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Research Article

Investigating the effect of an oxygenated additive in diesel engines fuelled with bio-fuel blends from chlorella emersonii

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Abstract

Recent environmental concerns raise fuel prices; hence we need the alternative petroleum source product. Currently, biodiesel is commercially produced from jatropha, cotton seeds, pongamia, mustard, chlorella emersonii (CE) seeds poses operational problems due to some of the lower calorific values, physical and chemical operation, and durability issues due to lower calorific value. In the current investigation, CE oil is adopted to generate CE Methyl Ester (CEME), while higher alcohol butanol is used. The performance of single-cylinder C.I engine at a steady speed of 1500 rpm using various blends of B1 (100% CE bio-fuel), B2 (80% volume of biodiesel and 20% volume of butanol), B3 (80% vol of biodiesel, 10% volume butanol, and 10% volume of distilled water) and diesel. This engine output, such as brake-specific fuel consumption (BSFC), brake thermal efficiency (BTE), and exhaust emission characteristics such as carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbon (HC) was measured for different load conditions. Also, the smoke opacity, exhaust gas temperature (EGT), cylinder pressure, ignition delay (ID), and heat release rate (HRR) were measured. The findings were positive for the efficient usage of biodiesel with the introduction of butanol and offset a portion of the rising energy demand properties.

Keywords

Chlorella emersonii, Methyl ester, Butanol, Biofuel.

1.Introduction

The world is extremely concerned about the security of oil supplies and their continuous availability due to the trend toward modernization and industrialization. In these circumstances, biofuel energy is crucial for boosting a nation's economy [1]. First-generation fuels are produced from sugar, starch, animal, or fat oil crops. Bio-fuels of the second century were created from non-food crops such as manure, wheat stalks, and maize. The most prevalent second-generation biofuels are wood diesel, bio-methanol, bio-hydrogen, and mixed alcohols [2]. Algal fuel, a third-generation biofuel, generates 30 times as much power as conventional crops. Bio-fuels have always been an essential source of power in the conventional sense. Almost half of the world's population, particularly in rural areas, still relies on bio-fuels to provide cooking energy even in the present times. However, modern bio-fuels (bio-ethanol and biodiesel) have gained prominence due to numerous commercial, geopolitical, and environmental factors. Therefore, wood, biofuels, and other renewable non-fossil fuels are commonly called bio-energy and achieve industrial maturity [3].

Biodiesel made from vegetable oil is not a new concept; Rudolf Diesel's original diesel engine was fuelled by peanut oil. Research studies documented multiple forms of biodiesel from vegetable oil, including sunflower, karanji, pungamia, soybean, rapeseed, jatropha curcas, and others [4−10]. Despite reducing emissions trends, such as a 90% drop in air toxicity and a 95% reduction in carcinogens [11] due to their high oxygen (O_2) content, renewable nature, and biodegradable characteristics [12], they have several restrictions. There are drawbacks of employing edible vegetable oil as a substitute feedstock, such as the significant challenges of the global market for consumable foods, dangers to food security, and poverty in some developing nations [13]. So, if the supply is non-edible feedstock, it is preferable to find an adequate substitute feedstock that will not deplete the current vegetable oil cache [14−16]. Hence the motivation of this work is to

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identify suitable algae-based biofuel for the consumption of diesel engines.

Research on microalgae biodiesel has accelerated lately due to its appealing high lipid characteristics [17, 18]. Microalgae are aerobic organisms that can be found in freshwater and marine habitats that absorb sunlight, carbon dioxide (CO_2), and micronutrients into carbon-rich lipids [19]. Microalgae-based biodiesel has several advantages: it is a non-edible source with a greater oil output and algae that grows faster. Among other techniques, Microalgae-based biodiesel seems simple, more accessible, and cost-effective. This research aims to enhance the diesel engine's efficiency under the influence of a suitable chlorella emersonii methyl ester (CEME) biodiesel.

Section 2 illustrates a literature review to highlight the key aspects of the engine performance when using algae-based biodiesel as a fuel. The strategy used by the authors to gather the necessary experimental data is described in Section 3. The acquired results are graphically displayed in Section 4. The main conclusions and limits of the current study are elaborated in Section 5, the attempted research effort is concluded, and the potential for future study is highlighted in Section 6.

2.Literature review

Several studies have been conducted on microalgae biodiesel production and its economic viability and uses [18−21]. In a diesel engine, Haik et al. [22] employed algal oil derived from Nannochloropis sp. and Ankistrodesmus braunii. Algal oil methyl ester (AOME) usage resulted in a faster heat release rate (HRR), reduced combustion noise, and lower engine torque than diesel fuel. Scragg et al. [23] studied a biodiesel blend generated from the microalgae chlorella vulgaris with emulsion in a diesel engine. Compared to diesel and neat biodiesel blends, the emulsion fuel produces decreased NOx, exhaust gas temperature (EGT), and CO_2, but increased CO, O_2, and net performance levels were concluded.

Tsaousis et al. [24] compared the possibilities of biodiesel obtained from tetraselmis suecica, coastal chlorophyte algae, to croton oil (crotonisoleum). In contrast to croton oil, they discovered that algal oil had higher brake-specific fuel consumption (BSFC), smoke, and particles and reduced NOx and engine performance. In a diesel engine, Jayaprabhakar and Karthikeyan [25] compared the feasibility of employing AOME generated from Gracilaria verrucosa to rice bran methyl ester (RBME) at various injection techniques. Compared to rapeseed methyl ester (RME), aircraft maintenance engineering (AME) produced lower brake thermal efficiency (BTE), volumetric performance, smoke, unburnt hydrocarbon (UBHC), and higher NOx and BSFC levels. It was discovered that mixing 20% AME with diesel can help improve engine efficiency when marginally advanced injection timing. Islam et al. [26] tested the performance of methyl ester generated from marine algae of the dinoflagellate family (crypthecodinium cohinii) with petroleum diesel in a four-cylinder turbocharged diesel engine and waste cooking oil-diesel blends. Combining algal oil biodiesel with diesel up to 50% can increase efficiency and emission wavelength.

Makareviciene et al. [27] compared the performance of microalgae-based AOME and RME in engine. In contrast to diesel fuel, they advocated combining methyl esters, which had lower density, viscosity, calorific value, and oxidation stability and reduced hydrocarbon (HC), CO, and smoke emissions with identical NOx scenarios. In a single-cylinder diesel engine, Satputaley et al. [28] explored microalgae oil generated from Chlorella protothecoides. They discovered that adding methyl ester to microalgae oil reduced BTE and cylinder pressure. In contrast to Diesel, HC, CO, NOx, and smoke levels were decreased for microalgae oil-based methyl ester fuels.

Patil et al. [29] have employed AOME in a diesel engine to evaluate the performance optimization of nozzle geometry and compression ratio. Four biodiesel blends were prepared with varied propositions of biodiesel. Density and viscosity of biodiesel were discovered to be similar to diesel properties. The blend prepared with 40% biodiesel and 60% diesel combination outperforms other blends in terms of BTE and smoke emissions. The operational settings were adjusted to achieve complete combustion of biodiesel.

Subramaniam et al. [30] investigated the biodiesel made from Azolla pinnata algae and tried it in DI diesel engine. A20 exhibits closer estimates with diesel, which results in higher BTE and reduced emissions of HC, CO, smoke, and particles among the other blends tested. However, other emissions, such as nitrogen oxide and CO_2, were slightly higher. Elkelawy et al. [31] used biodiesel extracted from Scenedesmus obliquus algae and n-pentane additive to evaluate the performance test in the diesel engine. The engine efficiency of a biodiesel combination that included pentane was substantially better than that of pure diesel.

Ge et al. [32] examined the impact of bio-oil extracted from the Schizochytrium on diesel engines. The biofuel increased BTE and decreased hazardous gas emissions, except for NOx, to boost efficiency. Said et al. [33] experimented with the performance attributes of a diesel engine operating in tri-fuel conditions with micro AOME-diesel blends and oxyhydrogen gas combination. Except for nitrogen oxide emissions, the combustion of an algae biodiesel-diesel-oxyhydrogen-powered diesel engine was greatly enhanced by including oxyhydrogen in fuel economy and usage.

Ranjithkumar et al. [34] studied diesel engines' performance and emission attributes using Micro Algae Methyl Ester biodiesel as an alternate fuel. In comparison to diesel, it has better combustion and emission responses. Karthikeyan et al. [35] investigated the CI engine running with S. Marginatum macroalgae biodiesel/diesel blends. It has been found that biodiesel B20 blend combustion is more successful at high and part load conditions than under lower load conditions.

Karthikeyan et al. [36] have considered Stoechospermum marginatum macroalgae species along with Al_2O_3 nanofluid for research work on emission analysis of CI engine. Al_2O_3 nano-particles were added to B20 gasoline, improving engine performance as load power increased and BSFC decreased. A more significant decrease in CO, HC, and smoke levels was also identified. Saraswat and Chauhan [37] explored the possibilities of butanol and algal oil as alternative fuels for SI engines utilizing gasoline-butanol and gasoline-algae oil mixes. Algae fuel has decreased BTE while increasing BSFC, NOX, and CO emissions.

Subramani et al. [38] have evaluated the influence of adding Butylated hydroxytoluene anti-oxidants to an algae biodiesel blend, together with a change in fuel injection timing, on the emission control of a CI engine. According to the findings, anti-oxidant plays the most prominent role in reducing engine NOx emissions when using an algal biodiesel blend, followed by injection time, which is equally essential to smoke control and BTE. Rajak et al. [39] have worked on the effects of the spirulina microalgae (SMA) biofuel in a diesel engine at various loads. The findings demonstrated that including SMA reduced BTE and exhaust heat while increasing CO_2 emission.

Ge et al. [40] investigated the impact of the Botryococcus braunii microalgae along with the diesel. According to the results, adding microalgae blends with nano-particles improves BTE compared to neat diesel. Furthermore, due to the viscosity of the blends, the BSFC was accurately lowered. The combination of mixed fuel and nano-particles boosts the cylinder pressure and HRR. There was a noticeable decrease in CO, HC, and CO_2 emissions. Therefore, given the engine speed for the B30 mix, NOx emissions are still very high.

Krishania et al. [41] examined diesel engine emission variables using a mix of Jatropha, tyre pyrolysis oil, and SMA biofuel. The outcome demonstrates a reduction in smoke, PM, and NOX emission. Selvan et al. [42] have investigated twelve different blends of ethanol and oils extracted from algae, cotton seed, and eucalyptus. Comparatively, CO2, CO, NOx, and smoke emissions were reduced. Boomadevi et al. [43] investigated SMA biofuel with Jet-A fuel at different proportions. It was concluded that biofuel in a lesser proportion to the Jet–A fuel generated a satisfactory result. Kulanthaivel et al. [44] have conducted experimental evaluations in a diesel engine using Chlorella Vulgaris algae biodiesel and anhydrous ethanol. It was discovered that certain fuel mixtures' thermal efficiency under particular operational settings exceeded those of commercial diesel when the injection advance was set at 10.5º bulk thermal desorption chamber (BTDC).

Hossain et al. [45] investigated the effect of two synthesized blends on engine efficiency, combustion, and emission with fresh water microalgae high-level transistor logic (HTL) bio-crude called Scenedesmus sp. According to the current study, 25% and 50% algae blends might be suitable replacement fuels for diesel engines. Satputaley et al. [46] employed biodiesel from microalgae chlorella vulgaris to measure the CI engine's performance and combustion variables. The findings of tests using algal oil and algae biodiesel in diesel engines are similar to those obtained with diesel fuel. Researchers tried several strategies to increase the performance of diesel engines. Sequentially, they have validated the impact of various algal-based biofuels on the efficiency of diesel engines. To analyze the above literature review, we found that only limited work has been reported on the performance analysis of a CEME algal-based biofuel in diesel engines.

This study examines the potential of using CEME as an alternative fuel for diesel engines. The cultivated algae species were used to extract the chlorella emersonii (CE) oil. Then the CE oil is converted to CEME with the transesterification process. Test performance was conducted using CEME oil and analyzed through engine characteristics, regulated and unregulated emissions for four tests, namely, B1 (100 % CE), B2 (80% CE and 20% butanol), B3 (80% CE, 10% butanol, 10% distilled water) and diesel. Outputs were impressive as the CEME blends lowered the emissions, and behavior was closer to diesel concerning better performance and emission particulars.

3.Methods

3.1Algal biodiesel preparation

The experimental procedure followed in this paper is mentioned below as a step-by-step process.
Step 1: Growth and culture medium
Step 2: Biomass and oil extraction
Step 3: Transesterification methyl ester process
Step 4: Test fuel preparation

The raceway pond was combined with a paddlewheel to produce biodiesel in this research. The algae were now crushed and mashed using a machine. Algae oil is obtained from the combination above using soxhlet equipment and a hexane and ether solution. The blend was eventually given 24 hours to settle. After filtering and measuring the weight, the algal oil was recovered from the feedstock using vacuum evaporation and a rotary evaporator to liberate the accumulated hexane and ether solvents.

The equipment required to develop CEME included a thermometer, a condenser, a magnetic stirrer, a sample output device, and a 2-liter reactor. The acid-base catalyst technique was used to prepare biodiesel. To begin, the moisture is removed from the raw algal oil by heating it to 650°C in a rotating evaporator under a vacuum. A mixture of 6:1 molar methanol to raw oil and 1.5 percent sulphuric acid was processed with aforesaid pre-heated raw oil and agitated for 1 hour at 650ºC at 600rpm for transesterification. The esterified oil was extracted using a funnel separator from the alcohol, H_2SO_4, and contaminants. The extracted esterified oil was heated to 650°C for 1 hour to remove water and methanol in a rotary evaporator. Because the raw oil is quite viscous, transesterification is done after esterification to lower the viscosity further. For transesterification, the esterified oil was mixed with a 6:1 molar ratio of methanol to oil and 0.9 (wt. percent) of potassium hydroxide and swirled for 1 hour at 650ºC at 600rpm. The oil is then shifted to a funnel separator and left to settle for 24 hours. At the top layer, the end product CEME is formed, and settled glycerol is drained from the lower surface. The biodiesel contains several contaminants; these are eliminated by diluting it with distilled water and letting it an additional 24 hours to settle in the funnel separator. It is now possible to obtain pure biodiesel free of contaminants (*Figure 1*).

The biodiesel prepared for testing were B1 (100 % CE), B2 (80% CE and 20% butanol), and B3 (80% CE, 10% butanol, and 10% distilled water). B1 blend consists of 100% CEME, B2 consists of 80 % CEME + 20% butanol, and B3 consists of 80% CE+ 10% butanol+ 10% distilled water. The test biofuel blends were magnetically stirred for 30 minutes, and ultrasonication was done for 10 minutes. Then the test samples were checked for settling up to 96 hours and reported unsettled. Density, specific gravity, and calorific values were measured according to American society for testing and materials (ASTM) standards and mentioned in *Table 1*.

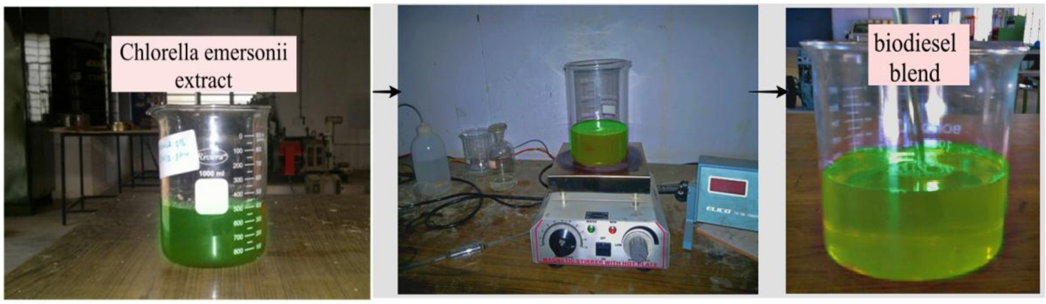

Figure 1 Extraction of Chlorella emersonii biodiesel for experiment

Table 1 Fuel blends characteristics

Fuel properties	**Density at 15°C Kg/m^3**	**Specific gravity**	**Calorific value MJ/Kg**
Diesel	832	0.840	45.5
B1 (100 % CE)	835	0.851	44.25
B2 (80% CE and 20% butanol)	838	0.856	43.625
B3 (80% CE, 10% butanol, 10% distilled water)	840	0.862	43

3.2Engine test procedure

Testing was performed on a Kirloskar engine (Make: Kirloskar), and the details are mentioned in *Table 2*. The outline view of the engine configuration is given in *Figure 2*. The engine is driven steadily at 1500 rpm and ensured with a non-contact optical sensor fixed beside the flywheel. Eddy current generators, electrical resistance sensors, and controllers were attached to the engine. The engine's voltage, current, and power were collected by the data acquisition system (DAS). The CO, CO_2, and HC content from the exhaust was examined with a gas analyzer. The exhaust gas was passed through the probe to the condensation filter to collect the moisture less gas. Then the moisture-less gas progresses to the non-dispersive infra-red (NDIR) sensor to determine the CO, CO_2, and HC emissions. The trial experiments were executed at 4 Kg load conditions of 2, 4, 6, and 8 Kg. Before using the blends, the engine started with diesel for 15 minutes to warm up. Also, testing the successive blends was permitted a 10-minute engine run with diesel to confirm entire fuel combustion. The trials were performed using four blends, diesel, B1, B2, and B3.

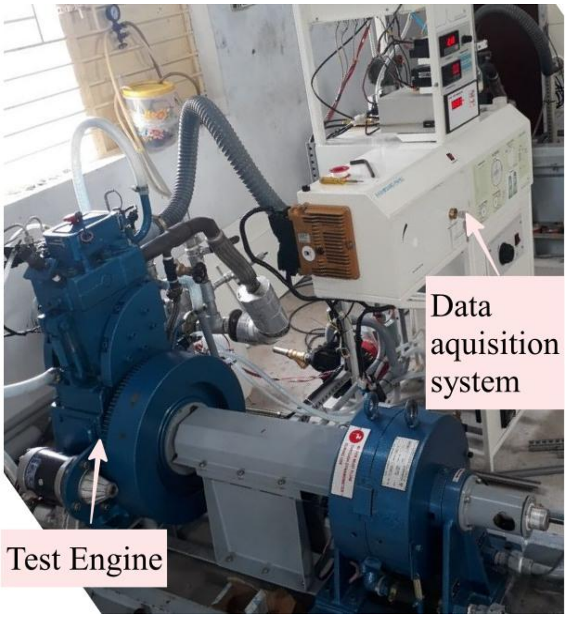

Figure 2 Engine setup layout

Table 2 Engine details

Make	Kirloskar
Stroke	4
Bore × Stroke	87.5 × 110 (mm)
Cylinder	1
Power	4.4 kW
Compression ratio	17.5 : 1
Injection time	23 deg. before TDC (static)
Nozzle hole diameter	0.3 mm
Nozzle quantity	3
Speed	1500 rpm
Nozzle hole angle	120 deg

4.Results

4.1Performance analysis

Figure 3 demonstrates the difference in the test engine's brake thermal output with different loads applied using CE blends and diesel. BTE values of B2 and B3 mixture are very close to that of diesel and higher than diesel in load condition of 6 Kg. Generally, pure biodiesel has lesser efficiency when compared to diesel. Brake power (BP) and BTE increase with higher load conditions due to increased fuel supply. Blends B2 and B3 have similar or better output on higher loads when compared with diesel. BTE for B2 and B3 is more elevated than B1 at higher load conditions.

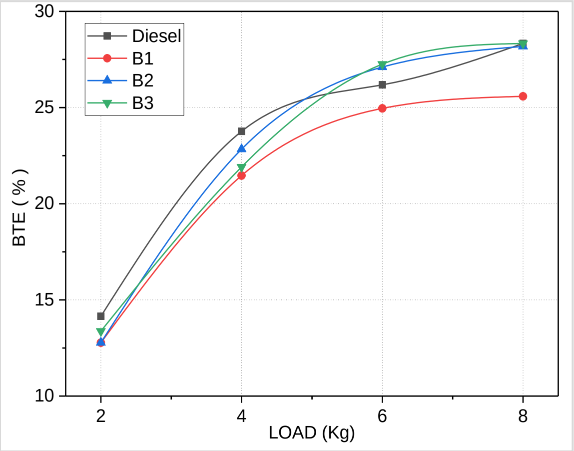

Figure 3 Break thermal efficiency (BTE) performance related to load conditions of engine using diesel and CE blends

Figure 4 demonstrates the variability of the standard fuel usage with different load conditions in the test engine for Chlorella emersonii blends with butanol. Specific fuel consumption of 100% Chlorella emersonii is very close to that of diesel, and in a load of 8 Kg, it is higher than the diesel. However, Chlorella emersonii 100% gives the best result. BSFC reduces with respective load for diesel and all blends. When the load increases, fuel supply increases to maintain combustion, and BSFC reduces. Chlorella emersonii B1 blend consumes higher BSFC than B2, B3, and diesel. On average, the BSFC was lower in the B3 blend.

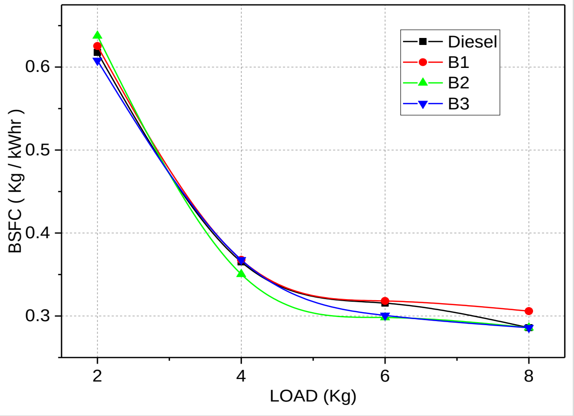

Figure 4 BSFC vs. applied load for CE blends and diesel

Figure 5 reveals the difference in brake power under various loads for CE blends with diesel in the test engine. The brake power of 20% butanol blend B2 is very close to that of diesel. BP of all three blends is slightly lesser than diesel on all load settings. The BP of all three blends is almost similar in all load conditions.

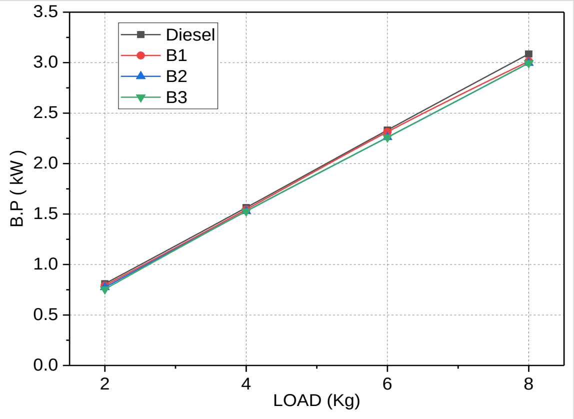

Figure 5 Brake power vs. load output for CE blends & diesel

Figure 6 shows variation in ignition delay (ID) of diesel and CEME blends. It has been shown that when the quantity of CEME in the blend increases, the ID increases. Compared to diesel fuel, B1 has a shorter ID when running at full load. As engine load increases, ignition latency reduces because of faster fuel-air mixing, higher engine cylinder temperature, diluted exhaust gases, and heat detention in earlier combustion cycles.

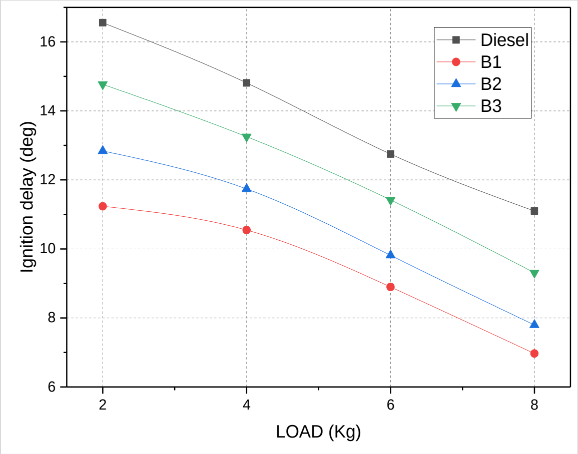

Figure 6 ID difference vs engine load

Figure 7 illustrates the cylinder pressure change according to crank angle for CEME blends and diesel. It was evident that the cylinder pressure of all CEME blends is significantly larger than diesel fuel. The diesel fuel has the lowest peak pressure, while the B1 blend has the most elevated peak pressure.

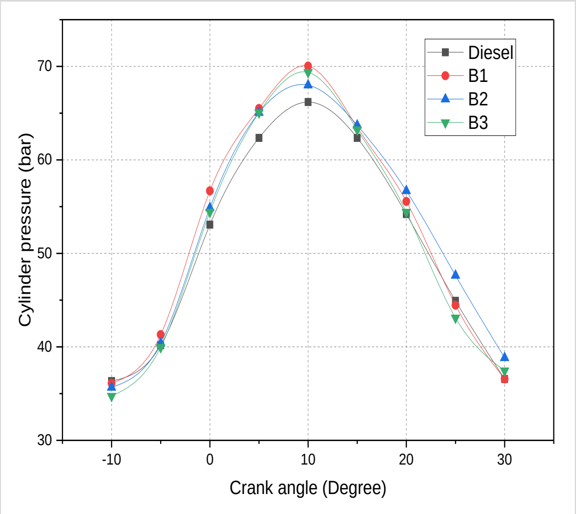

Figure 7 Cylinder pressure difference vs. crank angle

Figure 8 depicts the variation in HRR according to crank angle at various engine loads for all test fuels. It has been discovered that the amount of CEME in the blend significantly impacts the maximal HRR. The combustion of CEME diesel blends begins earlier. The fluctuation in exhaust temperatures for all test fuels is depicted in *Figure 9*. CEME mixes have a greater EGT than diesel fuel under all load conditions. EGT rises when the engine load rises because more gasoline is pumped into the cylinder chamber to keep the engine running steadily.

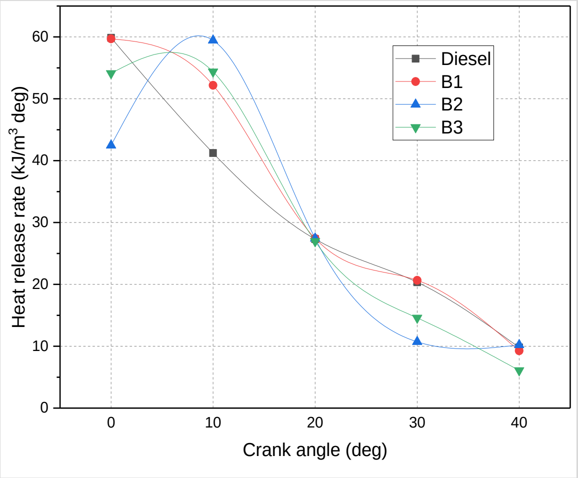

Figure 8 HRR variations vs. crank angle

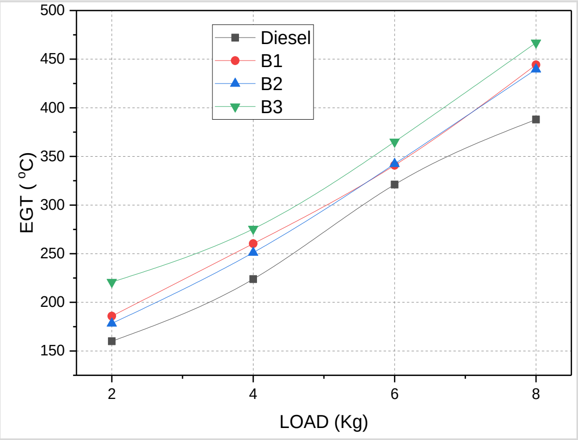

Figure 9 EGT difference vs. engine load

4.2Emission analysis

Figure 10 depicts the change in carbon monoxide emission with different loads for CE blends and diesel. 100% CE B2 had the lowest CO emission for all loads compared with diesel and other blends, owing to natural oxygen content [4]. Blend B3 releases lesser CO emissions than diesel on load conditions 4 and 6. However, it increased on the load condition of 8 Kg. The volume of CO on blend B2 was higher than diesel under all load conditions.

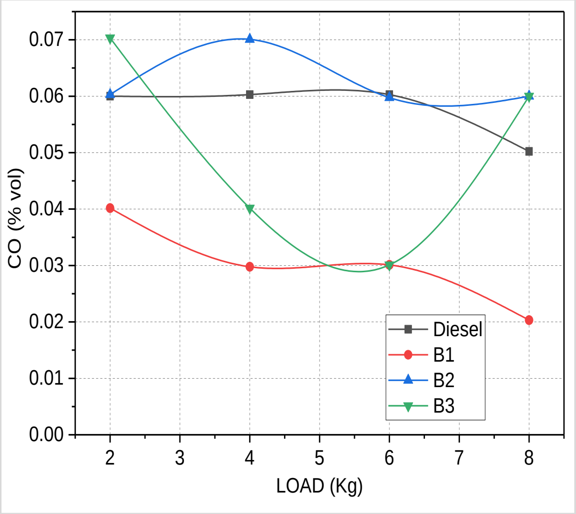

Figure 10 CO emission vs. load for chlorella emersonii blends and diesel

Figure 11 shows carbon dioxide pollution levels against load conditions for CE blends and diesel. CO_2 emissions at all loads for different CE blends compared with diesel. 100% CE has the lowest CO_2 emission for all loads compared to all other blends. Usually, CO_2 emissions are lower in natural CT biodiesel than in diesel and other blends due to higher oxygen content. CO_2 emission of Diesel, B1, and B2 increases as the additional load is added. However, in the B3 blend, CO_2 emission decreases under 4 and 6 load conditions and increases on higher loads.

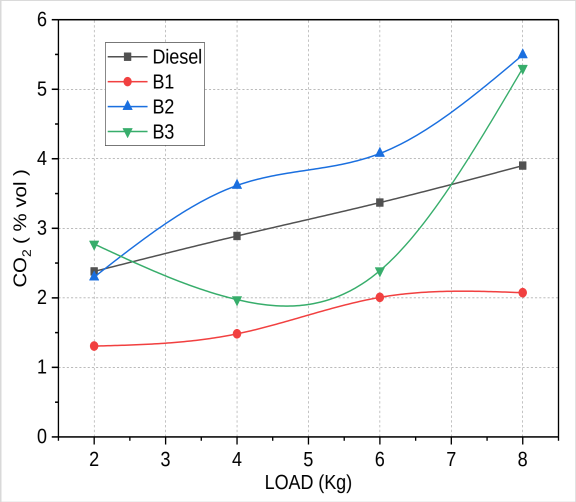

Figure 11 CO2 with load for Chlorella emersonii and diesel blends

Figure 12 compares the HC emission values for various CE blends to diesel for all loads. CE B3 has the lowest emission compared to diesel for all loads. Due to incomplete combustion, HC emission rises sharply on lower and higher loads. B1 CE bio-fuel releases lower HC emissions due to higher carbon atoms and oxygen content. Adding butanol increases HC emissions in B2 and B3 blends. HC emissions are higher in the B2 blend overall comparatively. Emissions of HC vary in the B3 blend under different load conditions as a reaction of distilled water. *Figure 13* shows the smoke intensity of diesel and CEME blends. Over the load range, CEME combinations generated less smoke emissions than diesel fuel.

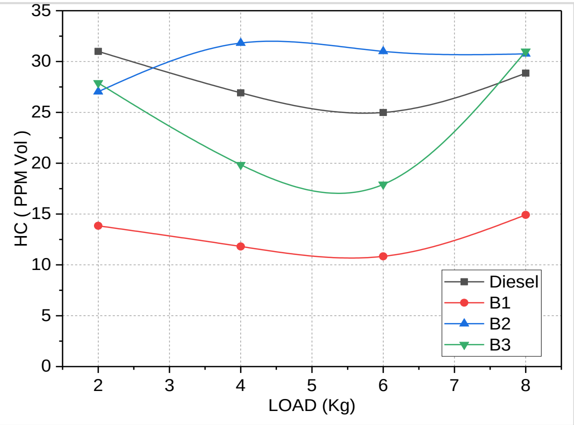

Figure 12 Hydrocarbon emission on various load condition for CE blends and diesel

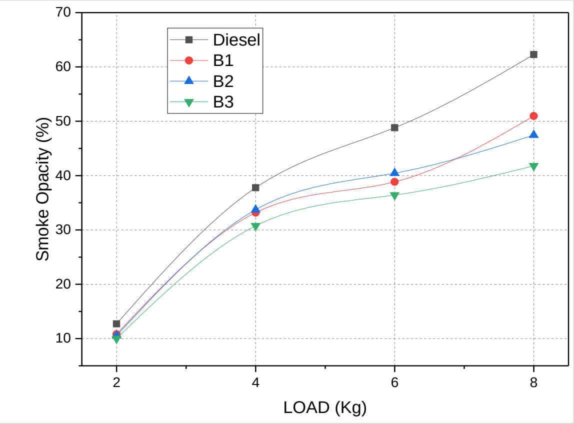

Figure 13 Smoke opacity difference vs engine load

5.Discussion

Brake thermal efficiency (BTE)

Compared to other CEME mixes, the B1 stays similar to diesel in all engine loads. This may be due to the blend's higher heating value and the presence of oxygen in the mix. There is a considerable decline in BTE as the amount of CEME in diesel fuel increases. This may be attributable to the fuel's increased viscosity and reduced energy level. In relation to other blends, the B10 blend, particularly with reduced viscosity, improves fuel atomization, vaporization, and air-fuel contact.

Brake specific fuel consumption (BSFC)

B1 gasoline has a greater consumption rate, which can be linked to the B1 blend's kinematic viscosity and calorific value, similiar to diesel than the other blends. The B2 sample had the highest BSFC at higher loads, which could be attributable to increased thermal efficiency and shorter ignition delays, encouraging smoother engine performance, particularly at higher loads.

Brake power

Increased biodiesel viscosity can reduce power output due to ineffective atomization and combustion.

CO emission

Diesel emits more CO than CEME fuel because of O_2 shortfall in diesel, which outperforms CEME blends because it contains fuel-associated O_2 molecules. Complete combustion occurs when O_2 is present, converting carbon monoxide molecules to carbon dioxides and preventing the creation of intermediates (CO) during combustion.

CO_2 emission

CEME and its blends with diesel emit more CO_2, indicating more O_2 in biodiesel, which promotes complete combustion. It could be explained by a higher fuel density and a lower calorific value, which affects the combustion efficiency of fuel molecules, resulting in less CO_2.

Hydrocarbon emission

CEME and its mixes emit less HC due to oxygen in biodiesel, which improves combustion and reduces HC production. In contrast, some arguments have been made that greater biodiesel viscosity can increase HC production and reduce power output due to poor atomization and combustion.

EGT

CEME blends have a greater EGT than diesel fuel because of the oxygen available, better atomization, and fuel vaporisation. At greater engine loads, the EGT between the blends was higher. With larger loads, there is more relative fuel involved in burning.

ID

The ID reduces as engine load rises owing to faster fuel-air mixing, increased engine cylinder temperature, diluted exhaust gases, and heat confinement in earlier stages of combustion. Because fuel evaporation is accelerated at higher temperatures, the chemical delay is minimized, the overall delay duration is shortened, and ID of B1, B2, B3, and diesel fuel is reduced at greater engine loads. The decreased igniting delay duration for most biodiesels than diesel fuel was attributable to a greater cetane number and intrinsic oxygen concentration in biodiesels.

Smoke opacity

The CEME blends emit lower smoke over the load range compared to diesel. It might be ascribed to biodiesel's reduced C/H ratio, increased O_2 compounds, and lack of covalent bonds, all leading to better combustion and oxidation in fuel-rich regions. B1 (100 percent CE) has higher smoke levels due to larger fuel droplets, a slower evaporation rate, and a slower air-fuel blending frequency, generating more significant quantities of carbon particulates in the exhaust as smoke opacity.

Cylinder pressure

The B1 blend has the lowest peak pressure, while diesel fuel has the greatest peak pressure. It is owing to CEME blend's increased viscosity and reduced calorific value. CEME-diesel mixes constantly affect atomization, vaporization, air-fuel mixing frequency, and lowering cylinder pressure. The ID for B1 blend (100 percent CE) is the shortest, resulting in a minimal amount of fuel accumulating during combustion and decreased cylinder pressure.

HRR

The heat produced during the diffusion combustion cycle of CEME blends is the same as that of a diesel mix, even though the beginning of combustion changes linearly. CEME's excess O2 content from earlier combustion phases persists in combustion at later stages. In contrast to diesel fuel, the diffusion burning cycle of CEME blends was prominent. It is because of the twin impacts of complete combustion in CEME mixes because of surplus O_2 molecules and diesel's increased heating range compared to CEME.

5.1Limitations of the study

Many factors were not examined in this study. Therefore, it is recommended that additional research could be done on these diesel engines using CEME biofuel to ascertain their thermal efficiency. The application of cetane enhancer gasoline additives must be combined with other tried-and-true methods for boosting combustion, such as preheating the intake air and using turbochargers with the proper capacity. Both of these methods will recycle heat energy wasted in engine exhaust, which can decrease diesel engine exhaust gas. To reduce the impact of ID, injection timing can also be advanced. It may enable the injected fuel to generate spray in an improved way and vaporize more quickly, improving combustion. Identifying opportunities to enhance the engine's overall performance may be possible using simulation- research of the diesel engine combustion operating with CEME.

A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion

The performance behaviour of a diesel engine driven by CEME blends and diesel is investigated experimentally. These inferences are made in view of the findings.

- The CEME and its blends decreased BTE while increasing BSFC. The B2 blend is less efficient and uses more gasoline when compared to diesel. The ID, peak cylinder pressure, and rapid heat release were reduced when CEME blends were used. Higher EGT values in CEME blends than in diesel indicate that biodiesel has a better diffusion combustion phase.
- The existence of O_2 atoms coupled to fuel in CEME and its blends leads to decreased levels of HC, CO, and smoke emissions. However, CO_2 emissions were significantly greater than when using straight DIESEL, particularly at part load.
- The transesterification process of CEME biodiesel is a simple and economical way to solve viscosity-related issues encountered with vegetable oils. The dual-fuel expenses can be minimized significantly than the usage of pure diesel.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author’s contribution statement

Saranraj I: Conceptualization, investigation, data curation, writing-original draft, writing- review and editing. **Ganesan S:** Writing-analysis and interpretation of results, study conception, supervision, investigation on challenges and draft manuscript preparation.

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Appendix I

S. No.	Abbreviations	Description
1	AME	Aircraft Maintenance Engineering
2	AOME	Algal Oil Methyl Ester
3	ASTM	American Society for Testing and Materials
4	BP	Brake Power
5	BSFC	Brake Specific Energy Consumption
6	BTDC	Bulk Thermal Desorption Chamber
7	BTE	Brake Thermal Efficiency
8	CE	Chlorella Emersonii
9	CEME	Chlorella Emersonii Methyl Ester
10	CEO	Chlorella Emersonii Oil
11	CRDI	Common Rail Direct Injection
12	CO	Carbon Monoxide
13	CO2	Carbon Dioxide
14	DAS	Data Acquisition System
15	EGT	Exhaust Gas Temperature
16	HC	Hydro Carbon
17	HRR	Heat Release Rate
18	HTL	High-Level Transistor Logic
19	ID	Ignition Delay
20	NDIR	Non-Dispersive Infra-Red
21	RBME	Rice Bran Methyl Ester
22	RME	Rapeseed Methyl Ester
23	SMA	Spirulina Micro Algae
24	UBHC	Unburnt Hydrocarbon