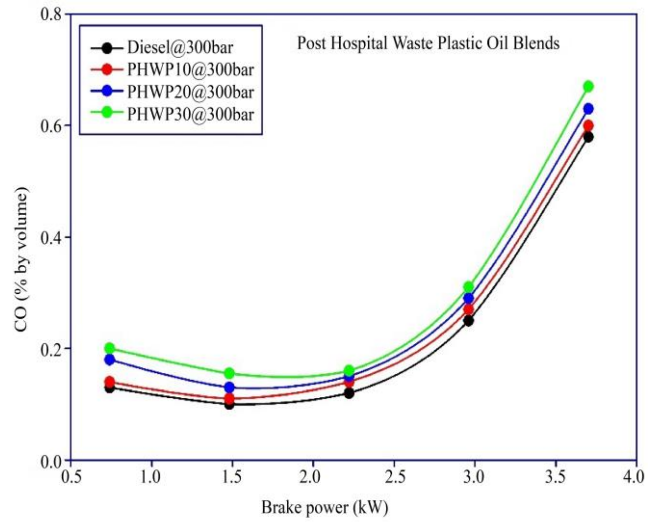

Fig. 5 Impact of PHWP blends on CO emission (% by volume)

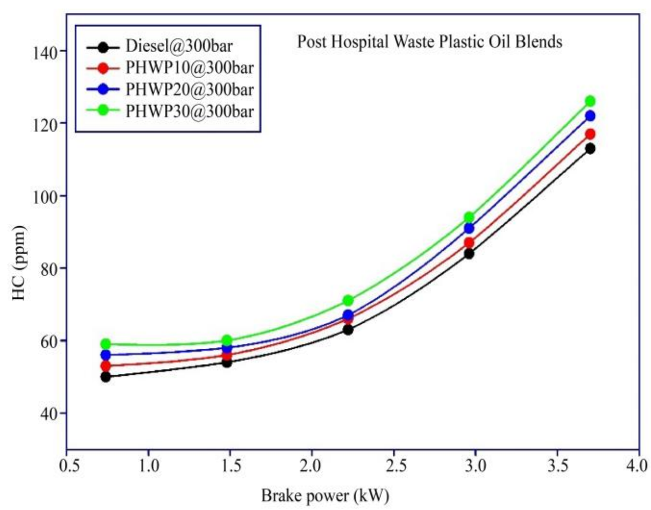

Fig. 6 Impact of PHWP blends on HC emission (ppm)

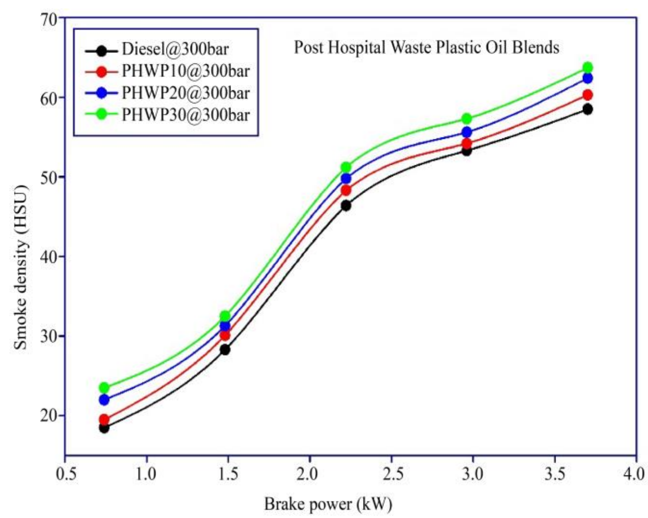

Fig. 7 Impact of PHWP blends on Smoke density (HSU)

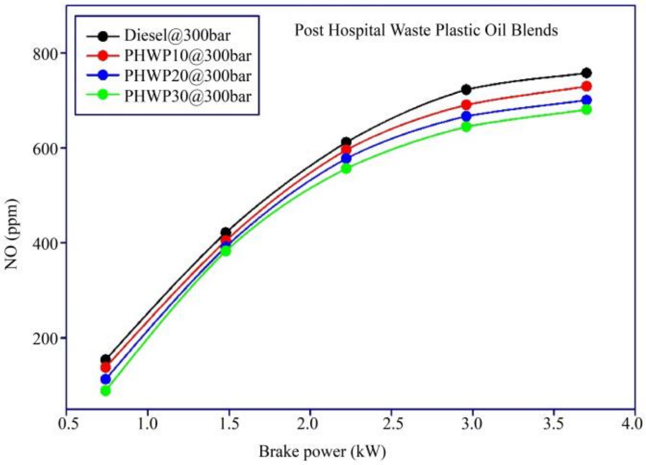

Fig. 8 Impact of PHWP blends on NOx emission (ppm)

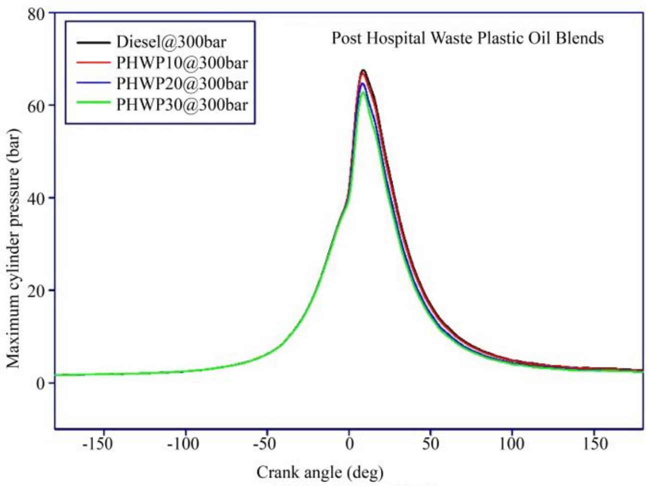

Fig. 9 Impact of PHWP blends on in-cylinder pressure

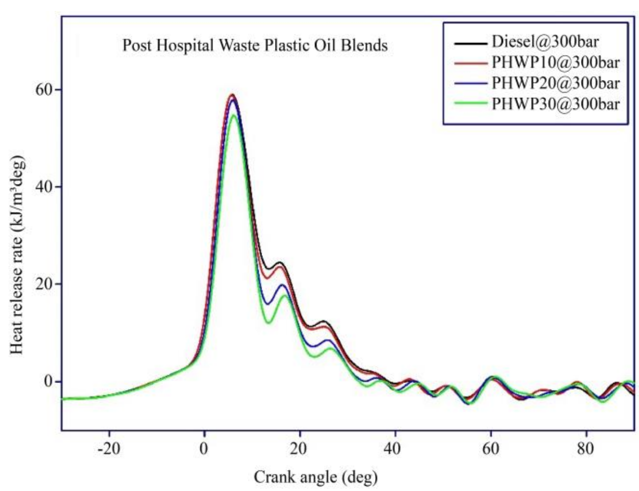

Fig. 10 Impact of PHWP blends on heat release rate

The variation in the cylinder pressure (bar) with respect to crank angle (degree) when PHWP blends are used as fuel in CRDI diesel engines is shown in Figure 9. From the figure, it is clear that the in-cylinder pressure was drastically reduced with the increase in the percentage of PHWP oil with diesel fuel. Proper mixing of the fuel with air and efficient atomization is crucial for uniform combustion. Higher density and viscosity of PHWP oil can lead to poor atomization, non-uniform combustion and reduced combustion stability. The in-cylinder pressure of diesel fuel was found to be 67.6537 bar. Whereas cylinder pressure for PHWP10, PHWP20 and PHWP30 blends were 66.8533, 64.5558, and 62.7503 bar respectively. The in-cylinder pressure was decreased by 4.62% when the PHWP30 was used as fuel in the CRDI diesel engine.

The Heat Release Rate (HRR) with respect to the crank angle of PHWP oil blends are shown in Figure 10. From the figure, it is clear that the HRR was increased with the increase in the percentage of PHWP oil with diesel fuel. The composition and properties of the post-hospital waste oil blend significantly influence the heat release rate. Waste oils typically contain a mixture of fatty acids, triglycerides, and other hydrocarbons, which may have different combustion characteristics compared to conventional diesel fuel [24]. The combustion characteristics of the PHWP oil blends, including its cetane number, volatility, and calorific value, influence the heat release rate profile. The HRR of the diesel fuel was 58.9268 kJ/m^{3}deg. Whereas it was 58.5997, 57.8645 and 54.7151 kJ/m^{3}deg for PHWP10, PHWP20 and PHWP30 blends respectively.

6. Conclusion

- When using a blend of post-hospital waste oil as fuel in a CRDI diesel engine, several factors influence the heat release rate and subsequently affect engine performance and emissions.
- Changes in combustion characteristics and fuel properties can also affect emissions and heat losses in the engine. Higher emissions or increased heat transfer to the cooling system can reduce the available energy for useful work output, thus lowering brake power and BTE.
- Variations in combustion characteristics compared to conventional diesel fuel may require adjustments to engine calibration parameters to achieve optimal performance and emissions.
- Adjustments to injection timing and pressure may be necessary when using alternative fuels like waste oil blends to ensure proper atomization, mixing, and combustion.

References

[1] D. Damodharan et al., "Utilization of Waste Plastic Oil in Diesel Engines: A Review," *Reviews in Environmental Science and Bio/Technology*, vol. 18, no. 4, pp. 681-697, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[2] Viswanath K. Kaimal, and P. Vijayabalan, "A Detailed Study of Combustion Characteristics of a DI Diesel Engine Using Waste Plastic Oil and its Blends," *Energy Conversion and Management*, vol. 105, pp. 951-956, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[3] Amar Kumar Das et al., "Energy, Exergy and Emission Analysis on a DI Single Cylinder Diesel Engine Using Pyrolytic Waste Plastic Oil Diesel Blend," *Journal of the Energy Institute*, vol. 93, no. 4, pp. 1624-1633, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[4] Khatha Wathakit et al., "Characterization and Impact of Waste Plastic Oil in a Variable Compression Ratio Diesel Engine," *Energies*, vol. 14, no. 8, pp. 1-18, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] Sunaryo Sunaryo et al., "Performance and Fuel Consumption of Diesel Engine Fueled by Diesel Fuel and Waste Plastic Oil Blends: An Experimental Investigation," *Automotive Experiences*, vol. 4, no. 1, pp. 20-26, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[6] Rajan Kumar et al., "Experimental Evaluation of Waste Plastic Oil and its Blends on a Single Cylinder Diesel Engine," *Journal of Mechanical Science and Technology*, vol. 30, pp. 4781-4789, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[7] Viswanath K. Kaimal, and P. Vijayabalan, "A Study on Synthesis of Energy Fuel from Waste Plastic and Assessment of its Potential as an Alternative Fuel for Diesel Engines," *Waste Management*, vol. 51, pp. 91-96, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[8] S. Ananthakumar, S. Jayabal, and P. Thirumal, "Investigation on Performance, Emission and Combustion Characteristics of Variable Compression Engine Fuelled with Diesel, Waste Plastics Oil Blends," *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 39, pp. 19-28, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[9] C.A. Rinaldini et al., "Performance, Emission and Combustion Characteristics of a IDI Engine Running on Waste Plastic Oil," *Fuel*, vol. 183, pp. 292-303, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[10] Amar Kumar Das et al., "Optimization of Engine Parameters and Ethanol Fuel Additive of a Diesel Engine Fuelled with Waste Plastic Oil Blended Diesel," *Process Integration and Optimization for Sustainability*, vol. 4, no. 4, pp. 465-479, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[11] Hariram Venkatesan et al., "Experimental Study on Combustion and Performance Characteristics in a DI CI Engine Fuelled with Blends of Waste Plastic Oil," *Alexandria Engineering Journal*, vol. 57, no. 4 pp. 2257-2263, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[12] Amar Kumar Das et al., "Study on the Performance and Emission Characteristics of Pyrolytic Waste Plastic Oil Operated CI Engine Using Response Surface Methodology," *Journal of Cleaner Production*, vol. 328, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] P. Senthil Kumar, and G. Sankaranarayanan, "Investigation on Environmental Factors of Waste Plastics into Oil and its Emulsion to Control the Emission in DI Diesel Engine," *Ecotoxicology and Environmental Safety*, vol. 134, no. 2, pp. 440-444, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[14] Mohanraj Chandran, Senthilkumar Tamilkolundu, and Chandrasekar Murugesan, "Characterization Studies: Waste Plastic Oil and its Blends," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 42, no. 3, pp. 281-291, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[15] S. Padmanaba Sundar et al., "Experimental and Feasibility Study on Nano Blended Waste Plastic Oil Based Diesel Engine at Various Injection Pressure: A Value Addition for Disposed Plastic Food Containers," *Fuel Processing Technology*, vol. 242, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[16] R.K. Singh et al., "Waste Plastic to Pyrolytic Oil and its Utilization in CI Engine: Performance Analysis and Combustion Characteristics," *Fuel*, vol. 262, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[17] C. Syed Aalam, and C.G. Saravanan, "Effects of Nano Metal Oxide Blended Mahua Biodiesel on CRDI Diesel Engine," *Ain Shams Engineering Journal*, vol. 8, no. 4, pp. 689-696, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[18] Revu Krishn Mohan et al., "Alternative Fuel Production from Waste Plastics and their Usability in Light Duty Diesel Engine: Combustion, Energy, and Environmental Analysis," *Energy*, vol. 265, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[19] C. Syed Aalam, C.G. Saravanan, and M. Kannan, "Experimental Investigations on a CRDI System Assisted Diesel Engine Fuelled with Aluminium Oxide Nanoparticles Blended Biodiesel," *Alexandria Engineering Journal*, vol. 54, no. 3, pp. 351-358, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[20] Ankit Verma et al., "Engine Fuel Production from Waste Plastic Pyrolysis (WPO) and Performance Evaluation in a CI Engine with Diesel Blend," *Journal of Materials and Environmental Sciences*, vol. 9, no. 6, pp. 1712-1721, 2018. [Google Scholar] [Publisher Link]

[21] Hariram Venkatesan et al., "Assessment of Waste Plastic Oil Blends on Performance, Combustion and Emission Parameters in Direct Injection Compression Ignition Engine," *International Journal of Ambient Energy*, vol. 40, no. 2, pp. 170-178, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[22] Dunga Simhana Devi, Ravinder Kumar, and Upendra Rajak, "Experimental Investigation of Performance, Emission and Combustion Characteristics of a CI Engine Fuelled by Blends of Waste Plastic Oil with Diesel," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 44, no. 3, pp. 7693-7708, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[23] S. Lakshmana Kumar, S. Radjarejesri, and R. Raj Jawahar, "Characterization of Waste Plastic Oil as Biodiesel in IC Engines," *Materials Today: Proceedings*, vol. 33, no. 1, pp. 833-838, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[24] C. Syed Aalam, C.G. Saravanan, and B. Prem Anand, "Impact of High Fuel Injection Pressure on the Characteristics of CRDI Diesel Engine Powered by Mahua Methyl Ester Blend," *Applied Thermal Engineering*, vol. 106, pp. 702-711, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[25] Krishnaraj Janarthanan, and Periyasamy Sivanandi, "Extraction and Characterization of Waste Plastic Pyrolysis Oil for Diesel Engines," *Journal of Cleaner Production*, vol. 366, 2022. [CrossRef] [Google Scholar] [Publisher Link]