Natural and Applied Sciences International Journal (NASIJ)
eISSN: 2788-4619 (online)
https://www.ideapublishers.org/index.php/nasij
Vol. 5, No. 1 (January-June), 2024, pp. 1-13
https://doi.org/10.47264/idea.nasij/5.1.1

Research Article

Investigations of carbon and particulate matter emissions of diesel engine using tertiary fuel

Sajjad Bhangwar*[1] | Zohaib Khan[2, 3] | Azhar Hussain Shah[1] | Arif Ali Rind[1] | Muhammad Siddique Baloch[1] | Irfan Gul[1] | Muhammad Nawaz[1]

1. Department of Mechanical Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, Sindh, Pakistan.
2. Mechanical Engineering Department, The University of Larkana, Larkana, Sindh, Pakistan
3. Faculty of Mechanical & Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia.

* Corresponding Author Email: sajjadbhangwar@quest.edu.pk

Abstract:

The modern development reveals that the world is facing an energy crisis due to the depletion of fossil fuel reserves. Biodiesel is renewable bioenergy made from vegetable oils, microalgae oil, and animal fats. The study involved adding 3,000 parts per million (ppm) of clove oil as an additive to the biodiesel. An endurance test was then conducted on a Compression Ignition (CI) engine for a duration of 100 hours, using three different fuel samples: pure diesel fuel (D100), a blend of 30% biodiesel and 70% diesel fuel (B30), and a blend of biodiesel with 3,000 ppm of clove oil (3000 ppm). To analyse the effects of fuel samples on carbon emissions from a CI engine. The results show that carbon monoxide (1.69%) is reduced in B30 and (7.49%) is reduced in CL3000 ppm. Carbon dioxide (7.97%) in B30 and 12.59% in CL3000 ppm are also reduced. Further particulate diesel engine emissions using biodiesel and clove oil-blend fuel samples were investigated. It was found that PM emissions were reduced when using clove oil-blend fuel.

Article History

Received:
14-Dec-2023

Revised:
24-Jan-2024

Re-revised:
19-Feb-2024

Accepted:
20-Feb-2024

Published:
29-Feb-2024

Keywords: Compression ignition engine, CI engine, Biodiesel, Clove oil, Carbon monoxide, Carbon dioxide, Fossil fuel, Energy crisis, Bioenergy, Renewable bioenergy.

How to Cite: Bhangwar, S., Khan, Z., Shah, A. H., Rind, A. A., Baloch, M. S., Gul, I., & Nawaz, M. (2024). Investigations of carbon and particulate matter emissions of diesel engine using tertiary fuel. *Natural and Applied Sciences International Journal (NASIJ), 5*(1), 1-13. https://doi.org/10.47264/idea.nasij/5.1.1

1. Introduction

Studies have shown that moving to various powertrains and fuels is required as part of the global effort to reduce emissions from road transportation. Due to this shift, the introduced technologies and design elements are new or substantially altered. The automotive sector aims to create cars and fuels that limit harmful emissions, such as Greenhouse Gases (GHG), in the environment (Stępień *et al.*, 2021). Interestingly, alcohol-doped fuels follow current developments in the design of internal combustion engines. This makes them suitable for optimising engine design and exploring the new technologies (Sun *et al.*, 2021; Bhangwar *et al.*, 2022a; b).

The use of alcohol-gasoline blends as an environmentally friendly alternative to traditional fuels is a significant consideration in developing vehicle propulsion systems. Numerous studies have indicated that using such blends can reduce emissions (Karavalakis *et al.,* 2012; Knoll *et al.*, 2009; Bhangwar *et al.*, 2024). The fuel characteristics impact engine control limits, efficiency and working characteristics optimization, and the quantity of harmful emissions. In order to guarantee proper performance characteristics and technological functionality. The fuel must be chosen. Any new fuel that is released onto the market needs to be modified to fit the needs of the current fleet of cars (Biernat *et al.*, 2023). Engine deposits form differently based on where they are and what influences them. The simultaneous occurrence of the deposit formation and removal processes leads to the creation of a given number of deposits. Even though the mechanisms of deposit formation are well recognised, the precise mechanisms at play are still poorly understood. Fuel injectors produce deposit precursors by oxidizing, condensing, and precipitating unstable compounds from the fuel, such as aromatics and olefins (Memon, 2022).

These components then undergo two different chemical processes to produce precipitates: self-oxidation at low temperatures and pyrolysis at high temperatures to produce coke as a precipitate. However, because both can happen in a temperature range where both reactions intersect, it has been challenging to draw a distinct line between the low- and high-temperature reactions (Mendiburu *et al.*, 2022). In contrast to thermal stability, oxidative stability measures the rate at which oxygen is used when producing oxidation products. Alkyl radicals produce hydrated peroxides and other oxidation products in oxidation processes responsible for deposit development (Martikainen *et al.*, 2023). High temperature is the main element influencing deposit formation on injector tips in GDI and PFI (Port Fuel Injection) engines (Mendiburu *et al.*, 2022).

High olefin and sulfur concentrations in the fuel are additional elements that aid in deposit formation. High pressure and the combustion mixture's gases in the engine's combustion chamber have a sizable direct chemical effect on injector creation (Ogunsola, A. 2023). Thermal oxidation and polymerisation processes in the fuel lead to deposits, such as resins and lakes, which challenge engine designers and fuel manufacturers, particularly those in the additive industry (Panithasan & Venkadesan, 2023). PIB dissolves well in hydrocarbons but not in alcohol, which can increase deposits on engine components and the fuel injection system. Therefore, DCA-type additives explicitly designed for alcohol-blended fuels are necessary (Rajpoot *et al.*, 2023). The engine assessments are carried out on the various engine generations to determine the development of the harmful deposits on various engine components (Simhadri *et al.*, 2023).

Hydroperoxide formation can result in the production of various secondary oxidation products, such as aldehydes and ketones. These products can obstruct fuel lines and pumps, highlighting the need for acceptable oxidation stability levels in the biodiesel industry (Uğuz *et al.*, 2019). Rancimat, PetrOXY, and EN14112 are just a few of the methods and standards that are employed to identify these levels. The acceleration test, on which the Rancimat analysis technique is based, gauges how much the oxidation of volatile fatty acids increases the water's conductivity in a sample (Supriyono *et al.*, 2015). The EN14112 standard, originally developed to assess the stability of oils, can now be used to test the oxidative stability of biodiesel. This standard specifies a minimum induction time of 6 hours for biodiesel assessed by Rancimat analysis at 110 °C (Pardauil *et al.*, 2011).

In natural fatty acid structures, the isomerisation of double bonds results in saturated structures as the oxidation products. Biodiesel's density and viscosity values are increased due to these saturated high molecular weight structures (Jain & Sharma, 2010). The formation of molecules that could weaken the oxidation stability of biodiesel can be stopped or reduced by applying specific chemicals. In order to inhibit the process of food deterioration, antioxidants are widely utilised in food preparation. The phenolic groups are the most effective and widely utilised primary antioxidants because of their processes (De Sousa *et al.*, 2014; Schirmann *et al.*, 2019). The recent years have seen a rise in the usage of the natural additives in the industrial goods like food, medicine, cosmetics, and fuel. These organic compounds act as an antioxidant and lessen or eliminate the harmful effects of certain chemicals (Kreivaitis *et al.*, 2013; Bharti & Singh, 2020).

There are two types of antioxidants: natural and manufactured. Synthetic antioxidants have typically improved biodiesel's oxidation stability (Mahaser *et al.*, 2023; Ismail & Ali, 2016). On the other hand, natural antioxidants like tocopherols, gossypol, and many others are cost-effective compared to synthetic antioxidants and easily available. Additionally, natural antioxidants are eco-friendly, while synthetic ones are toxic and non-biodegradable. Therefore, using natural antioxidants reduces costs and environmental impact while increasing benefits (Moser *et al.*, 2012; Dunn *et al.*, 2005).

The literature review reflects that significant studies have been conducted to investigate Compression Ignition (CI) engine emissions using different fuels. However, minimal studies have been reported in the literature to investigate CI engine parameters using clove oil. In addition, Moreover, carbon emissions and Particulate Matter (PM) emissions were also not reported. Therefore, investigation of carbon emissions of C. I use biodiesel and clove oil as additives to explore the engine's life better. The study aimed to investigate the carbon emissions of CI engines on each fuel. The analysis also included the determination of the effect of fuel on the engine on PM emissions of the engine.

2. Materials and methods

The studies used a single-cylinder, four-stroke, water-cooled, direct-injection diesel engine, which has been widely employed in the agronomic region to pull the underground water towards the irrigated grounds (see Figure 1). Table-1 presents the engine specifications in detail and systematically. The measuring tools used in the study were connected to the testing setup to record various features of the studies. In Figure 2, the measuring tools are succinctly listed. To improve the precision of measuring the performance and emission Figure 2, the experimental work was done at 1400 rpm and constant Nm load in a lab environment.

Three different fuels were used in the experiment: clove oil (CL3000 ppm), biodiesel mixed fuel (B30), and diesel (D100). They were analysed to determine their effects on the characteristics of carbon and particle emissions. As per ASTM recommendations, the characteristics of diesel oil and its blends were measured. The specifics of the device were used to determine the properties of the PM emissions are as follows. The 531 AEROCET en masse. The PM1, PM2.5, PM7, and PM10 mass concentration ranges, with a concentration range of 0–1 mg/m3.

Figure 1: Engine test bed

Figure 2: PM meter

Table-1: Diesel engine specifications

Stroke	80 mm
Speed	2600 RPM
Displacement	0.353 L
Compression ratio	21-23
Mean effective pressure	576 Kpa
Piston mean speed	6.93 m/s
specific fuel consumption	278.8 g/kWh
Specific oil consumption	4.08 g/kWh
Cooling water consumption	1360 g/kWh
Injection pressure	14.2+0.5 Mpa
Valves clearance	Inlet valve 0.15-0.25mm
Maximum engine power	7.7 kW
Maximum engine torque	80 Nm

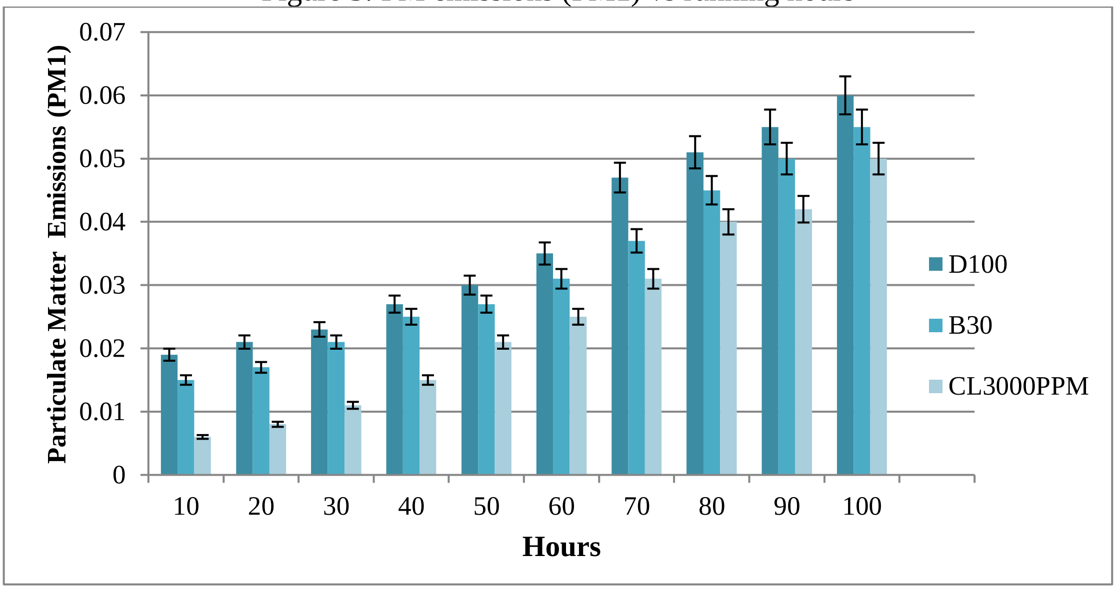
3. Result and discussions

This section of the study analyses the PM emissions and the carbon emissions of CI engines during 100 hr long-term analysis using tertiary fuel such as diesel, biodiesel blended fuel and clove oil.

3.1. Particulate matter emissions of diesel engine

Using clove oil reduced the amount of PM emissions at the exhaust over engine running hours. This was likely caused by the oil's oxygen concentration, which likely helped soot develop. PM's presence significantly decreased PM's mass concentration (Bhutto *et al.*, 2023; Agrawal *et al.*, 2009).

Figure 3: PM emissions (PM1) vs running hours



Diesel-blend fuel was found to be more effective in inhibiting the formation of elemental carbon and reducing overall PM emissions. Increasing the blending ratio of biodiesel led to a decrease in total particle amount, particularly in particles larger than 50 nm. In tests, it was discovered that a fuel ternary blend containing clove oil emits fewer PM emissions (PM-1, PM-2.5, PM-7, and PM-10) than diesel fuel and fuels containing biodiesel. Clove oil's high oxygen content might contribute extra oxygen during combustion, lowering anoxic conditions locally and preventing soot formation (Millo *et al.*, 2021). However, Figures 3-6 indicate that there was only a slight variation in PM1.0, PM2.5, PM7, and PM10 emissions among the different fuel samples tested.

Figure 4: PM emissions (PM2.5) vs running hours

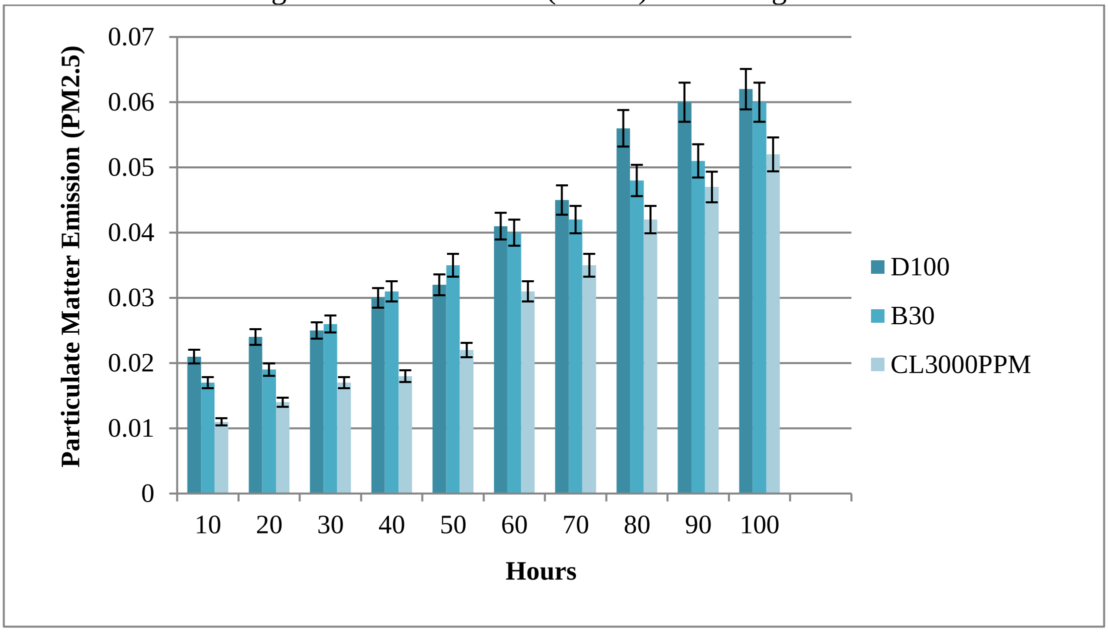


Figure 5: PM emissions (PM7) vs running hours

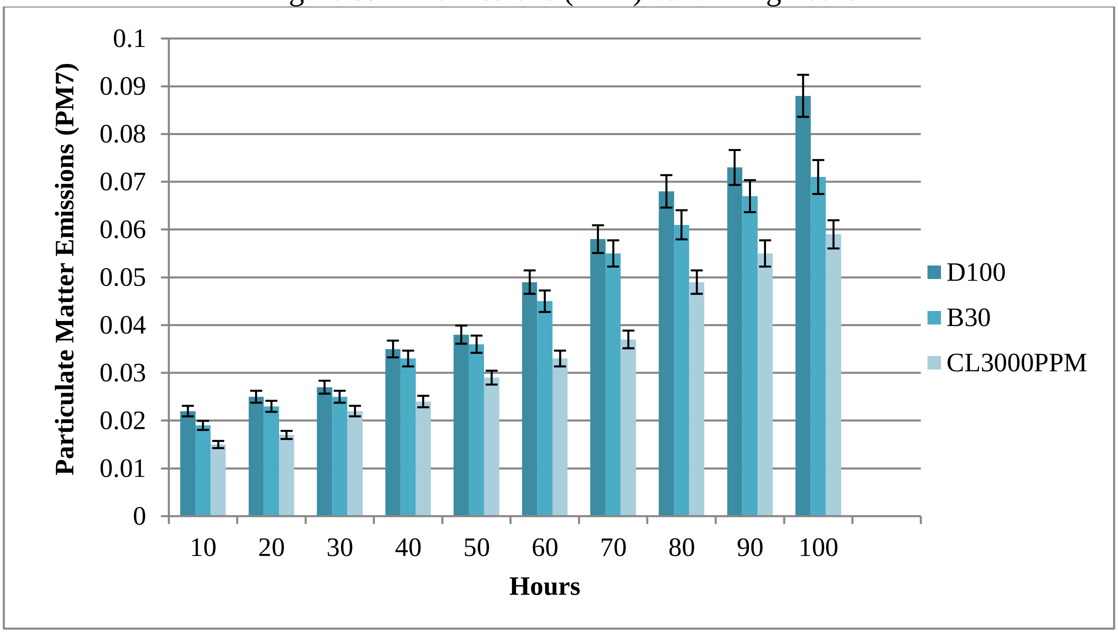
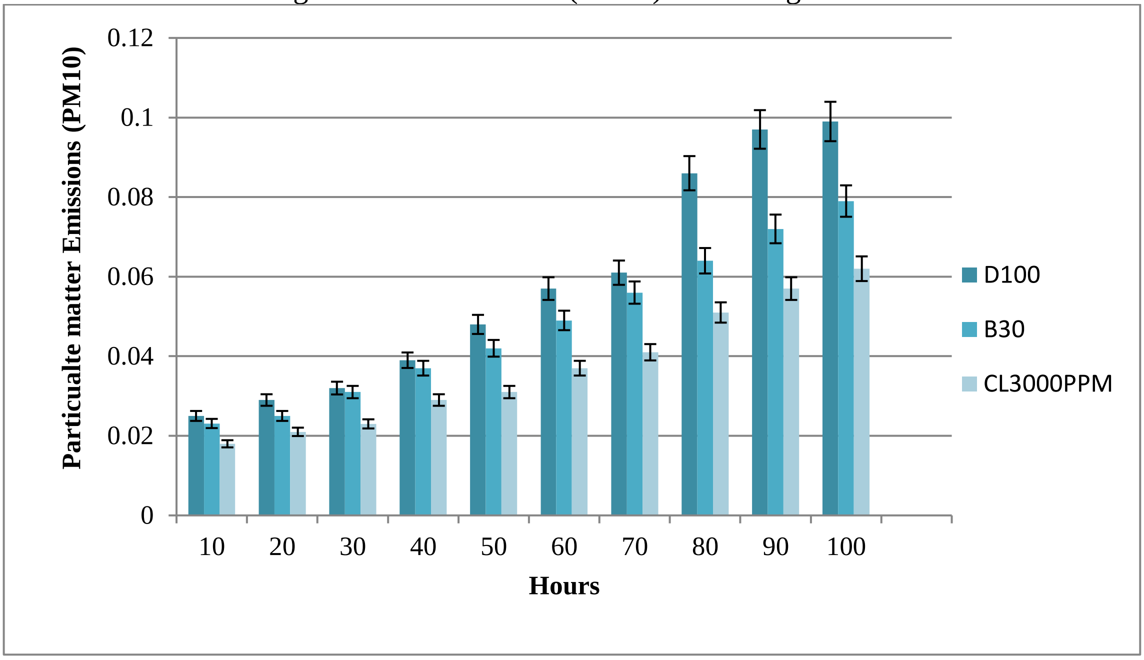


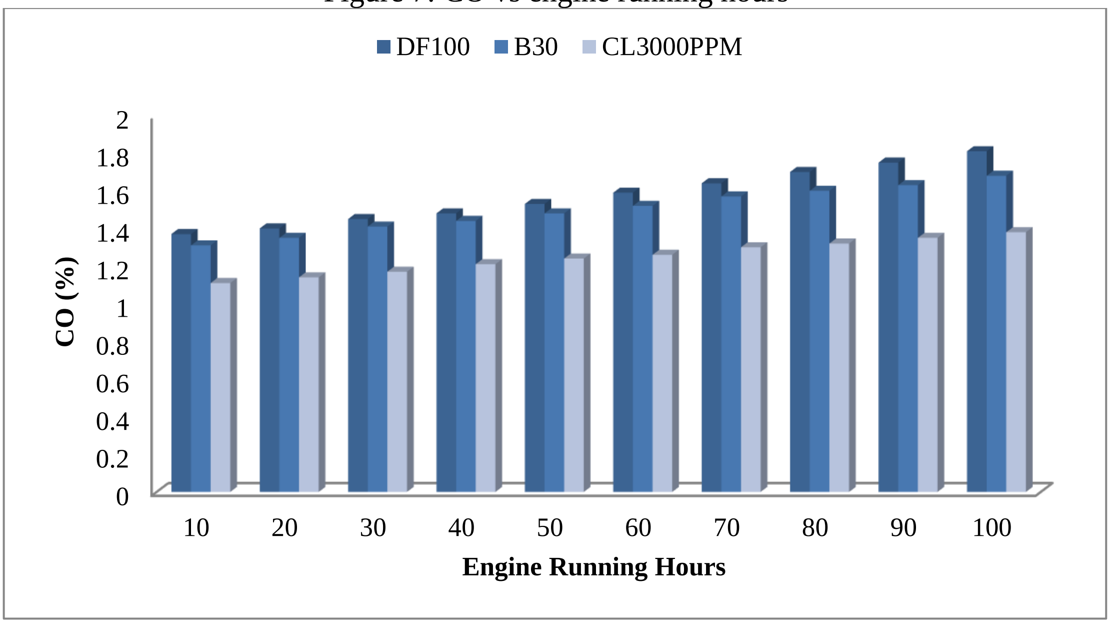
Figure 6: PM emissions (PM10) vs running hours



3.2. Carbon Monoxide (CO)

Colourless and odourless, CO is a gas. It is a harmful gas because it attaches to red blood cells and prevents them from absorbing oxygen. It develops when incomplete combustion processes occur or when inadequate mixing reduces the amount of oxygen available (Petzold *et al.*, 2011). Though thermal combustion is the most frequent source of carbon monoxide, several environmental and biological sources also contribute significantly to its production and release. It is toxic and very hazardous in small spaces. The generation of CO is influenced by factors that affect the air-fuel ratio, including intake pressure temperature, engine operating conditions, and intake tube vacuum.

Figure 7: CO vs engine running hours

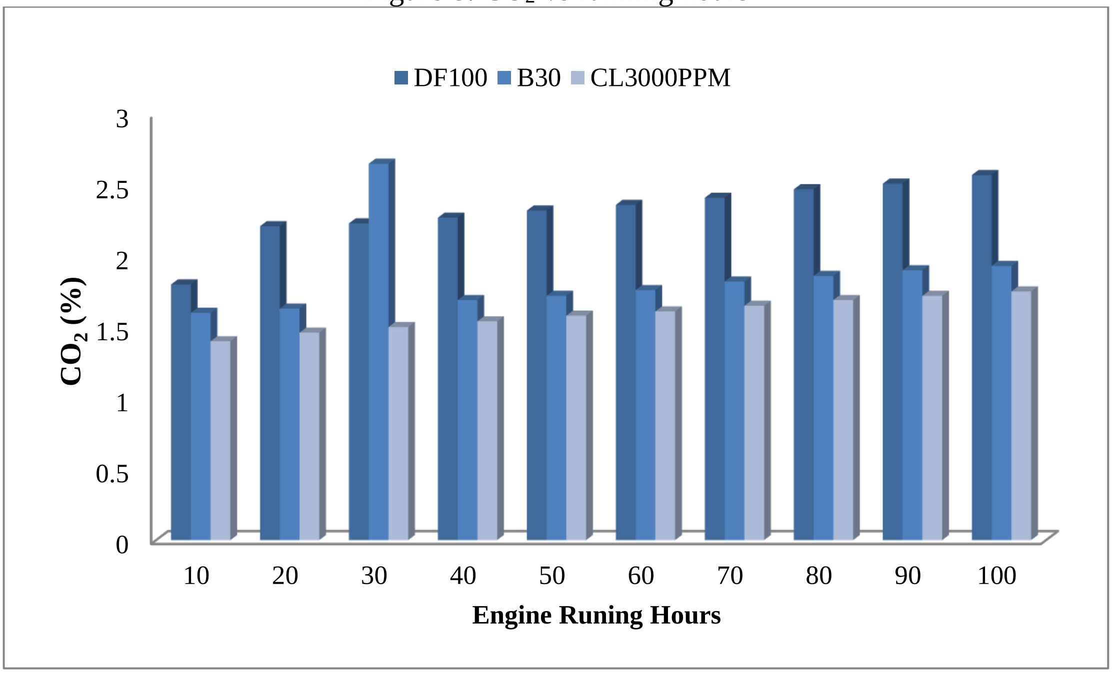


The results of the CO emission tests for the diesel fuel, the biodiesel blends, and the clove oil as an antioxidant are shown in Figure 7 with respect to the engine running hours. Figure 7 shows that incomplete fuel combustion caused CO emissions for D100 to rise compared to diesel fuel. Additionally, it has been observed that fatty acid saturation regulates CO emission and that it decreases as the saturation level rises. Burning in the absence of oxygen and a lower flame temperature led to the development of CO. Diesel's high viscosity suggested poor spray properties, which led to unburned fuel. Additionally, compared to utilising diesel fuel, using diesel fuel in the engine results in lower air/fuel ratios. CO emissions from pure diesel are decreasing with the inclusion of biodiesel. As a result of the highest saturation levels, the engine was fuelled with B30 and B30-CL3000PMM, leading to the lowest amount of CO emission being reached. Finally, the findings of the study demonstrated that B30's CO emissions (1.69%) were lower than those of diesel fuels. Compared to the diesel fuel, CL3000 PPM (7.49%) caused a further drop.

3.3. Carbon Dioxide (CO_2)

One of the main contaminants in the air is the carbon dioxide (CO_2). The most prevalent greenhouse gas in the Earth's atmosphere is CO_2, a colourless, odourless, non-flammable gas (Dunn, 2005). Figure 8 displays CO_2 about the number of hours the engine was operating during the experiment. It should be noted that using pure diesel fuel results in higher CO_2 emissions. At constant speed and the same throttle settings, CO_2 emissions from utilising diesel and their blends as engine test fuels were evaluated. When biodiesel is added to diesel fuel as an additive, the CO_2 emissions drop compared to those of pure diesel fuel. CO_2 is produced once combustion is complete. Due to the high viscosity of diesel fuel, biodiesel and clove oil were added as a ternary blend to reduce the viscosity and density of the mixtures and facilitate complete combustion. Finally, the findings of the study demonstrated that B30 (7.97%) and B30-CL3000 PPM (12.48%) produced less CO_2 than diesel fuel when used under identical operating conditions.

Figure 8: CO_2 vs running hours



4. Conclusions

Practical tests were conducted on a single cylinder water-cooled horizontally diesel engine using diesel, fuel mixed with biodiesel and fuel mixed with clove oil to assess carbon emissions and particulate emissions. It was found that adding clove oil to diesel and biodiesel blends reduced carbon emissions. However, using biodiesel blended fuel resulted in lower particulate matter emissions than pure diesel. Furthermore, adding clove oil to biodiesel blended fuel resulted in even lower particulate matter emissions compared to using pure diesel under similar engine operating conditions. Furthermore, to improve emission characteristics, ternary blends of diesel, biodiesel, and clove oil were found to be more effective than binary blends of diesel and biodiesel. Therefore, further research is needed to investigate using ternary blends of n-pentanol with different biofuels for future Compression Ignition (CI) engines. It was concluded that renewable fuels could offer good engine performance and emissions, suggesting that using waste cooking oil directly in engines should be promoted as an efficient option for waste recovery and reducing dependence on fossil fuels in the future.

Declaration of conflict of interest

The author(s) declared no potential conflicts of interest(s) with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship and/or publication of this article.

ORCID iD

Sajjad Bhangwar	https://orcid.org/0000-0002-8704-9178
Zohaib Khan	https://orcid.org/0009-0003-6119-7230
Azhar Hussain Shah	https://orcid.org/0009-0006-0398-8183
Arif Ali Rind	https://orcid.org/0009-0006-6272-8285
Muhammad Siddique Baloch	https://orcid.org/0009-0006-3303-3855
Irfan Gul	https://orcid.org/0009-0003-0421-5383
Muhammad Nawaz	https://orcid.org/0009-0000-7439-9104

Publisher's Note

IDEA PUBLISHERS (IDEA Publishers Group) stands neutral with regard to jurisdictional claims in the published maps and institutional affiliations.

References

Agrawal, H., Malloy, Q. G., Welch, W. A., Miller, J. W., & Cocker III, D. R. (2008). In-use gaseous and particulate matter emissions from a modern ocean going container vessel. *Atmospheric Environment*, *42*(21), 5504–5510. https://doi.org/10.1016/j.atmosenv.2008.02.053

Bhangwar, S., Ghoto, S. M., Abbasi, A., Abbasi, M. K., Rind, A. A., Luhur, M. R., ... & Mastoi, S. (2022a). Analysis of particulate matter emissions and performance of the compression ignition engine using biodiesel blended fuel. *Engineering, Technology & Applied Science Research*, *12*(5), 9400–9403. https://doi.org/10.48084/etasr.5204

Bhangwar, S., Liaquat, A. M., Luhar, M. R., Abbasi, A., Kumar, L., Rajput, U. A., & Mastoi, S. (2022b). Production of biodiesel and analysis of exhaust particulate emissions and metal concentration of lubricant oil of the compression ignition engine. *Frontiers in Energy Research*, *10*, 1057611. https://doi.org/10.3389/fenrg.2022.1057611

Bhangwar, S., Memon, L. A., Luhur, M. R., & Rind, A. A. (2024). Experimental investigation of effects of tertiary fuel on carbon deposition and emissions level of compression ignition engine. *South African Journal of Chemical Engineering*, *47*, 291–299. https://doi.org/10.1016/j.sajce.2023.11.012

Bharti, R., & Singh, B. (2020). Green tea (Camellia assamica) extract as an antioxidant additive to enhance the oxidation stability of biodiesel synthesized from waste cooking oil. *Fuel*, *262*, 116658. https://doi.org/10.1016/j.fuel.2019.116658

Bhutto, A. R., Hussain, T., Kumar, L., Bhangwar, S., & Shah, A. H. (2023). Comparative Investigation of Performance Analysis & Carbon Emission of Biodiesel and Conventional Fuel. *Journal of Applied Engineering & Technology (JAET)*, *7*(2), 55–69. https://doi.org/10.55447/jaet.07.02.118

Biernat, K., Chłopek, Z., & Grzelak, P. L. (2023). Influence of the Use of EtG Synthetic Fuel in Spark-Ignition Engines on Vehicle Fuel Consumption and Pollutant Emissions. *Energies*, *16*(17), 6273. https://doi.org/10.3390/en16176273

De Sousa, L. S., De Moura, C. V. R., De Oliveira, J. E., & De Moura, E. M. (2014). Use of natural antioxidants in soybean biodiesel. *Fuel*, *134*, 420–428. https://doi.org/10.1016/j.fuel.2014.06.007

Dunn, R. O. (2005). Effect of antioxidants on the oxidative stability of methyl soyate (biodiesel). *Fuel Processing Technology*, *86*(10), 1071–1085. https://doi.org/10.1016/j.fuproc.2004.11.003

Ismail, S. A. E. A., & Ali, R. F. M. (2016). Enhancing oxidative stability of biodiesel samples subjected to cations contamination during storage using Lantana camara L. (Verbanaceae) leaves extracts. *Biochemical Engineering Journal*, *110*, 143–151. https://doi.org/10.1016/j.bej.2016.02.009

Jain, S., & Sharma, M. P. (2010). Review of different test methods for the evaluation of stability of biodiesel. *Renewable and Sustainable Energy Reviews, 14*(7), 1937–1947. https://doi.org/10.1016/j.rser.2010.04.011

Karavalakis, G., Durbin, T. D., Shrivastava, M., Zheng, Z., Villela, M., & Jung, H. (2012). Impacts of ethanol fuel level on emissions of regulated and unregulated pollutants from a fleet of gasoline light-duty vehicles. *Fuel*, *93*, 549-558. https://doi.org/10.1016/j.fuel.2011.09.021

Knoll, K., West, B., Huff, S., Thomas, J., Orban, J., & Cooper, C. (2009). *Effects of mid-level ethanol blends on conventional vehicle emissions* (No. 2009-01-2723). *SAE Technical Paper*. https://doi.org/10.4271/2009-01-2723

Kreivaitis, R., Gumbytė, M., Kazancev, K., Padgurskas, J., & Makarevičienė, V. (2013). A comparison of pure and natural antioxidant modified rapeseed oil storage properties. *Industrial Crops and Products, 43,* 511–516. https://doi.org/10.1016/j.indcrop.2012.07.071

Mahaser, J. A., Bhangwar, S., Khan, M. A., Shah, A. H., Sarwar, A., Luhur, M. R., & Nawaz, M. (2023). Analysis of metal concentration, performance and noise emissions of the CI engine. *Natural and Applied Sciences International Journal (NASIJ), 4*(2), 94–107. https://doi.org/10.47264/idea.nasij/4.2.6

Martikainen, S., Salo, R., Kuuluvainen, H., Teinilä, K., Hooda, R. K., Datta, A., Sharma, V. P., … & Rönkkö, T. (2023). Reducing particle emissions of heavy-duty diesel vehicles in India: Combined effects of diesel, biodiesel and lubricating oil. *Atmospheric Environment: X, 17*, 100202. https://doi.org/10.1016/j.aeaoa.2023.100202

Memon, T. A. (2022). Assessment of Rice Residues as Potential Energy Source in Pakistan. *Sukkur IBA Journal of Emerging Technologies, 5*(1), 41–53. https://doi.org/10.30537/sjet.v5i1.982

Mendiburu, A. Z., Lauermann, C. H., Hayashi, T. C., Mariños, D. J., da Costa, R. B. R., Coronado, C. J., ... & de Carvalho Jr, J. A. (2022). Ethanol as a renewable biofuel: Combustion characteristics and application in engines. *Energy, 257*, 124688. https://doi.org/10.2166/wst.2023.397

Millo, F., Vlachos, T., & Piano, A. (2021). Physicochemical and mutagenic analysis of particulate matter emissions from an automotive diesel engine fuelled with fossil and biofuel blends. *Fuel*, *285*, 119092. https://doi.org/10.1016/j.fuel.2020.119092

Moser, B. R. (2012). Efficacy of gossypol as an antioxidant additive in biodiesel. *Renewable energy*, *40*(1), 65–70. https://doi.org/10.1016/j.renene.2011.09.022

Ogunsola, A. D., Durowoju, M. O., Ogunkunle, O., Laseinde, O. T., Rahman, S. A., & Fattah, I. M. R. (2023). Shea butter oil biodiesel synthesized using snail shell heterogeneous catalyst: Performance and environmental impact analysis in diesel engine applications. *Sustainability, 15*(11), 8913. https://doi.org/10.3390/su15118913

Panithasan, M. S., & Venkadesan, G. (2023). Evaluating the outcomes of a single-cylinder CRDI engine operated by lemon peel oil under the influence of DTBP, rice husk nano additive and water injection. *International Journal of Engine Research, 24*(2), 308–323. https://doi.org/10.1177/14680874211047743

Pardauil, J. J., Souza, L. K., Molfetta, F. A., Zamian, J. R., Rocha Filho, G. N., & Da Costa, C. E. F. (2011). Determination of the oxidative stability by DSC of vegetable oils from the Amazonian area. *Bioresource Technology*, *102*(10), 5873–5877. https://doi.org/10.1016/j.biortech.2011.02.022

Petzold, A., Marsh, R., Johnson, M., Miller, M., Sevcenco, Y., Delhaye, D., ... & Raper, D. (2011). Evaluation of methods for measuring particulate matter emissions from gas turbines. *Environmental Science and Technology*, *45*(8), 3562–3568. https://doi.org/10.1021/es103969v

Rajpoot, A. S., Saini, G., Chelladurai, H. M., Shukla, A. K., & Choudhary, T. (2023). Comparative combustion, emission, and performance analysis of a diesel engine using Carbon Nanotube (CNT) blended with three different generations of biodiesel. *Environmental Science and Pollution Research, 30*, 125328–125346. https://doi.org/10.1007/s11356-023-28965-0

Schirmann, J. G., Angilelli, K. G., Dekker, R. F., Borsato, D., & Barbosa-Dekker, A. M. (2019). 3, 3′, 5, 5′-tetramethoxybiphenyl-4, 4′-diol: a new antioxidant enhancing oxidative stability of soybean biodiesel. *Fuel*, *237*, 593–596. https://doi.org/10.1016/j.fuel.2018.10.044

Simhadri, K., Rao, P. S., & Paswan, M. K. (2023). Effect of changing injection pressure on Mahua oil and biodiesel combustion with CeO2 nanoparticle blend on CI engine performance and emission characteristics. *International Journal of Hydrogen Energy, 48*(66), 26000–26015. https://doi.org/10.1016/j.ijhydene.2023.03.267

Stępień, Z., Żak, G., Markowski, J., & Wojtasik, M. (2021). Investigation into the impact of the composition of ethanol fuel deposit control additives on their effectiveness. *Energies*, *14*(3), 604. https://doi.org/10.3390/en14030604

Supriyono, S. H., Almeida, M. F., Dias, J. M. (2015). Influence of synthetic antioxidants on the oxidation stability of biodiesel produced from acid raw *Jatropha curcas* oil. *Fuel Processing Technology*, *132*, 133–138. https://doi.org/10.1016/j.fuproc.2014.12.003

Sun, Z., Li, X., Nour, M., & Xu, M. (2021). Investigation of flash boiling spray and combustion in SIDI engine under low-speed homogeneous lean operation. *SAE Technical Paper*. https://doi.org/10.4271/2021-01-0467