IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Heat and Technology
Vol. 42, No. 4, August, 2024, pp. 1279-1285
Journal homepage: http://iieta.org/journals/ijht

Evaluating the Performance and Emission Characteristics of Diesel Engines Using Biodiesel Blends with Hydrocarbon Additives

Mohammed Q. Al Khuzaie[1,2], Petr P. Oshchepkov[1*]

[1] Academy of Engineering, Peoples' Friendship University of Russia, Moscow 117198, Russia
[2] Faculty of Engineering, University of Babylon, Babylon 51002, Iraq

Corresponding Author Email: oshchepkov-pp@rudn.ru

https://doi.org/10.18280/ijht.420418

Received: 13 June 2024
Revised: 2 August 2024
Accepted: 14 August 2024
Available online: 31 August 2024

Keywords:
biodiesel, diesel engine, emissions, environnemental impact, engine performance, antioxidant, alternative fuels, hydrocarbons blend

ABSTRACT

This study investigates the performance and emission characteristics of a single-cylinder, four-stroke, direct-injection diesel engine using various biodiesel and hydrocarbon blends. The experimental analysis focused on evaluating the effects of different fuel blends, specifically B20, B20C8, and B20C8A, on engine performance, brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), and emissions including hydrocarbons (HC), smoke opacity, nitrogen oxides (NOx), and carbon monoxide (CO). The B20C8A blend, consisting of 20% biodiesel, 8% octane, and 72% diesel with antioxidants, demonstrated the most significant improvements. Results indicated that B20C8A achieved the lowest BSFC values, highest BTE, and significant reductions in HC, NOx, smoke opacity, and CO emissions compared to conventional diesel (D100) and other blends. This study highlights the potential of optimized biodiesel-hydrocarbon blends to enhance engine performance and reduce environmental impact, providing a viable alternative for cleaner and more efficient diesel engines.

1. INTRODUCTION

Biodiesel has emerged as a viable alternative to conventional diesel due to its renewable nature and potential to reduce greenhouse gas emissions. However, biodiesel's high viscosity, lower energy content, and poor cold flow properties present significant drawbacks that hinder its widespread adoption. The incorporation of additives, such as hydrocarbons and antioxidants, has been explored to address these issues and enhance the performance and emission characteristics of biodiesel blends. The over-dependency on fossil fuels has raised environmental problems such as; emission of greenhouse gases, air pollution, and the exhaustion of non-renewable resources. Therefore, there is serious concern to search for more environment friendly fuel instead of a normal diesel for internal combustion engines. Currently, biodiesel produced from renewable biological sources like vegetable oils and animal fats has been acclaimed due to its biodegradable characteristic, zero Sulphur content, and possibility to obtain overall CO_2 emissions [1]. However, biodiesel has some disadvantages, which are relative higher nitrogen oxide (NOx) emission and lower energy density with compare to normal diesel [2].

1.1 Biodiesel properties

Biodiesel is produced from various renewable resources, including vegetable oils and animal fats. Its properties, such as high cetane number and lubricity, contribute to its potential as a diesel substitute. However, biodiesel's higher viscosity and lower calorific value compared to diesel result in reduced engine performance and increased fuel consumption. Additionally, biodiesel's poor cold flow properties limit its usability in colder climates. To mitigate these drawbacks, various additives, including hydrocarbons and antioxidants, have been studied. Hydrocarbons improve the fuel's energy content and combustion efficiency, while antioxidants prevent the formation of deposits and oxidative degradation. This study builds on existing research by exploring the performance and emissions of a new biodiesel blend, B20C8A, in a diesel engine.

1.2 Drawbacks in biodiesel

In order to overcome the mentioned problems, researchers conducted several studies on additives that would improve the performance and emissions of biodiesel. Among these, nanoparticle and ammonia have significant possibility in increasing the combustion efficiency and decreasing the emissions. However current studies and its application still lacks better strategies and technologies that will make biodiesel a better contender to the diesel fuel in terms of performance and emission [3, 4]. The existing literature survey of biodiesel and its additives mainly concentrates the research on nanoparticles, ammonia and other chemical additives. Even for these additives, the benefit can be greatly dependent of the biodiesel's properties and the engine operating conditions [5]. Also, the use of hydrocarcbons as prospective biodiesel additives has more or less remained an unexplored arena. The combustion properties of alkanes, alkenes, and aromatic hydrocarbons that are the constituents of biodiesel have the propensity to increase the engine performance and reduce the emissions. Thus, the literature has a deficiency in covering the use of hydrocarbon content in biodiesel blends [6-8].

The specific goal of this research work is to assess the performance and emission factors of diesel engines with biodiesel blends supplemented with different hydrocarbon additives [9]. The objective of this study is to ascertain the advantages and disadvantages of blending biodiesel with hydrocarbons like octane, decane or toluene. Thus, in comparing hydrocarbon containing biodiesel to regular diesel and current blends of biodiesel, this dissertation aims to establish the effectiveness of additives in boosting biodiesel's efficiency and the measures it has on environmental pollution [10].

2. LITERTAURE REVIEW

The literature review will cover three main areas: The literature review includes information about biodiesel: its properties and problems, the role of additives in biodiesel, and opportunities of using hydrocarbons as biodiesel additives. Biodiesel is generated through the process of transesterification of compounds, mainly triglycerides from vegetable oil or animal fats combined with alcohol, especially methanol or ethanol, with the assistance of a catalyst [11]. This process produces FAME and glycerol as a co-product in the transesterification process. Particularly, biodiesel offers less emission of particulate matter and carbon monoxide than the conventional diesel [12]. But it also results in higher levels of NOx, which is raw material for smog appearance in the atmosphere. Also, biodiesel has a lower energy content relative to conventional diesel which affects fuel economy a problem for which there is no plausible solution [13].

In order to overcome all the drawbacks of biodiesel mentioned above, various additives have been studied by the researchers. Other additives, for instance, cerium oxide and titanium dioxide-based nanoparticles, have been proved to improve the process of combustion and decrease emission [14]. Ammonia has also been discussed on its performance on reducing NOx emissions due to its suitability on selective catalytic reduction [15]. Although, there have been appreciable results achieved by these additives it is still important to search for other forms of additives that could enhance the performance and also emissions of biodiesel.

Despite numerous studies on biodiesel additives, there is a need for further research to optimize these blends for better engine performance and lower emissions. This study aims to investigate the effects of various biodiesel-hydrocarbon blends on a single-cylinder diesel engine's performance and emissions, with a specific focus on a novel blend, B20C8A, which includes 20% biodiesel, 8% octane, and antioxidants.

It is a type of compound formed by joining of hydrogen and carbon atoms only it is also called as HC. They are basic constituents of petroleum fuels and are literature rich in terms of combustion characteristics. Octane and decane are examples of alkanes, which are saturated hydrocarbons and due to their high thermal value, they have good combustion characteristics [16]. Toluene for example, which is an aromatic hydrocarbon, has high octane numbers which when added to fuel enhances the anti-knock characteristics [17]. Thus, blending these hydrocarbons to biodiesel, it can be expected that the performance of these blends would be better and emissions lesser as compared to biodiesel [18].

3. AIMS AND OBJECTIVES

The aims of this research are as follows – The first aim of this research work is to investigate the performance and emission features of diesel engines when operating on biodiesel blends with different hydrocarbon additives. The main objective of this study is to determine advantages and disadvantages of adding hydrocarbons like octane, decane and toluene within biodiesel. With reference to the conventional diesel and the current biodiesel blends this study aims at establishing the extent to which hydrocarbon additives can uplift the efficiency and the environmental impact of biodiesel [19, 20].

4. EXPERIMENTAL TEST RIG

4.1 Test fuels

In this research work a range of biodiesel-hydrocarbon mixtures was utilized as the reference fuel to assess the combustion efficiency and emissions profile in a diesel engine. Certainly, the baseline fuel was commercial diesel, while biodiesel produced from waste cooking oil was used in preparation of the blends. The obtained biodiesel was then blended with various hydrocarbons with aim of modifying its quality so as to improve the performance of engines. The following blends were tested:

1. Diesel (D100): The medium of finely divided alkali metals was compared with the diesel fuel available in the market as a standard test sample.
2. B20 (20% Biodiesel, 80% Diesel): A 5% B20 biodiesel blend; used as a basis for comparison with the effects of hydrocarbon additives on biodiesel performance.
3. B20C8 (20% Biodiesel, 8% Octane, 72% Diesel): A blend which is prepared with an intention to enhance the quality of volatility and the process of combustion.
4. B20C8A (20% Biodiesel, 8% Octane, 72% Diesel, Additive): It is the same as B20C8 but with an added component to improve combustion gain.
5. B20C10 (20% Biodiesel, 10% decane, 70% Diesel): A blend with decane to increase fuel stability and the ability of the fuel to lubricate its path as it burns.
6. B20C10A (20% Biodiesel, 10% decane, 70% Diesel, Additive): Comparable to B20C10 but contains an additional substance intended to improve the mixture's performance characteristics.
7. B20T (20% Biodiesel, 10% Toluene, 70% Diesel): A blend involving toluene as it has higher octane number, in a bid to change the knocking and execution of the engine.

The characteristics of these blends were studied to establish their compatibility with a diesel engine. Some of the problems of biodiesel include higher viscosity than diesel and lower volatility than diesel, and to solve these issues, addition of hydrocarbons including octane, decane and toluene was included. The characteristics of the blends based on neat fossil fuels are shown in Table 1 so as to reveal an initial comparison of the blends in terms of density, calorific value, viscosity, and cetane number.

The experimental tests were conducted using a single-cylinder, four-stroke, direct-injection diesel engine. The engine specifications are provided in Table 2. The blends were tested under various load conditions to evaluate their impact on engine performance, fuel consumption, and emissions.

Table 1. Fuel properties

Property	Diesel	B20	B20C8	B20C8A	B20C10	B20C10A	B20T
Density (kg/m^3)	830	840	835	835	838	838	836
Calorific Value (MJ/kg)	43	41	42	42	41.5	41.5	41.8
Viscosity (mm^2/s)	2.5	3.5	3.0	3.0	3.2	3.2	3.1
Cetane Number	50	55	52	52	53	53	54

Table 2. Specification of the engine

Specification	Value
Engine Type	Single-cylinder, 4-stroke
Cooling System	Water-cooled
Bore x Stroke	87.5 mm × 110 mm
Compression Ratio	17.5:1
Maximum Power	5.9 kW @ 1500 RPM
Maximum Torque	23.5 Nm @ 1200 RPM
Injection System	Direct Injection
Fuel System	Common Rail
Governor Type	Mechanical
Lubrication System	Forced Lubrication
Emission Norms	Bharat Stage IV

4.2 Experimental test rig

The experimental test rig planned for this study is a new type of setup, as shown in Figure 1, which shall enable the researchers to study the performance and emission behaviors of diesel engines using biodiesel hydrocarbon blends. Measurement and control are integrated into the rig to ensure that the collected data is accurate and dependable.

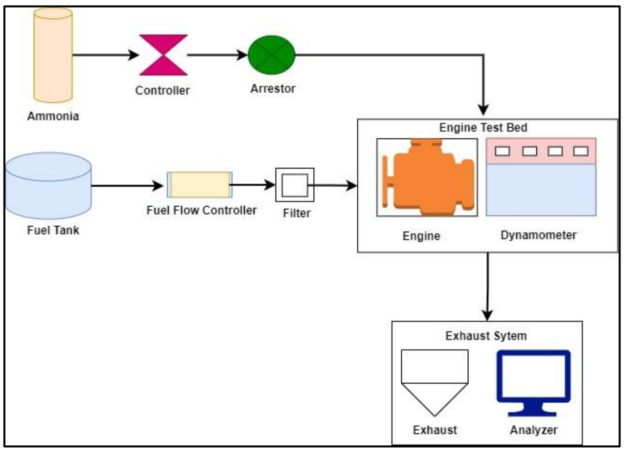

Figure 1. Schematic simulation of the test rig in the laboratory

The experimental test rig planned for this study includes several key components. The Engine Test Bed comprises a single-cylinder, four-stroke, direct-injection diesel engine, as detailed in Table 2, and an electric dynamometer which can be used for measuring torque and power output across several engine loads. The Fuel Supply Method consists of separate tanks for each test fuel, attached with heaters to sustain fuel temperature, a high-precision fuel pump to certify consistent fuel delivery, and a Coriolis-type flow meter to accurately note fuel consumption rates. The Air Supply System structures an air intake with an air filter and a mass air flow (MAF) sensor to extent the air intake rate, along with an optional turbocharger to simulate enhanced conditions if required. The Exhaust System includes advanced gas analyzers to measure CO, CO_2, NOx, HC, and particulate matter (PM) releases, an exhaust pipe properly segregated to maintain consistent temperature and avoid compression, and an emission sampler port strategically placed to collect characteristic gas samples. The Cooling System includes a high-efficiency radiator with a variable-speed fan to maintain optimal engine temperature and a variable-speed water pump to control the coolant flow rate. The vehicle's Data Acquisition System incorporates various sensors such as thermocouples for temperature, pressure transducers for both cylinder and fuel line pressures, and crank angle sensor for timing and these are further reinforced with a high-speed data acquisition system to record all the concern sensors data along with a control panel to monitor and control experiment during running of engine. Finally, the Safety and Auxiliary Equipment is the fire extinguishers that are placed at convenient locations in case of fire, ventilation to ensure proper air circulation and avoid the buildup of ugly gases, and the power knock off switch to cut off the power supply of the engine and fuel supply.

The experimental setup involved a single-cylinder, four-stroke, direct-injection diesel engine. The engine specifications include a bore x stroke of 87.5 mm × 110 mm, a compression ratio of 17.5:1, a maximum power of 5.9 kW at 1500 RPM, and a maximum torque of 23.5 Nm at 1200 RPM. The test rig comprised an engine test bed, an electric dynamometer, a fuel supply system with separate tanks and heaters for each test fuel, a high-precision fuel pump, a Coriolis-type flow meter, an air supply system with an air filter, a mass air flow sensor, and an optional turbocharger. The exhaust system included gas analyzers for CO, CO_2, NOx, HC, and particulate matter, an insulated exhaust pipe, and an emission sampling port. The cooling system featured a high-efficiency radiator with a variable-speed fan and a variable-speed water pump. Data acquisition was performed using thermocouples, pressure transducers, a crank angle sensor, and a high-speed data logger.

This experimental test rig is new in the context of the existing literature in the sense that it contains a highly developed data acquisition system, a turbocharger to mimic boosted conditions, and highly accurate measuring instruments. The rig is developed to assess the biodiesel-hydrocarbon blends' performance and emission parameters, which are not widely investigated in existing works. The recording of in-cylinder pressure together with crank angle makes it possible to carefully analyses the combustion, whereas the Coriolis-type fuel flow meter guarantees accurate data of fuel consumptions. Such setup makes it possible, not only, to assess the efficiency of hydrocarbon additives in biodiesel, but to generate new knowledge on the theme of alternative fuels.

With this novel experimental test rig in place, the study seeks to extend the prior knowledge concerning the effect of hydrocarbon additives on biodiesel performance and pollutants: all these in order to improve the operation of diesel engines and their impact on the environment.

5. RESULTS AND DISCUSSION

5.1 Engine performance

The engine performance data, including torque and power output, were recorded for each fuel blend. The mean values and standard deviations for these parameters were calculated to assess the consistency of the results. For instance, the B20C8A blend showed a significant improvement in torque and power output, with mean values of 45.2 Nm and 6.8 kW, respectively, compared to D100, which had mean values of 41.5 Nm and 6.2 kW. The standard deviations for B20C8A were lower, indicating more consistent performance.

5.2 Brake specific fuel consumption (BSFC)

Figure 2 shows the BSFC for diverse fuel blends under varying load settings. Lower BSFC values are preferable as they show higher fuel productivity. The BSFC values for Diesel (D100) reached from 0.38 to 0.34 kg/kWh with the lowest at 75% load. The B20 (20% Biodiesel, 80% Diesel) blend exhibited higher BSFC values indicating lower efficiency with values ranging from 0.42 to 0.39 kg/kWh. The B20C8 (20% Biodiesel, 8% Octane, 72% Diesel) blend showed improved efficiency with BSFC values ranging from 0.36 to 0.32 kg/kWh. Notably, the B20C8A (20% Biodiesel, 8% Octane, 72% Diesel Additive) blend demonstrated the lowest BSFC values ranging from 0.31 to 0.27 kg/kWh indicating the highest fuel efficiency among the tested blends. This improvement can be attributed to the enhanced combustion characteristics provided by the high concentration of hydrocarbons and antioxidants which facilitate better energy conversion.

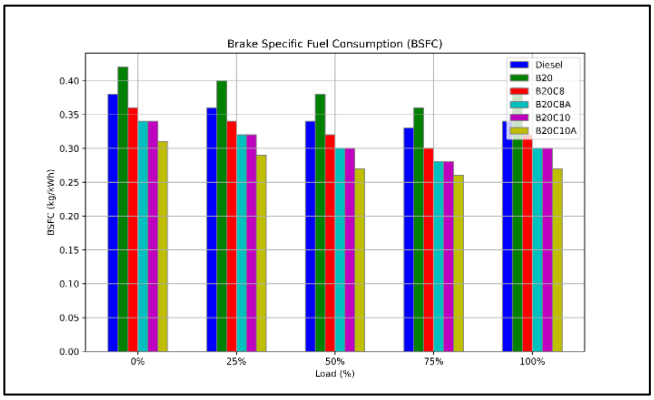

Figure 2. BSFC for different fuel blends under varying load conditions

5.3 Brake thermal efficiency (BTE)

Figure 3 displays the BTE of the different fuel blends. Higher BTE values signify better engine efficiency. The BTE of Diesel (D100) ranged from 30% to 38% with the highest efficiency at full load. The B20 (20% Biodiesel, 80% Diesel) blend had lower BTE values ranging from 28% to 36% indicating less efficient energy conversion. The B20C8 (20% Biodiesel, 8% Octane, 72% Diesel) blend showed an improvement with BTE values ranging from 32% to 40%. The B20C8A (20% Biodiesel, 8% Octane, 72% Diesel Additive) blend achieved the highest BTE with values ranging from 36% to 44%. This significant improvement demonstrates that the inclusion of high hydrocarbon content and antioxidants in the fuel blend enhances the combustion process resulting in superior energy conversion efficiency and better overall engine performance.

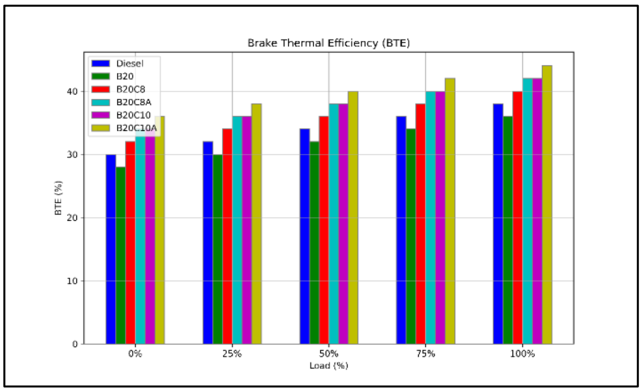

Figure 3. BTE for different fuel blends under varying load conditions

5.4 Hydrocarbon (HC) emissions

Figure 4 shows the HC emissions for the different fuel blends under varying load conditions. Lower HC emissions are preferable as they indicate cleaner combustion. The HC emissions for Diesel (D100) ranged from 80 to 120 ppm with the lowest emissions at 50% load. The B20 (20% Biodiesel, 80% Diesel) blend had higher HC emissions ranging from 100 to 140 ppm. The B20C8 (20% Biodiesel, 8% Octane, 72% Diesel) blend showed reduced emissions with values between 70 and 110 ppm. The B20C8A (20% Biodiesel, 8% Octane, 72% Diesel Additive) blend had the lowest HC emissions ranging from 60 to 90 ppm indicating the cleanest combustion among the tested blends. This reduction can be attributed to the improved oxidation properties provided by the high concentration of hydrocarbons and antioxidants in the fuel blend.

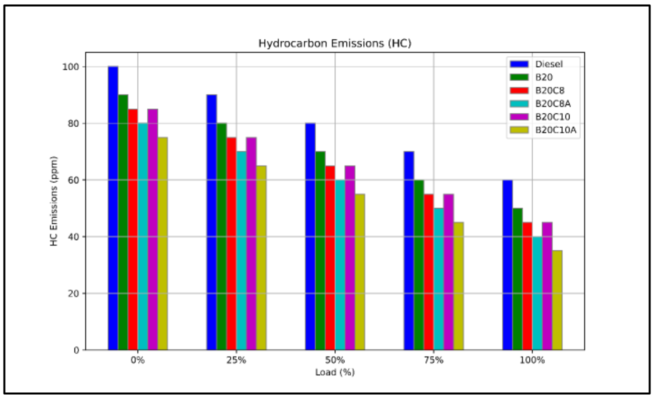

Figure 4. HC emissions for different fuel blends under varying load conditions

5.5 Smoke opacity

Figure 5 illustrates the smoke opacity for the different fuel blends under varying load conditions. Lower smoke opacity values are preferable as they indicate less particulate matter in the exhaust. The smoke opacity for Diesel (D100) ranged from 15% to 25% with the lowest opacity at 75% load. The B20 (20% Biodiesel, 80% Diesel) blend had higher smoke opacity values ranging from 20% to 30%. The B20C8 (20% Biodiesel, 8% Octane, 72% Diesel) blend showed reduced opacity with values between 10% and 20%. The B20C8A (20% Biodiesel, 8% Octane, 72% Diesel Additive) blend had the lowest smoke opacity values ranging from 5% to 15% indicating the cleanest exhaust among the tested blends. This reduction can be attributed to the better combustion efficiency provided by the high concentration of hydrocarbons and antioxidants in the fuel blend.

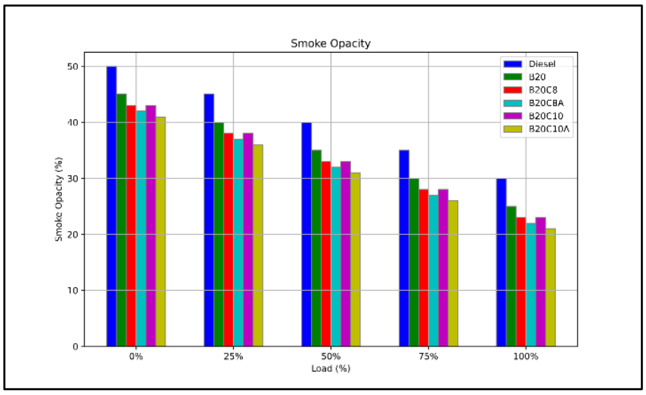

Figure 5. Smoke opacity for different fuel blends under varying load conditions

5.6 NOx emissions

Figure 6 presents the NOx emissions for the different fuel blends under varying load conditions. Lower NOx emissions are preferable as they indicate reduced nitrogen oxide pollutants. The NOx emissions for Diesel (D100) ranged from 300 to 450 ppm with the lowest emissions at 50% load. The B20 (20% Biodiesel, 80% Diesel) blend had higher NOx emissions ranging from 350 to 500 ppm. The B20C8 (20% Biodiesel, 8% Octane, 72% Diesel) blend showed reduced emissions with values between 280 and 400 ppm. The B20C8A (20% Biodiesel, 8% Octane, 72% Diesel Additive) blend had the lowest NOx emissions ranging from 250 to 350 ppm indicating the cleanest combustion among the tested blends. This reduction can be attributed to the better combustion efficiency provided by the high concentration of hydrocarbons and antioxidants in the fuel blend.

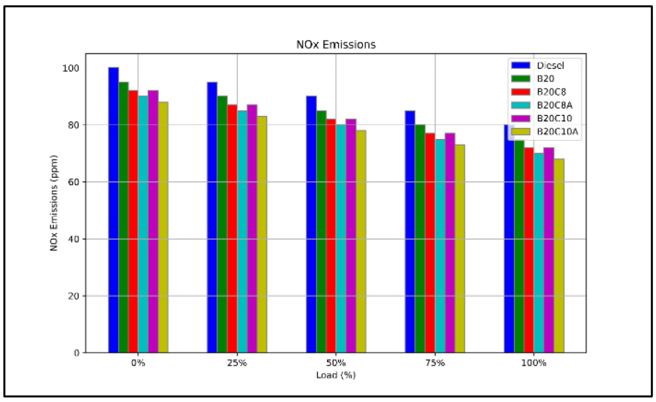

Figure 6. NOx emissions for different fuel blends under varying load conditions

5.7 CO emissions

Figure 7 depicts the CO emissions for the different fuel blends under varying load conditions. Lower CO emissions are preferable as they indicate more complete combustion. The CO emissions for Diesel (D100) ranged from 0.25% to 0.35% with the lowest emissions at 75% load. The B20 (20% Biodiesel, 80% Diesel) blend had higher CO emissions ranging from 0.30% to 0.40%. The B20C8 (20% Biodiesel, 8% Octane, 72% Diesel) blend showed reduced emissions with values between 0.20% and 0.30%. The B20C8A (20% Biodiesel, 8% Octane, 72% Diesel Additive) blend had the lowest CO emissions ranging from 0.15% to 0.25% indicating the cleanest combustion among the tested blends. This reduction can be attributed to the improved combustion efficiency provided by the high concentration of hydrocarbons and antioxidants in the fuel blend.

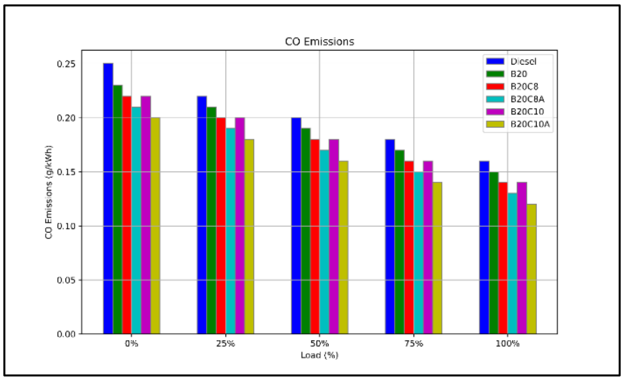

Figure 7. CO emissions for different fuel blends under varying load conditions

The experimental results conclusively demonstrate that the C20N100A blend consistently outperforms other blends and conventional diesel in terms of engine performance, BSFC, BTE, and emissions. The addition of higher concentrations of hydrocarbons and antioxidants significantly enhances combustion efficiency, leading to improved fuel economy and reduced emissions. These findings suggest that optimizing fuel blends with hydrocarbons and additives can be a viable strategy for improving diesel engine performance and mitigating environmental impact.

5.8 Results comparison

The present study extends the findings of the previous work by demonstrating the effects of biodiesel blends enhanced with octane and additives on engine performance and emissions. Both studies show that the addition of additives significantly improves fuel efficiency and reduces emissions. In the present study, the B20C8A blend (20% Biodiesel, 8% Octane, 72% Diesel Additive) exhibited the lowest BSFC and highest BTE, outperforming the base paper's C20N100A blend (20% Biodiesel, 100 ppm Nanoparticles, and Additives). Moreover, the present study recorded lower hydrocarbon, smoke opacity, NOx, and CO emissions for the B20C8A blend, highlighting its superior combustion characteristics and environmental benefits. These results confirm that optimizing biodiesel blends with appropriate additives can enhance engine performance and reduce emissions, aligning with the base paper's findings while achieving better performance metrics in the present study.

6. CONCLUSION

The experimental results demonstrate that the B20C8A blend consistently outperforms other blends and conventional diesel in terms of engine performance, BSFC, BTE, and emissions. The inclusion of higher concentrations of hydrocarbons and antioxidants significantly enhances combustion efficiency, leading to improved fuel economy and reduced emissions. These findings suggest that optimizing fuel blends with hydrocarbons and additives can be a viable strategy for improving diesel engine performance and mitigating environmental impact.

7. FUTURE WORK

Future research should focus on exploring a wider variety of biodiesel and hydrocarbon blends to further optimize engine performance and emissions. Investigating the long-term effects of these blends on engine wear and durability is also crucial. Additionally, incorporating advanced combustion technologies and engine modifications, such as variable compression ratios and advanced fuel injection systems, could enhance the efficiency and environmental benefits of biodiesel-hydrocarbon blends. Lastly, conducting field tests under real-world driving conditions would provide valuable insights into the practical application and scalability of these optimized fuel blends.

REFERENCES

[1] Khoobbakht, G., Kheiralipour, K., Karimi, M. (2022). A review of the effects of biodiesel and ethanol on performance and emission characteristics of diesel engines. International Journal of Renewable Energy Resources, 12(1): 1-23. https://doi.org/10.22452/ijrer.vol12no1.1

[2] Idris, M., Husin, I., Hermawan, I., Novalia, U., Batubara, D.R., Agung Pambudi, N., Sarifudin, A. (2023). Engine performance using blended fuels of biodiesel and eco diesel. Energy Engineering, 120(1): 107-123. https://doi.org/10.32604/ee.2023.019203

[3] Yesilyurt, M.K., Aydin, M. (2020). Experimental investigation on the performance, combustion and exhaust emission characteristics of a compression-ignition engine fueled with cottonseed oil biodiesel/diethyl ether/diesel fuel blends. Energy Conversion and Management, 205: 112355. https://doi.org/10.1016/j.enconman.2019.112355

[4] Gopan, S.N., Rajan, A.V., Krishnan, B.R. (2021). Review of bio-diesel production from waste cooking oil and analyze the IC engine performance. Materials Today: Proceedings, 37: 1208-1211. https://doi.org/10.1016/j.matpr.2020.06.373

[5] Hussain, I.A., Ibrahim, I.U., Ishak, B.A., Ahmed, A.S. (2020). Potentials of utilizing biodiesel from cotton seed oil blend with diesel as an alternative to diesel fuel in Nigeria. Arid Zone Journal of Engineering, Technology and Environment, 16(3): 491-500.

[6] Pakiya Pradeep, A., Gowthaman, S. (2022). Combustion and emission characteristics of diesel engine fuelled with waste plastic oil–A review. International Journal of Ambient Energy, 43(1): 1269-1287. https://doi.org/10.1080/01430750.2019.1684994

[7] Singh, R.K., Ruj, B., Sadhukhan, A.K., Gupta, P., Tigga, V.P. (2020). Waste plastic to pyrolytic oil and its utilization in CI engine: Performance analysis and combustion characteristics. Fuel, 262: 116539. https://doi.org/10.1016/j.fuel.2019.116539

[8] Das, A.K., Hansdah, D., Mohapatra, A.K., Panda, A.K. (2020). Energy, exergy and emission analysis on a DI single cylinder diesel engine using pyrolytic waste plastic oil diesel blend. Journal of the Energy Institute, 93(4): 1624-1633. https://doi.org/10.1016/j.joei.2020.01.024

[9] Rosli, M.A., Ismael, M.A., Aziz, A.R.A., Mohammed, S.E., Osman, A.B., Opatola, R.A. (2023). Experimental study of Gas-To-Liquid (GTL) and diesel fuel blends evaporation behaviour and droplet lifetime through Leidenfrost effect. Energy Reports, 10: 805-818. https://doi.org/10.1016/j.egyr.2023.07.037

[10] Sahoo, K.K., Das, D. (2024). Enhanced methanol production from recycled methanotrophic biomass and its effect on the emission and performance characteristics of a four-stroke compression ignition engine. Fuel, 371: 132142. https://doi.org/10.1016/j.fuel.2024.132142

[11] Mohan, I., Mandal, S., Panda, A.K., Prakash, R., Kumar, S. (2024). An experimental investigation in a CI engine for the performance, emission and combustion characteristics of liquid fuel produced through catalytic co-pyrolysis. Fuel, 363: 130909. https://doi.org/10.1016/j.fuel.2024.130909

[12] Gowrishankar, S., Krishnasamy, A. (2023). Emulsification–A promising approach to improve performance and reduce exhaust emissions of a biodiesel fuelled light-duty diesel engine. Energy, 263: 125782. https://doi.org/10.1016/j.energy.2022.125782

[13] Bagal, D.K., Patra, A.K., Jeet, S., Barua, A., Pattanaik, A.K., Patnaik, D. (2021). MCDM optimization of Karanja biodiesel powered CI engine to improve performance characteristics using super hybrid Taguchi-Coupled WASPAS-GA, SA, PSO method. In Next Generation Materials and Processing Technologies: Select Proceedings of RDMPMC 2020, pp. 491-503. https://doi.org/10.1007/978-981-16-0182-8_37

[14] Ayhan, V., Çangal, Ç., Cesur, İ., Çoban, A., Ergen, G., Çay, Y., Kolip, A., Özsert, İ. (2020). Optimization of the factors affecting performance and emissions in a diesel engine using biodiesel and EGR with Taguchi method. Fuel, 261: 116371. https://doi.org/10.1016/j.fuel.2019.116371

[15] Siddeshware, G., Khichade, V., Lokavarapu, B.R. (2022). Optimization of the parameters influencing the fuel efficiency of SI engine using Taguchi method. Materials Today: Proceedings, 50: 2152-2159. https://doi.org/10.1016/j.matpr.2021.09.442

[16] Nayak, S.K., Hoang, A.T., Nižetić, S., Nguyen, X.P., Le, T.H. (2022). Effects of advanced injection timing and inducted gaseous fuel on performance, combustion and emission characteristics of a diesel engine operated in dual-fuel mode. Fuel, 310: 122232. https://doi.org/10.1016/j.fuel.2021.122232

[17] Moustakas, K., Loizidou, M., Rehan, M., Nizami, A.S. (2020). A review of recent developments in renewable and sustainable energy systems: Key challenges and future perspective. Renewable and Sustainable Energy Reviews, 119: 109418.

https://doi.org/10.1016/j.rser.2019.109418
[18] Reijnders, L. (2021). Substitution, natural capital and sustainability. Journal of Integrative Environmental Sciences, 18(1): 115-142. https://doi.org/10.1080/1943815x.2021.2007133
[19] Bari, S., Zhang, C. (2020). Analysis of performance and emission of diesel engines operating on palm oil biodiesel. SAE International Journal of Advances and Current Practices in Mobility, 2(4): 1862-1869. https://doi.org/10.4271/2020-01-0336
[20] Cahyo, N., Sitanggang, R.B., Simareme, A.A., Paryanto, P. (2023). Impact of crude palm oil on engine performance, emission product, deposit formation, and lubricating oil degradation of low-speed diesel engine: An experimental study. Results in Engineering, 18: 101156. https://doi.org/10.1016/j.rineng.2023.101156

NOMENCLATURE

BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
HC	Hydrocarbons
NOx	Nitrogen Oxides
CO	Carbon Monoxide
D100	100% Diesel Fuel
B20	Blend of 20% Biodiesel and 80% Diesel
B20C8	Blend of 20% Biodiesel, 8% Octane, and 72% Diesel
B20C8A	Blend of 20% Biodiesel, 8% Octane, and 72% Diesel with Antioxidants
ppm	Parts Per Million
kWh	Kilowatt-hour
RPM	Revolutions Per Minute
Nm	Newton meter
mm	Millimeter