https://doi.org/10.14669/AM/189510

THE INFLUENCE OF LOWER BLENDS OF ALGAE BIODIESEL ON DIESEL ENGINE PERFORMANCE AND EMISSIONS

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Abstract

In this study, we explore the effects of utilizing lower blends of algae biodiesel (B05, B07, B10) as well as B20 and compare their performance to that of conventional diesel fuel. The blending process involves the use of the transesterification method, which has been identified as suitable for this purpose. A single-cylinder water-cooled diesel engine with a compression ratio (CR) of 18:1 is employed for the performance and emission analysis. Various performance parameters, including Torque (T), Brake power (BP), Brake specific fuel consumption (BSFC), and Brake thermal efficiency (BTE), are assessed. Additionally, emission parameters, including Hydrocarbon (HC), Carbon monoxide (CO), Carbon dioxide (CO_2), and Nitrogen oxide (NO_x) concentration, are measured. The obtained results are then compared with the performance and emissions of pure diesel fuel. It is observed that there is minimal variation in torque and brake power when compared to diesel fuel. Furthermore, both brake power and brake thermal efficiency show slight improvements for B05, B07, and B10 blends as compared to pure diesel fuel. The BSFC remains relatively consistent across all lower blends. Notably, the concentration of Hydrocarbons (HC) and Carbon monoxide (CO) exhibit considerable reductions in the B05 and B07 blends compared to pure diesel fuel, as well as B10 and B20 blends. However, as the percentage of algae in the blend increases, Nitrogen oxide (NO_x) concentration become more pronounced.

Keywords: biodiesel; algae; higher blends; lower blends; performance; emissions

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https://doi.org/10.14669/AM/189510

1. Introduction

The depletion of petroleum fuel resources continues to rise alongside the ever-increasing vehicular population, leading to escalating costs. Additionally, the excessive use of petroleum-based fuels, such as diesel and petrol, significantly contributes to environmental pollution. Diesel engines, renowned for their cost-effectiveness, high energy conversion efficiency, and durability, are widely applied in commercial transport vehicles, buses, trucks, and various industrial off-road machinery. In light of the growing awareness of climate change and its devastating consequences, the need to address these issues for our survival has become apparent. There is a global consensus that air pollution is a principal catalyst for climate change, heightening the importance of addressing air pollution and preserving the environment. Numerous international organizations have been established to combat climate change resulting from pollutant emissions, with the internal combustion engine being a significant contributor. To mitigate emissions, it is crucial to explore three primary avenues: engine design modification, exhaust treatment, and alternative fuels. Researchers have diligently investigated alternatives to petroleum diesel to reduce consumption and environmental impact, with biodiesel emerging as a prominent solution, offering a host of advantages.

Numerous studies have assessed B20 and higher blends of various vegetable oils–edible as well as non-edible and fish oils, providing a wealth of information regarding their performance in engines. Parameters such as Brake power (BP), Brake specific fuel consumption (BSFC), Brake thermal efficiency (BTE), and emissions including Carbon monoxide (CO), Carbon dioxide (CO_2), Hydrocarbons (HC), and Nitrogen oxides (NO_x) have been thoroughly investigated. It has been demonstrated that B20 blends exhibit favourable engine performance characteristics but tend to produce elevated NO_x concentration. However, contemporary emission standards have grown increasingly stringent, with countries like India transitioning from Bharat Stage BS IV to BS VI norms from 2020. Consequently, B20 and higher biodiesel blends no longer meet these stringent emission standards. As the proportion of biodiesel in the blend increases, it becomes more viscous, potentially causing filter clogging and adversely affecting emissions due to incomplete combustion.

In light of these challenges, lower blends of biodiesel, such as B05, B07, and B10, present a compelling solution. These lower blends eliminate viscosity-related issues and filter clogging concerns. Nevertheless, there remains a dearth of comprehensive information regarding the performance and exhaust emissions associated with the use of lower biodiesel blends in diesel engines.

Faried et al. [7] provided an overview of various aspects related to the production of biodiesel from microalgae. The review covers several key areas, including the optimal conditions for cultivating microalgae, the design of processes for producing biodiesel from algae, the physicochemical properties of lipids extracted from microalgae, and the characteristics of the resulting biodiesel fuel.

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Ashwin et al. [3] studied and explored the third generation of microalgae feedstock cultivation and fuel production offers sustainable and economic benefits due to the microscopic nature of microalgae. The article explores different biomass pre-processing and extraction techniques for microalgae biodiesel production. Also, the article highlights and analyses the implementation of microalgae biodiesel in IC engines, including its output characteristics for different microalgae biodiesels.

Kesharvani and Dwivedi [10] reviewed and focused on algae as a third-generation feedstock for biodiesel production. It explores the advantages of algae, such as high oil yield and carbon neutrality. The study aims to understand biodiesel production and its application in diesel engines, both with and without nanoparticles additives. A comparative analysis is conducted to assess the production, performance, and emission aspects.

Nautiyal et al. [13] investigated the potential of a novel biodiesel derived from Spirulina platensis algae as an alternative fuel to conventional diesel. The study experimentally examined the impact of biodiesel on the performance, combustion, and emission characteristics of a diesel engine.

Canakci and Alptekin [5] studied properties of diesel fuels blended with the biofuel. Different biofuels used for study are sunflower oil, soya bean oil, cottonseed oil, corn oil, canola and waste palm oil. Properties studied and compared are density and viscosity. The blends prepared and tested are lower blends such as B02, B05, B10. B20 and higher blends as B50 and B75 are also studied. Results recorded show that with increase in proportion of biofuel in biodiesel blend there are increases in viscosity and density.

Karavalakis et al. [9] studied lower blends of edible oil i.e. soybean oil (B05 and B10) and found that for these blends there is increase in NO concentration. Increase in NO_x concentration is due to unsaturated soya blends. He tried saturated animal fat based biodiesel for which there is no increase in NO concentration. Lower blends also show a reduction in PM, HC and CO concentration.

Investigation of performance and emission in diesel engine with blends of neem oil biodiesel (B10, B20, B30) is presented by Nair et al. [12]. The result shows decrease in BSFC for B10 than B20 and B30. Blends of Neem oil used by them produces comparatively low No_x concentration. For B10 blend there will be 21.8% reduction of NO_x. Thus, improvement in performance is observed for B10 blend and a reduction in emissions is recorded as compared to other blends of neem oil biodiesel and diesel.

In [11], three blends of algae biodiesel (B05, B15, B25) are tested and compared with diesel for performance and emission study. For all three blends higher brake thermal efficiency and lower BSFC is observed. Increases in HC and CO emissions are observed. As blend proportion is increased, a rise in smoke density was also noticed as compared to diesel fuel.

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A lower blend of biodiesel B05 is tested by Ropkins et al. [14] on an instrumented probe vehicle and for different journey conditions. Replacing Diesel by B05 increases both NO_x and fuel consumption. There is no significant effect on CO, CO_2 and HC emission.

Abed et al. [2] did a comparative study of various blends of algae, jatropha and palm biodiesel and diesel fuel. They found a reduction in CO, HC and CO_2 concentration for B10 and B20 blend of algae, jatropha and palm oil biodiesel compared to diesel fuel. They also noted an increase in NO_x concentration for all B10 and B20 blends of tested biodiesel in comparison with diesel fuel.

Roy et al. [15] conducted and investigated different canola oil blends. They studied three different types of tests with B05, B10, B20, B50 and B100 with diesel, with additive wintron XC 30 and with kerosene. The result shows that for lower blends, i.e. B05 and B10, viscosity and calorific value is closer to diesel fuel. But for higher blends such as B20, B50 and B100 viscosity is higher and calorific value is lower. The addition of kerosene reduces the viscosity which is nearer to diesel if the percentage of kerosene increases he found there is a rise in BSFC, with a rise in biodiesel blend as well as for additive. A significant reduction in CO and HC is observed with biodiesel blend and with additive, but there is an increase in NO_x concentration. They observed a considerable deduction in NO_x concentration blend which uses kerosene as additive at all loading condition.

Yasin et al. [18] studied use of low proportion palm biodiesel blend i.e. B05 in multicylinder CI engine, results in torque and power output is similar to diesel fuel. NO_x concentration are reduced significantly. As compare to diesel fuel CO, CO_2 and HC concentration are also observed low.

Considerable decreases in CO and HC emissions are observed by Abedin et al. [1] for lower blends (B5 palm blend and ALB10 – Alexandrian laurel biodiesel). But BSFC for B5 blend was found to be higher.

Subramaniam et al. [17] tested various blends of algae fuel A10, A2, A30, A100 on diesel engine and compared results of performance parameters and emissions with diesel fuel. Experimental results show that for the A20 blend, thermal efficiency is higher than diesel and CO, HC concentration are lower. A slight increase in NO_x and CO_2 is observed. Also noted reduction in particulate matter and smoke.

Giridhan et al. [8] studied and compared performance and emission characteristics of various blends of algae biodiesel B05, B15, B25. with diesel fuel during testing in VCR diesel engine. For these blends thermal efficiency and mechanical efficiency is observed to be better than for diesel fuel. Investigation of CO and CO_2 emission is also done at various testing conditions in VCR (variable compression ratio) engine and results shown that these emissions for algae biodiesel blends are lower as compared to diesel fuel.

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Sathyamurthy et al. [16] investigated the use of corn oil methyl ester (COME) and its blends as alternative fuels in diesel engines due to concerns over global emissions and resource limitations. Results indicate that using B10 biodiesel blend improves engine performance, with a maximum efficiency of 33.98%. However, higher blend ratios (B20 and B30) lead to increased fuel consumption. Additionally, higher oxygen content in the fuel results in increased NO_x emissions and CO_2 production, while CO and HC emissions decrease.

Azad et al. [4] investigated two new ternary biodiesel blends, mixture of mandarin, crambe biodiesel and paraffin as an additive (ManCr–Pa) and mixture of avocado, bush nut biodiesel and paraffin (AvBn–Pa). These blends are designed to match diesel fuel properties more closely. Compared to diesel and typical B5 blends, the ternary blends show similar engine performance at high rpm but with significantly reduced carbon monoxide, hydrocarbons, and particulate matter emissions. Though there's a slight decrease in certain performance metrics like brake power and efficiency, the ternary blends outperform B5 blends in both performance and emissions, notably showing lower NO_x emissions.

Dhande and Navale [6] studied underscores biodiesel's potential as a sustainable alternative to traditional fuels, given concerns over fossil fuel scarcity and greenhouse gas emissions. Aligned with sustainable energy initiatives, the research explores neem biodiesel's impact on engine efficiency and emissions, emphasizing blends ranging from B10 to B20. Engine performance tests show improvements in specific fuel consumption and brake thermal efficiency with increasing load. Compared to pure diesel, these blends exhibit reduced hydrocarbons, carbon monoxide, and smoke opacity, though nitrogen oxides increase with load. Overall, the study highlights neem biodiesel as a viable and efficient alternative to traditional diesel, offering enhanced engine performance and reduced emissions.

Very few literature is available on lower blends of biodiesel and its use in diesel engine. B20 and higher biodiesel blends are not satisfying the existing stringent emission norms so its worth to work with lower blends of biodiesel i.e. B5, B7, B10.

2. Production of algae biodiesel

The initial step in determining the viability of a parent oil for use as biodiesel alongside traditional diesel fuel involves the measurement of its acid value. A crucial criterion for biodiesel suitability is that the acid value of the oil should typically fall within the range of 0.5 milligrams to 6 milligrams. In the case of algae-based oil, the measured acid value is 0.561, which comfortably falls within this acceptable range. Another pivotal property to consider is viscosity. Elevated viscosity beyond a certain threshold can lead to issues like filter clogging. To mitigate this concern, it is imperative to reduce the viscosity through an appropriate process. Among the various techniques employed in practice, the transesterification process

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stands out as the optimal method. This process involves converting the parent oil into biodiesel, adjusting its viscosity to closely match that of diesel fuel.

For the transesterification process, an ultrasonic bath method is employed, as illustrated in Figure 1. The resulting mixture is then placed in a separator for 24 hours to facilitate the separation of the ester component, as depicted in Figure 2. Ester, characterized by its lower density, remains at the upper layer. After this, a water wash is conducted using a centrifuge machine at 3000 rpm for 5 minutes. The resulting mixture is transferred to a separating funnel for a designated duration, as shown in Figure 3, to yield FAME (Fatty Acid Methyl Ester), commonly referred to as B100, as illustrated in Figure 4.

The transesterification reaction unfolds as follows:

$$\text{Triglycerides} + \text{Methanol} \rightarrow \text{Glycerine} + \text{Methyl Esters}$$

During this process, triglycerides derived from the parent oil undergo conversion into methyl esters and glycerine in the presence of a catalyst, often potassium hydroxide. The methyl ester component, which is the essential portion, can then be blended in varying volumes to formulate algae biodiesel blends.

Fig. 1. Ultrasonic bath

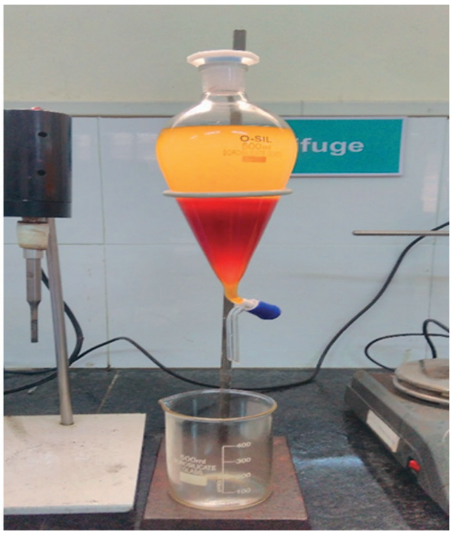

Fig. 2. Separating funnel

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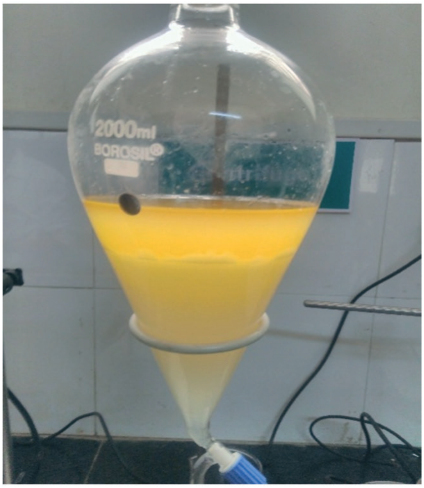

Fig. 3. After water wash

Fig. 4. Algae FAME B100

Following the production of algae FAME B100, the creation of blends is achieved through a magnetic stirring method. The resulting blends include B05, B07, B10, and B20. Several crucial properties of these blends, such as calorific value, flash point, cloud point, pour point, density, and viscosity, have been determined.

Calorific value of fuel is determined by using bomb calorimeter. 1 gram of fuel is burned in crucible of vessel and heat produced by combustion is equated with heat absorbed by water in calorimeter to get calorific value. Cloud point is the minimum temperature at which the first crystal formation starts. Pour point is the minimum temperature below which a liquid loses its flow characteristics. The cloud and pour points of the biodiesel and diesel fuel are tested by cloud and pour point apparatus. The Redwood viscosity value is the number of seconds required for 50 ml of oil to flow out of a standard viscos meter at a definite temperature. Flash point is the lowest temperature, at which the application of an ignition source causes the vapour of the fuel ignite momentarily and the flame to propagate across the surface of the liquid under the specified conditions of test. Flash point is determined with Pensky Martens apparatus.

The properties of these various algae biodiesel blends and conventional diesel fuel are summarized in Table 1.

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Tab. 1. Properties of lower blends of algae biodiesel

Property	Density [kg/m³]	Calorific value [kJ/kg]	Viscosity [mm²/sec]	Cloud point [⁰C]	Pour point [⁰C]	Flash point [⁰C]
B00	830	42000	2.60	- 4.0	- 9	55
B05	833	41840	2.75	- 2.0	- 5	49
B07	836	41750	2.85	- 1.5	- 3	42
B10	840	41510	3.10	- 1.0	- 3	42
B20	843	41480	3.30	1.0	-2.5	51
Ref Std ASTM	D1448	D6751	D445	D2500	D2500	ASTM D93
Instrument	hydrometer	bomb calorimeter	Redwood viscometer	Cloud point apparatus	Pour point apparatus	Pensky Martens apparatus

3. Experimental set up and procedure

The experimental setup comprises a computerized, single-cylinder, four-stroke, vertical, constant-speed, water-cooled diesel engine. The arrangement of the components is illustrated in Figure 5. To apply a load to the engine, an eddy current dynamometer is employed. The measurement of the rotational torque applied to the engine casing is accomplished using a strain gauge type load cell. Additionally, a crank angle sensor is utilized to monitor the crankshaft's rotational speed. To measure temperatures at various locations, PT100-Type K Resistance Temperature Detectors (RTD) are used.

Furthermore, an emissions gas analyser equipped with five channels is used to measure diverse concentrations, including CO, HC, CO_2, O_2, and NO_x. Data acquisition is facilitated by the Engine Soft software. Detailed specifications of both the engine and dynamometer can be found in Table 2.

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Fig. 5. Experimental test rig

Tab. 2. Specification of engine test rig

Descriptions	Specifications
Product	computerized single cylinder, 4 stroke, water cooled diesel engine
Make and capacity	Kirloskar 661 cc.
Bore and stroke	87.5 mm and 110 mm
Compression ratio	18:1
Power	5.2 kW at 1500 rpm
Torque measurement	eddy current type dynamometer – water cooled, Make-Saj
Dynamometer torque at speed	11.5 Nm at 6000 rpm
Crank angle sensor	resolution 1 deg, speed 5500 rpm
Data acquisition device	NI USB-6210, 16-bit, 250 kS/s
Temperature sensor	RTD Type K, PT100
Load sensor	load cell, strain gauge type, range 0–50 kg
Software for performance analysis	engine soft

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4. Results and discussions

Figures 6–9 show the results of torque, brake power, brake thermal efficiency and brake specific fuel consumption tests depending on the engine load and the type of test fuel.

Torque is a critical measure of the force responsible for initiating rotational movement in a shaft along a defined axis. It is worth noting that torque exhibits a direct correlation with the applied load, with the highest values typically attained under full load conditions. Specifically, for B5 fuel blend, torque reaches its peak, surpassing the performance of other blends. In the context of half-load conditions, torque experiences a modest increase ranging from 3% to 5% when compared to its counterpart, diesel, as shown in Figure 6. It is essential to emphasise that these findings reveal only minimal fluctuations in torque.

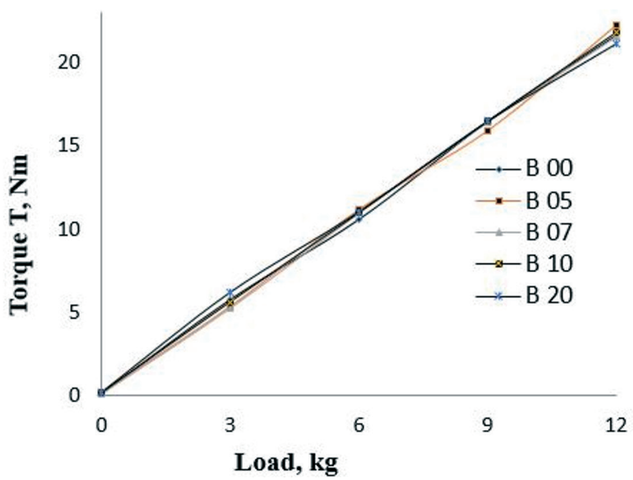

Fig. 6. Torque as a function of load

Brake power represents the power accessible at the engine's crankshaft. It is noteworthy that under no-load conditions, the brake power remains consistent across all fuel blends. However, when operating at partial and full load conditions, we observe slight variations in brake power for all blend types. There is a discernible enhancement in performance, as visually demonstrated in Figure 7.

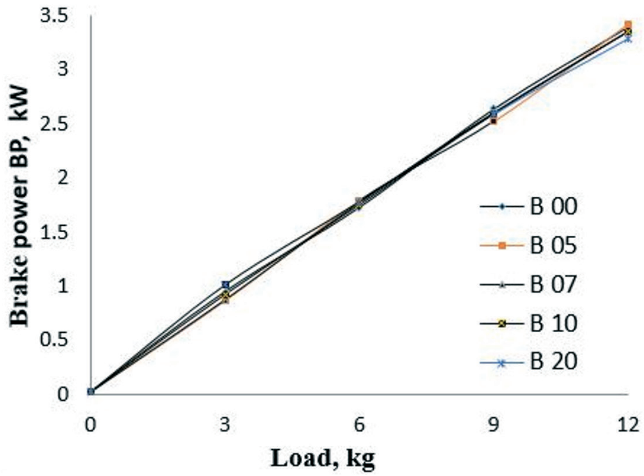

Fig. 7. Brake power as a function of load

The brake thermal efficiency, calculated as the ratio of obtained brake power to fuel power, serves as a crucial indicator of fuel efficiency. Higher values of brake thermal efficiency signify lower fuel consumption rates, making it an essential metric for assessing engine performance. We particularly observed increase in brake thermal efficiency, indicating improved fuel efficiency. Additionally, under full load conditions, specific biodiesel blends, such as B05, B07, B10, and B20, exhibit superior brake thermal efficiency compared to diesel. These blends outperform diesel by 2%, 6%, 8%, and 13%, respectively, as shown in Figure 8.

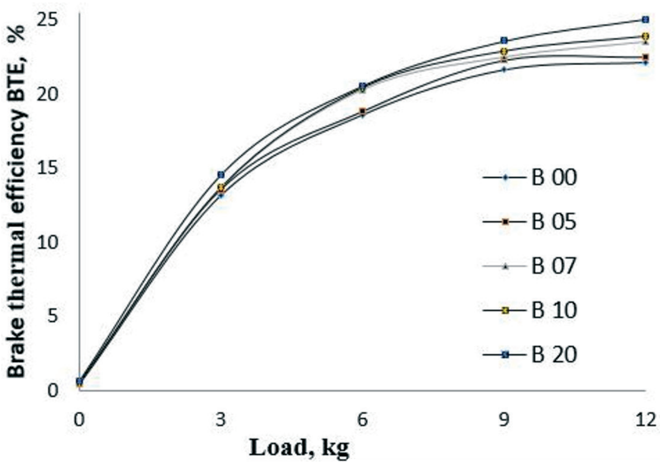

Fig. 8. Brake thermal efficiency as a function of load

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Despite the fact that algae-based biodiesel blends possess slightly lower calorific values than traditional diesel, there is a noteworthy enhancement in brake thermal efficiency. This improvement can be attributed to the high Cetane number of biodiesel blends derived from algae. Algae biodiesel is rich in saturated fatty acid esters, contributing to their elevated Cetane numbers and, consequently, enhanced engine performance and fuel efficiency.

Brake specific fuel consumption (BSFC) is a measure of fuel consumption in kilograms per unit of brake power output. A lower BSFC value signifies that the engine requires a smaller amount of fuel to generate a given amount of power. When examining blends B05, B07, B10, and B20, we observe a reduction in BSFC compared to diesel, with reductions of 5%, 10%, 2%, and 5%, respectively, as illustrated in Figure 9.

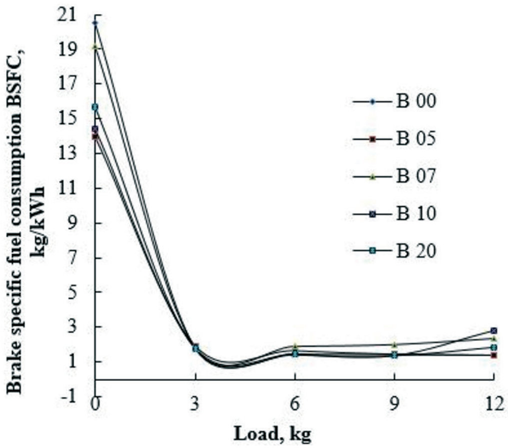

Fig. 9. Brake specific fuel consumption as a function of load

Notably, the B07 blend stands out by achieving an optimal BSFC condition, indicating that it delivers the most efficient fuel consumption performance of all the tested blends.

Figures 10–13 shows the results of hydrocarbon, carbon monoxide, carbon dioxide and nitrogen oxide emissions tests depending on the engine load and the type of test fuel.

Incomplete combustion of fuel leads to the presence of hydrocarbons in exhaust gases. The concentration of these hydrocarbons is typically measured in terms of parts per million (PPM) of carbon atoms. Elevated levels of hydrocarbons in the atmosphere can have detrimental effects on human health and contribute to the formation of smog. When considering blends B05, B07, B10, and B20, significant reductions in hydrocarbon concentration are evident, with decreases of 58%, 66%, 80%, and 90%, respectively, as clearly depicted in Figure 10. It is important to note that both lower blends and the B20 blend exhibit substantial reductions in hydrocarbon concentration, highlighting their environmental advantages.

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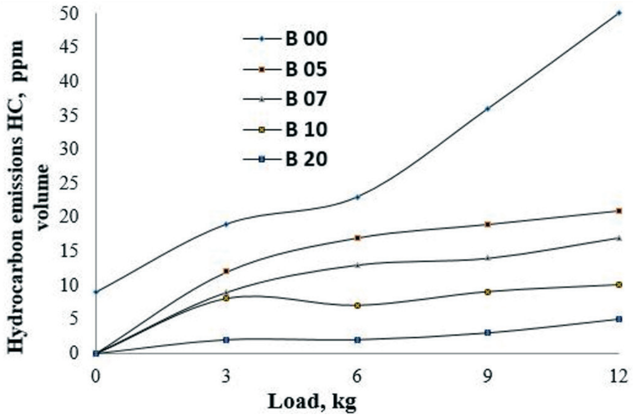

Fig. 10. Hydrocarbon emissions as a function of load

Lower blends of algae biodiesel can contribute to reduced HC emissions for several reasons such as oxygen content in fuel itself, higher cetane number compared to petroleum diesel, indicating better ignition quality. So blending improves the overall combustion efficiency of the fuel, thereby lowering HC emissions.

Elevated levels of carbon monoxide (CO) in exhaust gases stem from incomplete fuel oxidation, posing health risks such as headaches, dizziness, and lethargy when released into the atmosphere. Significant reductions in CO concentration are evident, with reductions of 16%, 27%, 32%, and 41% observed for B5, B7, B10, and B20 blends, as illustrated in Figure 11.

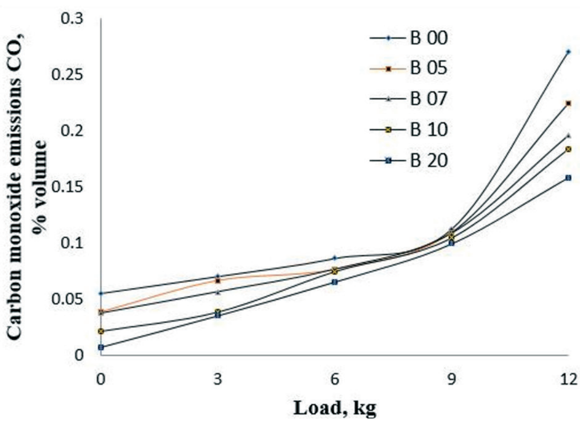

Fig. 11. Carbon monoxide emissions as a function of load

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This remarkable reduction in CO concentration can be attributed to the higher oxygen content in the fuel bonds of algae biodiesel blends, which is consumed more effectively during combustion. Consequently, algae biodiesel blends achieve more complete combustion compared to conventional diesel, resulting in substantially lower percentages of both hydrocarbons (HC) and carbon monoxide (CO) in the exhaust gases.

Carbon dioxide (CO_2) emissions in exhaust gases result from the complete combustion of fuels within an internal combustion engine. Diesel fuel typically contains slightly more carbon than petrol, and CO_2 is a significant greenhouse gas with a substantial impact on the atmosphere. There is an increase of 3%, 6%, 6.5%, and 10% in CO_2 concentration observed for B5, B7, B10, and B20 blends, respectively, when compared to diesel, as depicted in Figure 12.

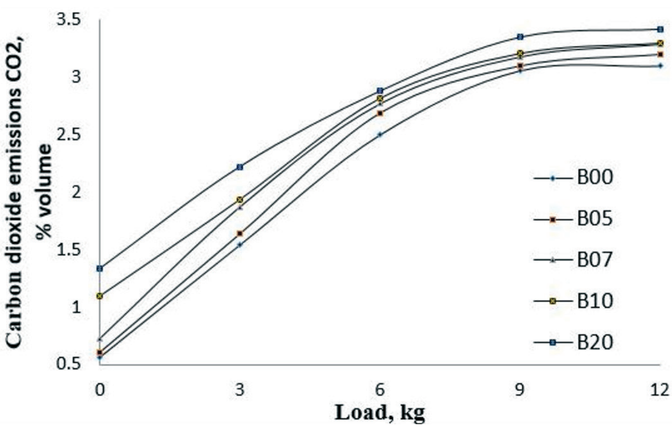

Fig. 12. Carbon dioxide emissions as a function of load

Biodiesels are oxygenated fuel which promotes more extensive carbon oxidation which promotes more extensive carbon oxidation during combustion, resulting in higher CO_2 emissions in the exhaust.

Nitrogen oxide (NO_x) emissions play a significant role in the formation of smog and are typically associated with high-temperature combustion reactions or high loading conditions in engines. When considering NO_x emissions for B5, B7, B10, and B20 blends, it becomes apparent that they are higher than those for diesel, with increases of 7%, 14%, 21%, and 24%, respectively, as depicted in Figure 13.

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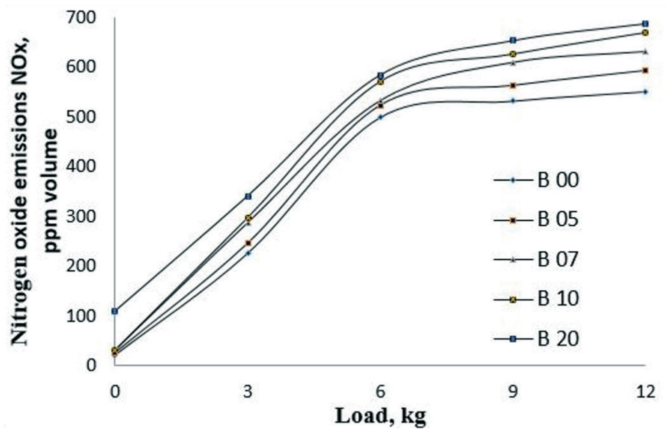

Fig. 13. Nitrogen oxide emissions as a function of load

This increase in NO_x concentration can be attributed to the rise in temperature as the loading increases. Elevated temperatures lead to higher NO_x concentration in the exhaust gases. When adequate oxygen is available, it facilitates complete combustion, subsequently raising the temperature of the reaction products and increasing the NO_x formation.

5. Uncertainty analysis

In engine testing, certain quantities are measured and then various parameters are determined from the measured data. Uncertainty (U) is associated with every measured quantity. When we finalise different parameters, it leads to an uncertainty in the derived result. Thus, it is essential to understand uncertainty in the final result from measurement uncertainties. Measured uncertainty is either due to use of particular instrument or human error. Uncertainty can be calculated using well verified statistical procedure so that it will describe quantity variation in output due to variation in input.

Let UX1, UX2......UXn be uncertainties in variables X1, X2, X3.........Xn. The uncertainty in result can be computed as absolute limit on uncertainties:

$$UR = \left|\frac{\partial R}{\partial X1}(UX1)\right| + \left|\frac{\partial R}{\partial X2}(UX2)\right| + \left|\frac{\partial R}{\partial X3}(UX3)\right| + \ldots\ldots\ldots + \left|\frac{\partial R}{\partial Xn}(UXn)\right| \tag{1}$$

When errors are with statistical tolerance, the probable error is modified in the above equation. The value lies somewhere within range which is specified by uncertainty. It is given by (2).

$$\frac{Uy}{y} = \sqrt{\left[\left(\frac{UX1}{X1}\right)^2 + \left(\frac{UX2}{X2}\right)^2 + \left(\frac{UX3}{X3}\right)^2 + \ldots\ldots\ldots\ldots\left(\frac{UXn}{Xn}\right)^2\right]} \tag{2}$$

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Where X1, X2, X3, …….. Xn are testing values of parameters and Uy is uncertainty.

Uncertainty calculated as described above for various performance parameters is as shown in Table 3.

Tab. 3. Uncertainty in various performance parameters

Parameter	Uncertainty [%], full load (12 kg)
Brake power	1.71
Brake mean effective pressure	2.24
Brake thermal efficiency	1.86
Brake specific fuel consumption	1.86
Volumetric efficiency	1.47
Heat carried by gas	0.74

Carbon monoxide and carbon dioxide ingredients in exhaust gas measured with NDIR (Non dispersive infrared analyser) hydrocarbon is measured with FID (Flame ionisation detector). No_x is measured with standard CLA analyser.

Uncertainty in emission calculated as above is shown in Table 4.

$$Uncerta\,\mathrm{int}\; y.in..emission = \frac{\mathrm{Re}\,solution}{Range}$$

Tab. 4. Uncertainty in emission content

Emission content	Resolution of gas analyser	Uncertainty [%]
Carbon monoxide	0.001%	0.006
Carbon dioxide	0.01%	0.05
Hydrocarbon	1 ppm	0.003
Oxides of nitrogen	1 ppm	0.02

6. Conclusion

The brake power under no-load conditions remains nearly consistent for all blends. However, at partial and full load conditions, there is a slight variation in brake power for all blends with a compression ratio of 18:1. The compression ratio of 18:1 yields the highest brake thermal efficiency. Brake specific fuel consumption experiences a slight increase from B5 to B20 blends, with the B07 blend demonstrating optimal conditions for brake-specific fuel consumption. HC concentration exhibit a significant reduction percentage when compared to diesel fuel, particularly for blends B05, B07, B10, and B20. Considerable reductions are also observed in CO concentration for lower blends compared to diesel. The percentage decrease is more

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pronounced for higher compression ratios due to the accelerated mixing rate of biodiesel and the higher presence of oxygen. CO_2 concentration are higher for lower blends, while an increase in NO_x concentration is noted for all lower blends compared to diesel.

In summary, the findings suggest that B05 and B07 blends show promise in terms of reduced HC and CO concentration. After considering the performance and emissions of lower blends, along with the comparison of B20 blend with diesel, the B7 blend is deemed suitable for use in diesel engines.

7. Nomenclature

BP brake power
BTE brake thermal efficiency
BSFC brake specific fuel consumption
BS Bharat stage
CR compression ratio
CO carbon monoxide
CO_2 carbon dioxide
COME corn oil methyl ester
FAME fatty acid methyl ester
FID flame ionization detector
HC hydrocarbon
NDIR non dispersive infrared
PPM parts per million
PM particulate matter
RTD resistance temperature detector
U uncertainty
VCR variable compression ratio

8. Acknowledgements

The authors thank PVG's COET, research centre Pune.

9. Declaration

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

https://doi.org/10.14669/AM/189510

10. References

[1] Abedin MJ, Kalam MA, Masjuki HH, Sabri MFM. Production of biodiesel from a non-edible source and study of its combustion, and emission characteristics: A comparative study with B5. Renewable Energy. 2016;88:20–29. https://doi.org/10.1016/j.renene.2015.11.027.

[2] Abed KA, Gad MS, El Morsi AK, Sayed MM, Elyazeed S.Abu. Effect of biodiesel fuels on diesel engine emissions. Egyptian Journal of Petroleum. 2019;28(2):183–188. https://doi.org/10.1016/j.ejpe.2019.03.001.

[3] Ashwin J, Ashok B, Alagumalai A, Chyuan OH, Le PTK. Critical review on third generation micro algae biodiesel production and its feasibility as future bioenergy for IC engine applications. Energy Conversion and Management. 2021;228:113655. https://doi.org/10.1016/j.enconman.2020.113655.

[4] Azad AK, Halder P, Wu Q, Rasul MG, Hassan NMS, Karthikeya V. Experimental investigation of ternary biodiesel blends combustion in a diesel engine to reduce emissions. Energy Conversion and Management. 2023;20:100499. https://doi.org/10.1016/j.ecmx.2023.100499

[5] Canakci M, Alptekin E. Determination of the density and the viscosities of biodiesel – diesel fuel blends. Renewable Energy. 2008;33:2623–2630. https://doi.org/10.1016/j.renene.2008.02.020.

[6] Dhande DY, Navale SJ. Experimental investigations on the performance and emissions of compression ignition engine fuelled with lower blends of neem-based biodiesel. Archives of Automotive Engineering–Archiwum Motoryzacji. 2024;103(1):57–76. https://doi.org/10.14669/AM/186109.

[7] Faried M, Samer M, Abdel Salam E, Yousef RS, Attia YA, Ali AS. Biodiesel production from microalgae: Processes, technologies and recent advancements. Renewable and sustainable energy reviews. 2017;79:893–913. https://doi.org/10.1016/j.rser.2017.05.199.

[8] Giridharan R, Rajan VA, Krishnan RB. Performance and emission characteristics of algae oil in diesel engine. Materials Today: Proceedings. 2021;37(2):576–579. https://doi.org/10.1016/j.matpr.2020.05.591.

[9] Karavalakis G, Johnson KC, Hajbabaei M, Durbin TD. Application of low-level biodiesel blends on heavy-duty (diesel) engines: Feedstock implications on NOx and particulate emissions. Fuel. 2016;181:259–268. https://doi.org/10.1016/j.fuel.2016.05.001.

[10] Kesharvani St, Dwivedi G. Algae as a feedstock for biodiesel production in Indian perspective. Materials Today: Proceedings. 2021;47:5873–5880. https://doi.org/10.1016/j.matpr.2021.04.295.

[11] Mahendran J, Saravanan K, Ragulnath D. Performance and emission characteristics of algae derived biodiesel processes. Materials Today: Proceedings. 2020;21:268–271. https://doi.org/10.1016/j.matpr.2019.05.427.

[12] Nair JN, Kaviti AK, Daram AK. Analysis of performance and emission on compression ignition engine fuelled with blends of neem biodiesel. Egyptian Journal of Petroleum. 2017;26(4):927–931. https://doi.org/10.1016/j.ejpe.2016.09.005.

[13] Nautiyal P, Subramanian KA, Dastidar MG, Kumar A. Experimental assessment of performance, combustion and emissions of a compression ignition engine fuelled with Spirulina platensis biodiesel. Energy. 2020;193:116861. https://doi.org/10.1016/j.energy.2019.116861.

[14] Ropkins K, Quinn R, Beebe J. Real-world comparison of probe vehicle emissions and fuel consumption using diesel and 5% biodiesel (B5) blend. Science of the Total Environment. 2007;376(1–3):267–284. https://doi.org/10.1016/j.scitotenv.2006.11.021.

[15] Roy MM, Wang W, Alawi M. Performance and emissions of a diesel engine fuelled by biodiesel–diesel, biodiesel–diesel-additive and kerosene–biodiesel blends. Energy conversion and management. 2014;84:164–173. https://doi.org/10.1016/j.enconman.2014.04.033.

[16] Sathyamurthy R, Balaji D, Gorjian Shiva, Jenoris Muthiya S, Bharathwaaj R, Vasanthaseelan S, et al. Performance, combustion and emission characteristics of a DI-CI diesel engine fuelled with corn oil methyl ester biodiesel blends. Sustainable Energy Technologies and Assessments. 2021;43:100981. https://doi.org/10.1016/j.seta.2020.100981.

https://doi.org/10.14669/AM/189510

[17] Subramaniam MK, Solomon JM, Nadanakumar V, Anaimuthu S, Sathyamurthy R. Experimental investigation on performance, combustion and emission characteristics of DI diesel engine using algae as a biodiesel. Energy Reports. 2020;6:1382–1392. https://doi.org/10.1016/j.egyr.2020.05.022.

[18] Yasin MHM, Paruka P, Mamat R, Yusop FA, Najafi G, Alias A. Effect of Low Proportion Palm Biodiesel Blend on Performance, Combustion and Emission Characteristics of a Diesel Engine. Energy Procedia. 2015;75:92–98. https://doi.org/10.1016/j.egypro.2015.07.145.