Research Article

Journal of Environmental Nanotechnology

An Assessment of the Environmental and Operational Benefits of Diesel-Biodiesel-Nano Additive Blends in Heavy-duty Diesel Engines

P. Vasanthkumar[1*], A. Santhoshkumar[1], M. Vikneswaran[1] and N. Senthilkumar[2]

[1]Department of Mechanical Engineering, SRM Institute of Science and Technology, Ramapuram Campus, Chennai, TN, India

[2]Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, TN, India

Received: 16.09.2024 Accepted: 05.11.2024 Published: 30.12.2024

*pvasanthme@gmail.com

ABSTRACT

As an alternative fuel with low fossil fuel dependency, biodiesel positively impacts the environment. Experimental tests were performed to determine the effect of diesel-biodiesel blends on Cummins diesel engines. Diesel blended with biodiesel in three variations (DB5, DB7.5, and DB10) tested at 11 rotational speeds (1000 to 2000 rpm) and four different load levels (9.4, 18.8, 28.2, and 37.5 kPa). A constant 30ppm of CeO_2 is added to all diesel-biodiesel blends. Various parameters were measured and analyzed, including effective power, specific fuel consumption, effective performance, and CO emissions. According to the results, biodiesel content in blends increased specific fuel consumption and reduced effective performance. The Effective power of an engine increases by 50% at 10 kPa and by 37.5% at 35 kPa when engine speed is increased. For DB5, performance is maximum at 1000 rpm about 34%, while at 2000 rpm, performance is minimum about 26%. Carbon monoxide (CO) emissions decreased with rising biodiesel ratio emissions among blends. As a result of this study, more insight is gained into the effect of diesel-biodiesel blends on exhaust emissions and engine performance.

Keywords: Diesel engine; Biodiesel blends; Engine performance; Exhaust emissions; Nano-additives.

1. INTRODUCTION

Transportation and many industrial applications have relied on fossil fuels for decades. The non-renewable nature of fossil fuels, the increasing scarcity, and the adverse environmental effects have prompted the exploration of sustainable energy sources (Wang and Azam, 2024). As a renewable fuel, biodiesel is made from various sources, including leftover cooking oils, vegetable oils, and animal fats. As one of the most effective and sustainable transportation options, it is biodegradable, non-toxic, and reduces greenhouse gases. While the use of biodiesel offers several advantages, its impact on engine efficiency and emissions remains a subject of ongoing research (Reddy *et al*. 2024). Understanding the impact of biodiesel mixtures on engine parameters and pollutant levels is crucial for optimizing the use of this alternative fuel and mitigating any potential drawbacks. Experimental investigations have contributed much to providing empirical data and insights that can inform the development and implementation of biodiesel-fueled engines (Godiño *et al*. 2022).

Biodiesel from Guizotiaabyssinica was investigated as a source of alumina and titanium nanoparticles in diesel engine emissions and functionality (Abishek *et al*. 2024). Utilization of an ultrasonic reactor for intensification of linseed biodiesel synthesis and evaluation of ternary fuel blends for engine performance (Ahmad *et al*. 2024). A S/AlMCM-41 catalyst was used to synthesize chicken feather meal biodiesel and analyze its performance in engines (Almalki *et al*. 2024). The impacts of hydrogenated and green biodiesels on environmental impact and analysis of a turbocharged diesel engine utilizing an ANN prediction approach (Ameresh *et al*. 2024). A hydrogen/Julifora biodiesel blend was evaluated to determine impact on emissions, combustion, and efficiencies of a DI-diesel engine (Anchupogu *et al*. 2023). Evaluated the effects of hydrogen-enriched and nano-CeO_2 mixed with waste cooking oil as biodiesel on a CRDI engine (Chetia *et al*. 2024). In the pre-combustion process, diesel-Karanja oil methyl ester (KOME) releases less heat than diesel. As a result of inflation retardation and combustion delay, diesel–KOME would burn for a longer time (Balu *et al*. 2023). Assessment of diesel engine combustion attributes and performance are fueled by diesel-biodiesel-zinc oxide nanoparticle blends (El-Adawy, 2023). The combustion efficiency and emissions rate of diesel engines using waste cooking biodiesel were assessed and predicted using extreme learning and quadratic regression models. An engine powered by Ceiba pentandra biodiesel was evaluated to determine its emissions, combustion parameters, and performance (Ergen, 2024; Gad and Alenany, 2024). Analyze the performance and rate of emissions of diesel-castor oil biodiesel-and-n-butanol mixtures influenced by Ni and Al nano-additives in diesel engines (Gaddigoudar *et al*. 2023). Developed a dual-fuel mode of operation in which hydrogen and sapota seed biodiesel are used as next-generation fuels in a diesel engine (Hassan *et al*. 2023). The studies span from 2023 to 2024 and encompass a variety of objectives, including reviews of nanoparticles' effects on biodiesel-driven engines, analysis of soot dynamics with biofuel blends, synthesis of biodiesel from waste sources using advanced nano-catalysts, and experimental investigations into the impact of biodiesel blends on engine combustion, efficiency, and emission characteristics (Jayabal, 2024) Key materials studied include biodiesel from various sources, nanoparticles, waste cooking oils, and additives like ethers, antioxidants, and cetane improvers (Jin *et al.* 2023). Research methodologies range from literature reviews and modeling studies to extensive experimental trials, highlighting improvements in BTE, emission reductions, and the potential of biodiesel to enhance diesel engine sustainability. The findings collectively underscore the positive implications of biodiesel and its blends for diesel engines. Using a heavy-duty Cummins diesel engine, this research will conduct an extensive investigation involving numerous experiments to evaluate the effects of diesel-biodiesel blends on its performance and emissions. Variations in biodiesel concentrations have a significant impact on engine parameters, including SFC, effective power, and effective performance. Different diesel-biodiesel blends are measured and compared for their carbon monoxide (CO) emissions.

2. MATERIALS AND METHODS

Testing was conducted on diesel engines with diesel-biodiesel blends to determine the impact of emissions characteristics and performance. The effective power output of a turbocharged, intercooled, six-cylinder engine was precisely measured using a water-cooled electrodynamic dynamometer, Zollner A-350. Based on the results of the study, three fuel mixtures were evaluated: DB5 (95% diesel, 5% biodiesel), DB7.5 (92.5% diesel, 7.5% biodiesel), and DB10 (90% diesel, 10% biodiesel). A constant 30ppm of CeO2 is added to all diesel-biodiesel blends. During the production of this mixture, biodiesel (B100) was used and supplied by ALDECO Solvent-Aided Crystallization (SAC). As shown in Fig. 1, the mixtures were prepared volumetrically and stored in labeled containers for use during the tests (Zeki *et al*. 2023). Detailed data for engine performance and emissions were collected through the establishment of a comprehensive test matrix that included an array of engine speeds and loads. Among the main components of the study were a Cummins QSB6.7 diesel engine, a Water-cooled electromagnetic dynamometer Zollner A-350, a portable emissions analyzer Testo 350 XL, and various auxiliary measuring devices (Zheng and Cho, 2024).

2.1 Engine and Dynamometer

A Cummins QSB6.7 engine fitted to a test bench came from a truck tractor and was turbocharged, intercooled, and compression-ignition. Zollner's A-350 dynamometer measured torque ranges from 0 to 500 nm and 0 to 1000 nm when coupled to this engine. Dynamometers function as brakes, absorbing the engine's effective power and measuring it. Various parameters could be adjusted through the test bench control module, including engine speed, load, and coolant flow by National Instruments (NI) DAQ Systems.

Fig. 1: DB5, DB7.5 and DB10 fuel labeling

2.2 Experimental Test Matrix

A comprehensive experimental test matrix was developed to cover various operating conditions. A total of 16 test points were defined, comprising 04 rotational speeds (2000, 1600, 1300, and 1000 rpm) and four load levels (9.4, 18.8, 28.2, and 37.5 kPa) in terms of mean effective pressure. Various parameters were measured and recorded for each test point, including engine speed, torque, fuel consumption, air intake conditions, emissions concentrations (CO_2, CO, and NOx), exhaust gas temperature, and relative humidity (Liu *et al*. 2022). A turbocharged diesel engine from a tractor-trailer was used with an intercooler. Fig. 2 displays the main technical characteristics of the engine and the arrangement of the engine during testing.

2.3 Emissions Measurements

The Testo 350 XL portable emissions analyzer, equipped with sensors for O_2, NO_2, SO_2, CO, CO_2, NOx, and HC, was employed to measure the exhaust gas emissions from the engine. The analyzer's sampling probe was installed in the engine's exhaust pipe, allowing for the collection and analysis of the exhaust gas sample.

2.4 Auxiliary Instrumentation

Several auxiliary instruments were utilized to measure and record various parameters during the tests:

- Emerson Micro Motion Coriolis flow meter for measuring fuel mass flow rate.
- Orifice plate meter for measuring air consumption.
- Testo 610 Hygrometer for monitoring ambient temperature and humidity.
- Cummins Insite program for accessing engine control module data.

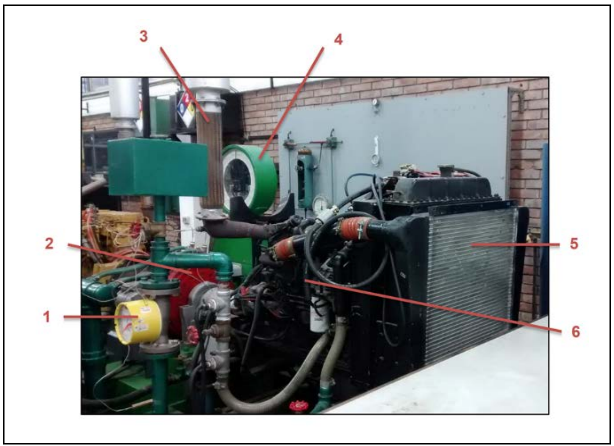

Fig. 2: Engine installation (1) Rotameter, (2) Dynamometer brake, (3) Exhaust pipe, (4) Analog torque meter, (5) Intercooler, (6) Cummins QSB6 and (7) Engine

2.5 Experimental Procedure

The experimental procedure involved the following steps:

- **Preparation of Fuel Mixtures**: The required volumes of diesel and biodiesel were carefully measured and blended to create the DB5, DB7.5, and DB10 mixtures, which were then stored in labeled containers.
- **Engine Warm-up**: Before initiating the tests, the engine was allowed to warm up to its operating temperature to ensure stable conditions.
- **Test Point Setup**: The optimized engine speed and load were established the test bench control module for each test point in the matrix.
- **Data Acquisition**: Once the engine reached steady-state conditions, the various measuring instruments were used to record the required data, comprising engine torque, speed, air intake conditions, fuel consumption, emissions concentrations, exhaust gas temperature, and relative humidity.
- **Mixture Change**: After completing the tests for a particular fuel mixture, the engine was shut down, and the fuel system was flushed to prepare for the next mixture.
- **Repeat Steps 2-5**: The entire process was repeated for each of the three fuel mixtures (DB5, DB7.5, and DB10) across the defined test matrix.

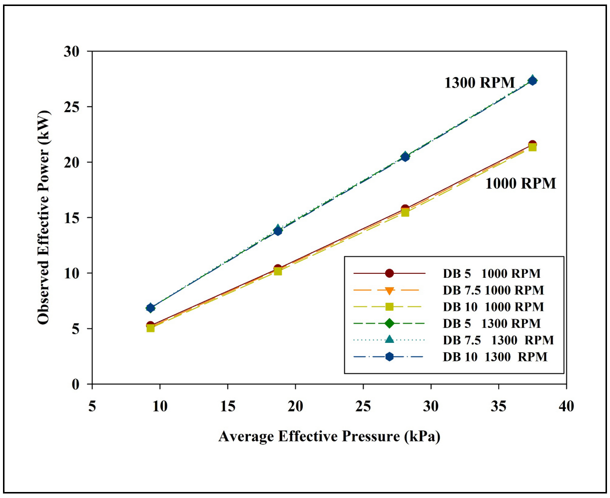

Fig. 3: Observed effective power vs average effective pressure @ 1000 rpm and 1300 rpm

3. RESULTS AND DISCUSSION

The experimental investigation yielded a comprehensive dataset, providing insights into the effects of diesel-biodiesel blends on engine performance and emissions. The key results and discussions are presented below:

3.1 Effective Power

The engine's power increases with increasing rotational speed and load. As expected, the results were similar for all three fuel mixtures (DB5, DB7.5, and DB10) since the effective power is directly related to the engine speed and load, which were established as input parameters. Fig. 3 and 4 show that, in general, effective power increases as the engine speed increases. This is because effective power depends on the rotational speed and load of the motor. In the tests carried out, both values were established as input data, so the effective power values for the 3 fuel mixtures (DB5, DB7.5, DB10) were similar at a constant speed and load. Diesel Engine performance enhanced by 4% for Biodiesel blends with Cerium Oxide (CeO_2).

Fig. 4 indicates that the highest value calculated for effective power is 41.5 kW at 2000 rpm and 37.5 kPa, while the lowest value reached 5.30 kW and was obtained at 1000 rpm and 9.4 kPa in Fig. 3. For intermediate speeds of 1300 rpm and 1600 rpm, the maximum values obtained were 27.3 kW and 33.7 kW, respectively, while the minimum values were 6.8 kW and 8.3 kW, respectively (Chetia *et al.* 2024; Gaddigoudar *et al.* 2023).

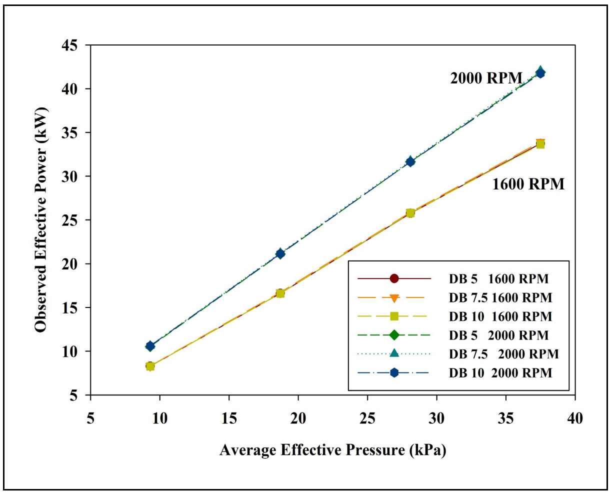

Fig. 4: Observed effective power vs average effective pressure @ 1600 rpm and 2000 rpm

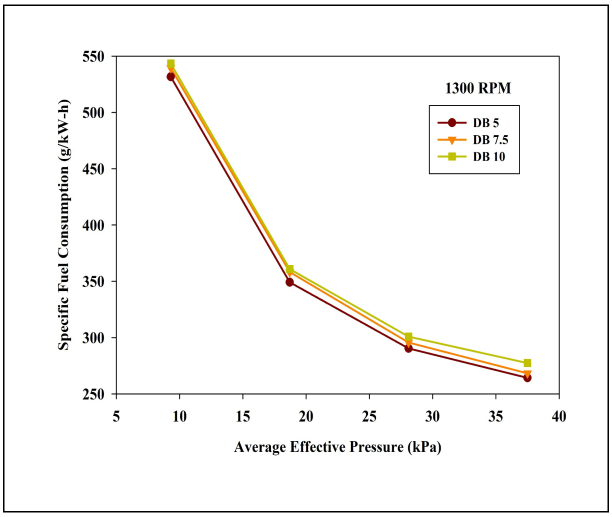

Fig. 5: SFC vs average effective pressure @ 1000 rpm

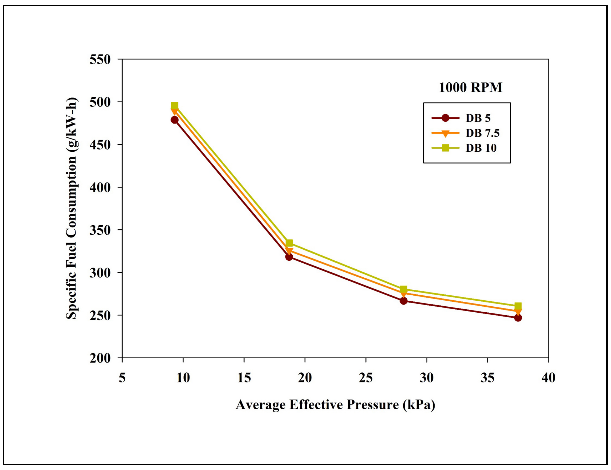

Fig. 6: SFC vs average effective pressure @ 1300 rpm

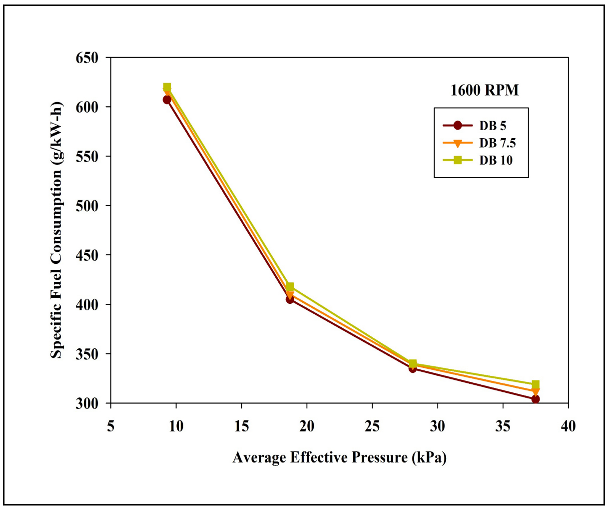

Fig. 7: SFC vs average effective pressure @ 1600 rpm

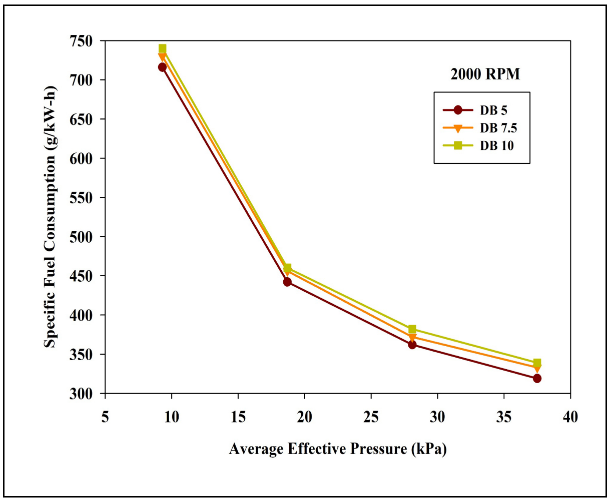

Fig. 8: SFC vs average effective pressure @ 2000 rpm

3.2 Specific Fuel Consumption

The specific fuel consumption decreased as the mean effective pressure increased, indicating better engine utilization for producing useful work at higher loads. However, specific fuel consumption increased with higher biodiesel content in the blends, with increases of up to 4% for DB10 compared to DB5 at 1000 rpm and 4.5% at 2000 rpm. This increase can be attributed to biodiesel's lower energy content per unit mass than conventional diesel. Fig. 5 to 8 show that specific fuel consumption decreases as the average effective pressure increases. This trend is independent of the motor's speed and the mixture used, since effective power is a variable calculated for a preset speed and load as the input data for the test.

The highest values were recorded at a speed of 2000 rpm, approximately 740 g/kW·h in Fig. 8, while the lowest values were at a speed of 1000 rpm (247 g/kW·h), both at 37.5 kPa in Fig. 5, where the effective power reaches its highest values in this test protocol (Li *et al*. 2024; Mahgoub, 2023). The lower specific fuel consumption demonstrates the engine's more efficient use to produce useful work and is directly related to the engine's effective efficiency. In the tests performed, this condition was found at the lowest rotational speed and the highest mean effective pressure. On the other hand, specific fuel consumption increases for constant speed and load as the percentage of biodiesel in the diesel mixture increases. This increase can be attributed to the lower energy content of biodiesel per unit mass (approximately 12% lower) compared to pure diesel. In other words, to achieve the same engine power, biodiesel's lower energy content must be compensated by higher fuel consumption. Increases of up to 4% were found for a speed of 1000 rpm (Fig. 3) and 4.5% for 2000 rpm (Fig. 6), both for the DB10 mixture and at the maximum effective average pressure tested of 37.5 kPa. These results are justified by the lower calorific value of the DB10 mixture and the fact that at 37.5 kPa, the power reaches its highest values (Maleki *et al*. 2024; Meng *et al*. 2023).

SFC slightly decreases with Biodiesel blend 5% with 30ppm of CeO_2. For the intermediate speeds of 1300 rpm (Fig. 7) and 1600 rpm (Fig. 8), there is also a percentage increase in the specific fuel consumption of the mixtures, with values between 1.5% and 3.5%. These results align closely with those found in the literature consulted in this study. From occrance 3% and 2.5% increases in original specific consumption with conventional diesel when using blends with 20% biodiesel in engines of similar performance (Mohammed *et al*. 2023).

3.3 Effective Performance

The engine's efficiency in converting fuel energy into mechanical work increases with increasing load. The highest effective performance of 34% was observed at the lowest tested speed of 1000 rpm for the DB5 mixture, while the lowest value of 26% was recorded at 2000 rpm. As the biodiesel content in the blends increased, the effective performance slightly decreased, with the most notable change occurring between DB5 and DB10 at 1000 rpm, reaching a 4% difference. Uncertainty management within the study ensured the reliability of these findings, with power and pressure measurements' uncertainties maintained below 0.5 kW and 0.8 kPa, respectively, and specific fuel consumption uncertainties under 9.5 g/kW.h. This rigorous approach to data integrity underpins the study's contributions to understanding the impact of biodiesel blends on diesel engine performance (Nadimi *et al*. 2024; Riyadi *et al*. 2023).

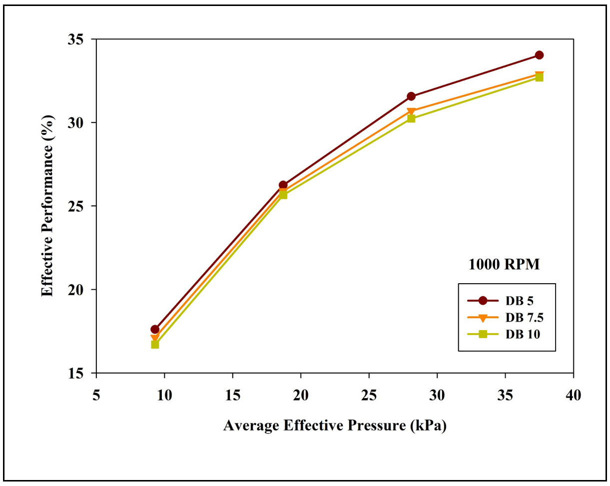

Fig. 9: Effective performance vs average effective pressure @ 1000 rpm

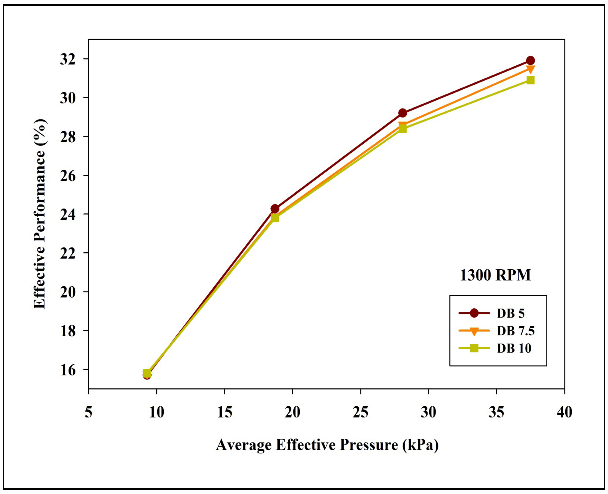

Fig. 10: Effective performance vs average effective pressure @ 1300 rpm

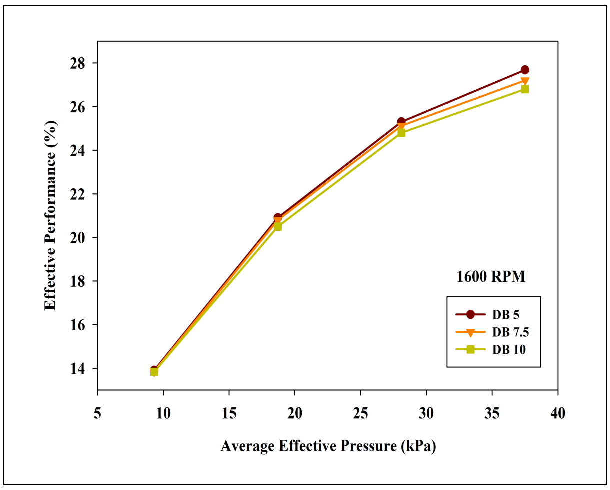

Fig. 11: Effective performance vs average effective pressure @ 1600 rpm

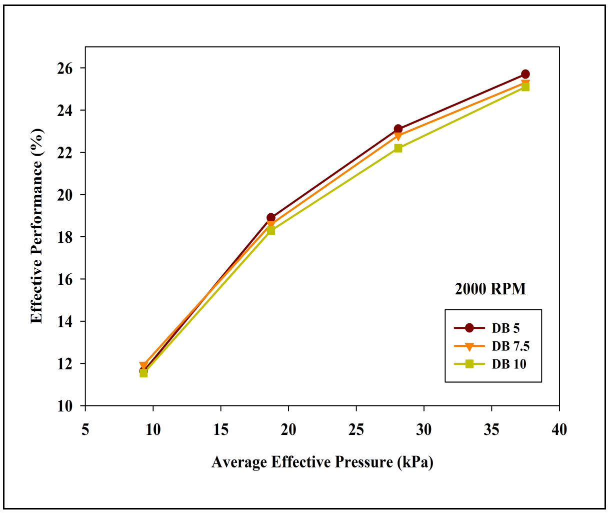

Fig. 12: Effective yield vs average effective pressure @ 2000 rpm

Fig. 9 to 12 present effective performance results versus mean effective pressure. You can see that the performance increases as the load on the engine increases. Effective performance is a parameter that indicates the efficiency of the engine in transforming the energy obtained from the fuel into mechanical energy, and it reaches its highest peak when the specific consumption reaches its lowest value. Therefore, as the load on the engine increases, it tends to make better use of the energy supplied by the fuel (Muhammed and Shaija, 2023).

The highest effective yield was found at the lowest rate tested, at 34% in Fig. 9, and its lowest value at the highest speed, at 26% in Fig. 12, both for the DB5 mixture and at the highest mean pressure (Sanl and Uludamar, 2024).

Combustion efficiency improved for the Biodiesel blend with CeO_2 at 1000rpm. To obtain a much more accurate effective yield value, it was necessary to balance the lower calorific values of each fuel (diesel and biodiesel) and their mass consumption, since as the percentage of biodiesel in the mixture increased, the energy content of the mixture decreased. This is why, when testing at the same load and speed, the effective yield for the highest blends (DB7.5 and DB10) tends to be lower than that for the 5% biodiesel blend (DB5). While it is true that the blending trends are quite similar, it can be seen that the effective yield is slightly higher when the percentage of biodiesel in the blend is lower. The most notable increase occurred at 1000 rpm between DB5 and DB10 in Fig. 9, reaching a percentage difference of 4% for maximum load (Roschat *et al*. 2024; Sayyed *et al*. 2024).

3.4 Carbon Monoxide

Carbon monoxide emissions increased with increasing speed and load in the tests. The highest CO values were obtained with the DB5 mixture (lowest biodiesel content) at 2000 rpm and the highest average effective pressure of 37.5 kPa. Biodiesel blend of 5% with 30ppm of CeO_2 reduced CO emission by 4.26%. For all three fuels tested, CO emissions decreased as the biodiesel content in the mixtures increased, with the highest percentage decrease of 4.26% observed between DB5 and DB10 at 1000 rpm and 28.1 kPa As shown in Fig. 13 to 16 (Sun *et al*. 2024).

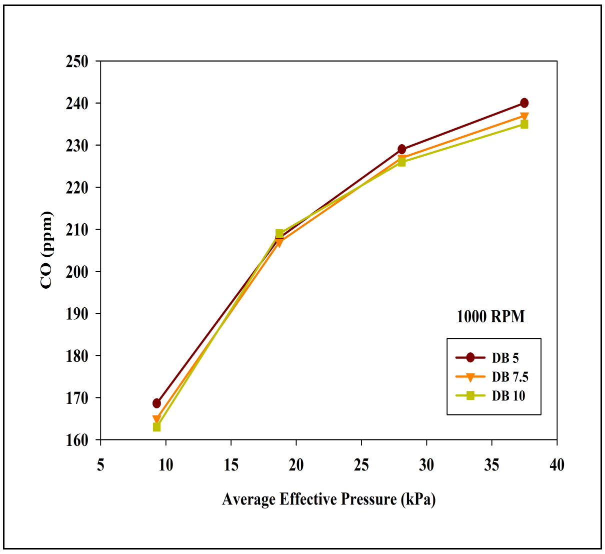

Fig. 3: CO vs average effective pressure @ 1000 rpm

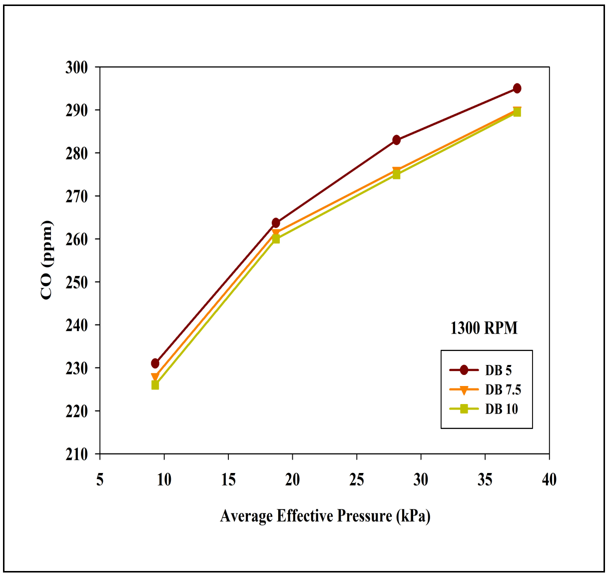

Fig. 4: CO vs average effective pressure @ 1300 rpm

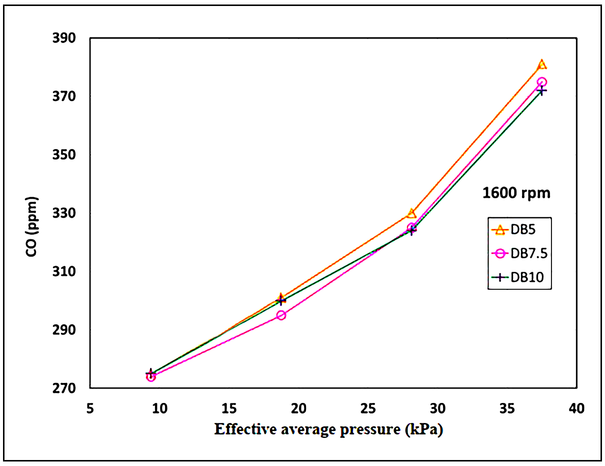

Fig. 55: CO vs average effective pressure @ 1600 rpm

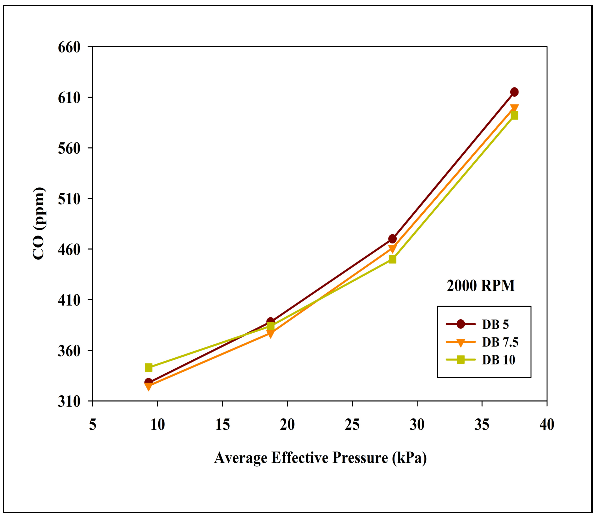

Fig. 16: CO vs average effective pressure @ 2000 rpm

4. CONCLUSIONS

An intercooled, turbocharged, six-cylinder Cummins QSB6.7 diesel engine and Zöllner A-350 electrodynamic dynamometer were used to measure its power output precisely.

- The test points comprised 16 rotational speeds (2000, 1600, 1300, and 1000 rpm) and four pressure levels (9.4, 18.8, 28.2, and 37.5 kPa). This study investigated biodiesel blends that contained 5%, 7.5%, and 10% biodiesel with a constant 30ppm CeO2 addition A higher engine speed at 10 kPa increases Effective power by 50%; at 35 kPa, it increases by 37.5%. A higher engine speed from 1600 rpm to 2000 rpm increases power by 25% at 10 kPa and by 41.67 percent at 35 kPa. Power output decreases about 2.55% to 4% when switching from DB5 to DB10 across a range of speeds. Effective power reaches 41.5 kW at 2000 rpm and 37.5 kPa, while the lowest value reaches 5.30 kW at 1000 rpm and 9.4 kPa, which indicates an increase by 23.15%. During intermediate speeds of 1300 rpm and 1600 rpm, maximum values were 27.3 kW and 33.7 kW, respectively, and minimum values were 6.8 kW and 8.3 kW, respectively, increased by 23.44%. Diesel Engine performance enhanced by 4% for Biodiesel blends with Cerium Oxide (CeO_2).

- Effective performance is maximum at 1000 rpm for DB5 about 34% while a minimum performance of 26% was observed at 2000 rpm. With increasing biodiesel content in the blends, the effective performance of the engine decreased slightly, with a significant difference between DB5 and DB10 at 1000 rpm of 4%. At the lowest speed tested, the best effective performance was observed, at 34%, and at the highest speed tested, at 26%, both for the DB5 mixture and for the highest mean pressure. Combustion efficiency improved for the Biodiesel blend with CeO_2 at 1000rpm.

- SFC increased with higher biodiesel content in the blends by up to 4% at 1000 rpm for DB10 and 4.5% at 2000 rpm for DB5. A speed increase of 4% was observed at 1000 rpm and a speed increase of 4.5% at 2000 rpm, both for the DB10 mixture, and at the maximum effective average pressure of 37.5 kPa. At 37.5 kPa, the power reaches its highest values due to the lower calorific value of the DB10 mixture. Among the mixtures at intermediate speeds, the specific fuel consumption increased by 1.5% to 3.5% between 1300 rpm and 1600 rpm. SFC slightly decreases with Biodiesel blend 5% with 30ppm of CeO_2.

- The amount of carbon monoxide emissions in the tests increased as the speed and load increased. The highest CO values were obtained with the DB5 mixture at 2000 rpm, with a maximum effective pressure of 37.5 kPa, corresponding to the highest maximum operating speed. All three of the fuels tested showed a significant reduction in CO emissions as the percentage of biodiesel in the mixtures increased, with the highest percentage reduction, 4.26%, being observed between the DB5 and DB10 at 1000 rpm and 28.1 kPa when the biodiesel content was increased. Biodiesel blend of 5% with 30ppm of CeO_2 reduced CO emission by 4.26%.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

COPYRIGHT

This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).

REFERENCES

Abishek, M. S., Kachhap, S., Rajak, U., Verma, T. N., Singh, T. S., Shaik, S., Cuce, E. and Alwetaishi, M., Alumina and titanium nanoparticles to diesel–*Guizotiaabyssinica (L.)* biodiesel blends on MFVCR engine performance and emissions, *Sustain. Energy Technol. Assessments*., 61, 103580 (2024). https://doi.org/10.1016/j.seta.2023.103580

Ahmad, A., Yadav, A. K., Singh, A., Singh, D. K. and Agbulut, U., A hybrid RSM-GA-PSO approach on optimization of process intensification of linseed biodiesel synthesis using an ultrasonic reactor: Enhancing biodiesel properties and engine characteristics with ternary fuel blends, *Energ*., 288, 129077 (2024). https://doi.org/10.1016/j.energy.2023.129077

Almalki, A. S. A., Alhadhrami, A., Alsanie, W. F., Kamarudin, S. K. and Pugazhendhi, A., Biodiesel synthesis from chicken feather meal using S/AlMCM-41 catalyst and engine performance analysis, *Environ. Res.*, 246, 118060 (2024). https://doi.org/10.1016/j.envres.2023.118060

Ameresh, H., Ravi Kiran Sastry, G. and Panda, J. K., A novel experimental performance and emission study on CRDI engine using hydrogenated and green biodiesels: A turbo powered engine with hydrogen dual fuel and ANN prediction approach, *Fuel*, 363, 130963 (2024). https://doi.org/10.1016/j.fuel.2024.130963

Anchupogu, P., Krupakaran, R. L., Venkateswarlu, S., Satish, S., Phaneendrareddy, S., Shohel, S. and Umamaheswarrao, P., Combined effect of hydrogen and with Julifora biodiesel blend (JFB20) on the combustion, performance and emission characteristics of a direct-injection diesel engine, *Mater. Today Proc.*, (2023). https://doi.org/10.1016/j.matpr.2023.05.089

Balu, P., Vasanthkumar, P., Govindan, P. and Sathish, T., An experimental investigation on ceramic coating with retarded injection timing on diesel engine using Karanja oil methyl ester, *Int. J. Ambient Energy.*, 44(1), 1031-1035 (2023). https://doi.org/10.1080/01430750.2022.2161632

Chetia, B., Debbarma, S. and Das, B., An experimental investigation of hydrogen-enriched and nanoparticle blended waste cooking biodiesel on diesel engine, *Int. J. Hydrogen Energy*., 49, 23–37 (2024). https://doi.org/10.1016/j.ijhydene.2023.06.088

El-Adawy, M., Effects of diesel-biodiesel fuel blends doped with zinc oxide nanoparticles on performance and combustion attributes of a diesel engine, *Alex. Eng. J.*, 80, 269–281 (2023). https://doi.org/10.1016/j.aej.2023.08.060

Ergen, G., Comprehensive analysis of the effects of alternative fuels on diesel engine performance combustion and exhaust emissions: Role of biodiesel, diethyl ether, and EGR, *Therm. Sci. Eng. Prog*., 47, 102307 (2024). https://doi.org/10.1016/j.tsep.2023.102307

Gad, M. S. and Alenany, A., Comparative diesel engine performance and emission forecasting using extreme learning and quadratic regression techniques burning waste cooking biodiesel, *Int. J. Hydrogen Energy*., 60, 94–106 (2024). https://doi.org/10.1016/j.ijhydene.2024.02.099

Gaddigoudar, P. S., Basavarajappa, Y. H., Banapurmath, N. R. and Harari, P. A., Effect of biogas flow rate on the combustion, emission and performance characteristics of dual fuel engine fuelled with ceiba pentandra biodiesel, *Mater. Today Proc.*, (2023). https://doi.org/10.1016/j.matpr.2023.06.259

Godiño, J. A. V., García, M. T., Aguilar, F. J. J. E., Experimental investigation and modelling of biodiesel combustion in engines with late direct injection strategy, *Energy Rep.*, 8, 7476-7487 (2022). https://doi.org/10.1016/j.egyr.2022.05.279

Hassan, T., Rahman, Md. M., Adib, A. R., Meraz, R. M., Rahman, Md. A. and Tushar, M. S. H. K., Effect of Ni and Al nanoadditives on the performance and emission characteristics of a diesel engine fueled with diesel-castor oil biodiesel-n-butanol blends, *Case Stud. Chem. Environ. Eng.*, 8, 100531 (2023). https://doi.org/10.1016/j.cscee.2023.100531

Jayabal, R., Effect of hydrogen/sapota seed biodiesel as an alternative fuel in a diesel engine using dual-fuel mode, *Process Saf. Environ. Prot.*, 183, 890–900 (2024). https://doi.org/10.1016/j.psep.2024.01.046

Jin, C., Wei, J., Chen, B., Li, X., Ying, D., Gong, L. and Fang, W., Effect of nanoparticles on diesel engines driven by biodiesel and its blends: A review of 10 years of research, *Energy Conv. Manag.*, 291, 117276 (2023). https://doi.org/10.1016/j.enconman.2023.117276

Li, J., Gong, S., Liang, Y., Wu, S., Liu, R. and Yang, W., Analysis of soot formation and oxidation processes in the diesel engine fueled by n-octanol/biodiesel blends based on a detailed soot population balance model, *Fuel*, 358, 130376 (2024). https://doi.org/10.1016/j.fuel.2023.130376

Liu, K., Pei, Z., Deng, B., Yang, J. and Li, Y., Experimental study on transient emissions characteristics of a heavy duty natural gas engine under world harmonized transient cycle, *Case Stud. Therm. Eng.*, 38, 102377 (2022). https://doi.org/10.1016/j.csite.2022.102377

Mahgoub, B. K. M., Effect of nano-biodiesel blends on CI engine performance, emissions and combustion characteristics – Review, *Heliyon*, 9(11), e21367 (2023).
https://doi.org/10.1016/j.heliyon.2023.e21367

Maleki, B., Venkatesh, K., Muthusamy, B. and Esmaeili, H., A cleaner approach towards magnetically assisted-electrolysis of biodiesel production using novel $MnFe_2O_4$@sawdust derived biochar nanocatalyst and its performance on a CI engine, *Energy Conv. Manag*., 299, 117829 (2024).
https://doi.org/10.1016/j.enconman.2023.117829

Meng, J., Xu, W., Meng, F., Wang, B., Zhao, P., Wang, Z., Ji, H. and Yang, Y., Effects of waste cooking oil biodiesel addition on combustion, regulated and unregulated emission characteristics of common-rail diesel engine, *Process. Saf. Environ. Prot*., 178, 1094–1106 (2023).
https://doi.org/10.1016/j.psep.2023.08.065

Mohammed, A. S., Atnaw, S. M., Ramaya, A. V. and Alemayehu, G., A comprehensive review on the effect of ethers, antioxidants, and cetane improver additives on biodiesel-diesel blend in CI engine performance and emission characteristics, *J. Energy Inst.*, 108, 101227 (2023).
https://doi.org/10.1016/j.joei.2023.101227

Muhammed, N. M. and Shaija, A., Biodiesel production from coconut waste cooking oil using novel solar powered rotating flask oscillatory flow reactor and its utilization in diesel engine, *Therm. Sci. Eng. Prog.*, 40, 101794 (2023).
https://doi.org/10.1016/j.tsep.2023.101794

Nadimi, E., Przybyła, G., Lovas, T. and Adamczyk, W., Effects of biodiesel injector configuration and its injection timing on performance, combustion and emissions characteristics of liquid ammonia dual direct injection engine, *J Energy Inst*., 114, 101605 (2024).
https://doi.org/10.1016/j.joei.2024.101605

Reddy, V.J., Hariram, N. P., Maity, R., Ghazali, M. F. and Kumarasamy, S., Sustainable Vehicles for Decarbonizing the Transport Sector: A Comparison of Biofuel, Electric, Fuel Cell and Solar-Powered Vehicles, *World Electr. Veh. J.*, 15(3), 93 (2024).
https://doi.org/10.3390/wevj15030093

Riyadi, T. W. B., Spraggon, M., Herawan, S. G., Idris, M., Paristiawan, P. A., Putra, N. R., R, M. F., Silambarasan, R. and Veza, I., Biodiesel for HCCI engine: Prospects and challenges of sustainability biodiesel for energy transition, *Results Eng.*, 17, 100916 (2023).
https://doi.org/10.1016/j.rineng.2023.100916

Roschat, W., Phewphong, S., Inthachai, S., Donpamee, K., Phudeetip, N., Leelatam, T., Moonsin, P., Katekaew, S., Namwongsa, K., Yoosuk, B., Janetaisong, P. and Promarak, V., A highly efficient and cost-effective liquid biofuel for agricultural diesel engines from ternary blending of distilled Yang-Na (*Dipterocarpus alatus*) oil, waste cooking oil biodiesel, and petroleum diesel oil, *Renew. Energy Focus*., 48, 100540 (2024).
https://doi.org/10.1016/j.ref.2024.100540

Sanli, B. and Uludamar, E., Effect of hydrogen addition in a diesel engine fuelled with diesel and canola biodiesel fuel: Energetic-exergetic, sustainability analyses, *Int. J. Hydrogen Energy*., 49, 1148–1159 (2024).
https://doi.org/10.1016/j.ijhydene.2023.10.128

Sayyed, S., Kulkarni, K., Das, R. K., Alam, T. and Eldin, S. M., Direct injection diesel engine characteristics fuelled with diesel, biodiesel and 1-butanol blends, *Case Stud. Therm. Eng.*, 53, 103826 (2024).
https://doi.org/10.1016/j.csite.2023.103826

Sun, X., Xu, L., Yuan, H., Wang, G. and Maleki, B., Boosted conversion of restaurant waste oil into biodiesel using Fe_3O_4@UiO-66-NH_2 magnetic heterogeneous nanocatalyst and its application on the diesel engine: Optimization via RSM, *Renew. Energy*., 223, 120007 (2024).
https://doi.org/10.1016/j.renene.2024.120007

Wang, J. and Azam, W., Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries, *Geosci Front.*, 15(2), 101757 (2024).
https://doi.org/10.1016/j.gsf.2023.101757

Zeki, Y., Murat Kadir, Y., Mevlut, A. and Hayri, Y., Understanding the performance, emissions, and combustion behaviors of a DI diesel engine using alcohol/hemp seed oil biodiesel/diesel fuel ternary blends: Influence of long-chain alcohol type and concentration, *Sci. Tech. Energ. Transition.*, 78 (2023). https://doi.org/10.2516/stet/2023003

Zheng, F. and Cho, H. M., The Comprehensive Effects of Nano Additives on Biodiesel Engines—A Review, *Energ.*, 17(16), 4126 (2024).
https://doi.org/10.3390/en17164126