Journal of
Environmental
Nanotechnology

Research Article

An Experimental Study on Algae Biodiesel with Nano-additives for Engine Performance and Emission Reduction

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Received: 06.06.2024 Accepted: 21.08.2024 Published: 30.09.2024
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ABSTRACT

Introducing nano-additives like aluminum oxide and cerium oxide into the B20 blend biodiesel exhibited encouraging outcomes of combustion efficiency and emission reduction. These additives likely catalyzed combustion, leading to more complete fuel burn and lower emissions. Additionally, the presence of nano-additives might have facilitated better fuel atomization and distribution within the combustion chamber, resulting in enhanced engine performance. The results indicate that adding nano-additives to biodiesel blends has significant potential for reducing environmental impact and enhancing engine longevity and efficiency. Moreover, the utilization of nano-additives represents a promising avenue for addressing the dual challenges of energy sustainability and environmental preservation. By harnessing the synergistic effects of nano-scale materials, such as aluminum oxide and cerium oxide, in biodiesel formulations, engineers and researchers can strive towards developing cleaner and more efficient propulsion systems. This holistic approach underscores the importance of cooperation across disciplines between materials science, engineering, and environmental studies to advance the frontiers of sustainable energy technologies. The study attempted to improve combustion efficiency and reduce emissions by introducing nano-additives like aluminum oxide and cerium oxide into B20 biodiesel. The outcome showed enhanced engine performance, more complete fuel burn, and significant potential for reducing environmental impact.

Keywords: Algae biodiesel; Nano-additive; Performance; Emission.

1. INTRODUCTION

The recent surge in diesel and petrol prices, coupled with concerns over environmental emissions, has underscored the pressing requirement for substitute energy sources (Sunil Kumar *et al.* 2023). One promising avenue is the utilization of waste for energy production (Kukana *et al.* 2022), particularly through processes like the transesterification of algae oil to produce biodiesel. However, challenges such as high viscosity and density in the resulting biodiesel hinder its efficiency. However, research indicates that biodiesel can greatly lower emissions and improve engine performance(Pooja and Mayur, 2012). One area of research focuses on enhancing biodiesel performance by incorporating nanoparticles (Reddy *et al.* 2021). Blends of algae biodiesel and diesel were tested, with the optimal blend identified as B20. Various nanoparticles, including aluminum oxide (Al_2O_3) and cerium oxide (CeO_2), were incorporated into various mixes to assess the effects on emissions and engine performance. The outcomes of the experiment showed significant advancements in combustion efficiency and a significant reduction in pollutants, particularly when CeO_2 nanoparticles were introduced. Fig. 1 illustrates algae biodiesel and diesel. Further experimentation sought to ascertain the optimal concentration of nanoparticles. As discovered, both Al_2O_3 and CeO_2 nanoparticles contributed to performance and reduced emissions. Specifically, nanoparticles led to increased brake thermal efficiency, decreased formation of HC and CO emissions, and mitigated soot production. These findings highlight the possibility of nanoparticle-enhanced biodiesel blends as a feasible method for satisfying both energy needs and environmental concerns.

Fig. 1: Algae biodiesel and Diesel

Another research delves into the combustion of Mahua oil and the result of diesel engines using biodiesel combined with cerium oxide nano-additions (Simhadri *et al.* 2023). B20 biodiesel with these nanoparticles exhibited lower hydrocarbon, carbon monoxide and oxides of nitrogen emissions (Nayak *et al.* 2022). The addition of aluminum oxide nanoparticles to blended biodiesel enhanced performance and decreased pollutants (Hoang, 2021). The study utilized aluminum oxide (Al_2O_3) with B20 to optimize performance and emissions from diesel engines, without engine modifications (Vinukumar *et al.* 2018). Additionally, cerium oxide (CeO_2) nano-additions were used to further cut pollutants and improve engine efficiency (Subramani and Karuppusamy, 2021). In addition, for emission, this experiment utilized cerium oxide nano-additive in blends and pure diesel to achieve combustion. The modification increased the heat release rate and cylinder pressure under full load conditions, decreased the ignition delay minute, shortened the combustion duration, im-improved BTE, decreased HC, CO, and soot, and increased emissions, according to the experimental results (Rajasekar and Naveenchandran, 2021).

2. LITERATURE REVIEW AND EXPERIMENTAL WORK

2.1. Properties of Algae Biodiesel

Fig. 2a and Fig. 2b illustrate machines used to find properties such as kinematic viscosity and fire point for algae biodiesel.

Table 1 outlines the specific equipment used to measure the characteristics of diesel, algae-based biodiesel, and B20 blends. The observed characteristics encompass acid value, iodine value, specific gravity, kinematic viscosity, cetane number, flash and fire points, calorific value, and density. The test parameters for B10, B20, B30, B40, B100, and D100 were examined. Table 1 shows the properties of D100, B100 and B20 blends. However, no significant improvement was observed in both density and kinematic viscosity. In comparison, gasoline blends demonstrated an enhancement in flash points.

(a) Kinematic viscosity measuring

(b) Fire point measuring

Fig. 2: Measuring algae biodiesel

Table 1: Diesel and Algae biodiesel properties

S. No.	Parameters	Diesel (D100)	Algae Biodiesel (B100)	B20
1	Density	0.842 g/cc	0.856 g/cc	0.8232 g/cc
2	Acid value	0.08 mg KOH/g	1.09 ml of NaOH/g of oil	0.45 ml of NaOH/g of oil
3	Cetane number	57.08	47.01	53 .61
4	Calorific value	41807 kJ/kg	41807 kJ/kg	10363 kJ/kg
5	Specific gravity	0.8813	0.8712	0.8228
6	Kinematic viscosity	2.73 cSt	1.65 cSt	2.98 cSt
7	Iodine value	100	102.93	26.06
8	Flash point	55 °C	118 °C	68 °C
9	Fire point	70 °C	126 °C	73 °C

2.2. FTIR Analysis

The Indian Institute of Technology, Madras, India, conducted FTIR-Spectroscopy testing. Figures 3 a and 3 b illustrate FTIR analysis graphs for diesel and algae biodiesel, respectively. The analysis focused on identifying various functional groups and interpreting the range of results. FTIR analysis found a considerable concentration of fatty acid methyl esters in biodiesel. The examination of functional groups and their vibrations served as the basis for this forecast. FTIR analysis allows for the effective evaluation of samples as small, enabling precise particle and residue identification and coating assessment.

2.3 GC-MS Analysis

The GCMS graphs illustrated in Figures 4 a and 4 b for diesel and algae biodiesel demonstrate the complete transesterification of triglycerides into fatty acid methyl esters using gas chromatography. This procedure was examined in the study. Thermo-gas spectroscopy-mass spectroscopy equipment and a data-gathering organization were utilized for gas chromatography-mass spectroscopy analysis in this work.

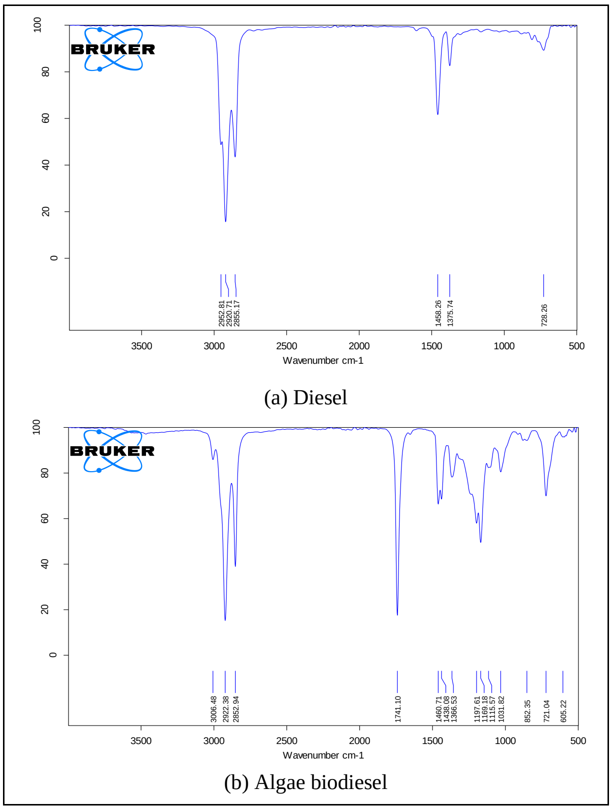


Fig. 3: FTIR Analysis

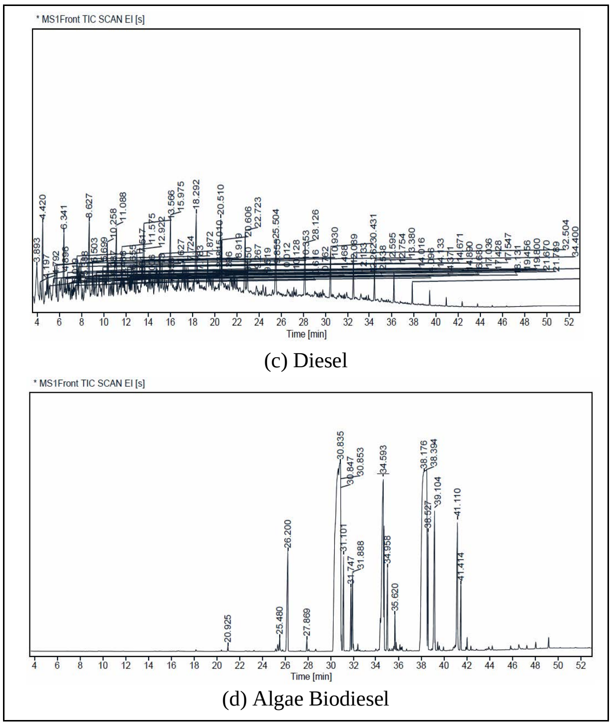


Fig. 4: GC-MS analysis

The presence of fatty acid methyl esters indicates that using biodiesel to replace fossil fuels is a feasible option. One milliliter of algal biodiesel was employed with nitrogen at the rate of one milliliter per minute through the column of the Perkin Elmer gas chromatograph-mass spectrometer. GC-MS provides the chemical breakdown of algal oil, revealing properties such as linoleic acid, making algal fuel a promising alternative to diesel fuel, as indicated by the findings of the GC-MS analysis.

2.4 Preparation of Nano-additives

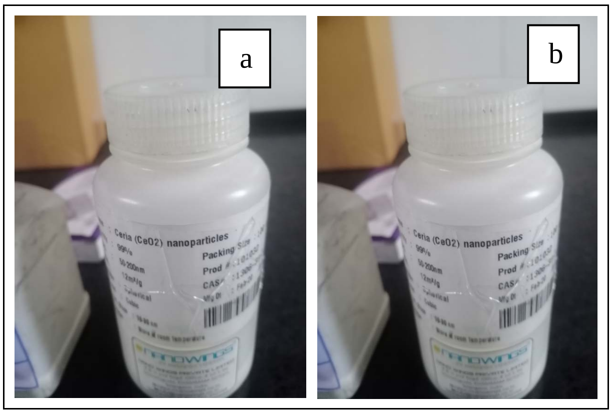


Fig. 5: Nano-additives (a) Cerium oxide and (b) Aluminium oxide

Aluminum oxide (Al_2O_3) and cerium oxide (CeO_2) nano-additives are measured by ppm and weighed. Fig. 5 (a) illustrates the cerium oxide nano additive and Fig. 5 (b) demonstrates the aluminum oxide nano-additive. Both were 100 nm in size and were procured from Apex Innovation, India, for this research. Tables 2 and 3 represent the characteristics of Al_2O_3 and CeO_2 nano-additives, respectively. In this research, an ultrasonicator was utilized, and nano-additives ranging from 25 ppm to 100 ppm were incorporated into the B20 (best) algae biodiesel blend.

Table 2: Aluminium oxide (Al_2O_3) Nano-additive specification

Item	Specification
Manufacturer	Apex Innovation, Maharashtra, India
India Chemical name	Aluminium oxide (Al_2O_3)
Ppm size	25, 50, 75, 100
Specific surface area	>196m^2/g

2.5 Research Process

Algae oil transesterification was completed to produce algae biodiesel, and the properties of B10, B20, B30, B40, B100, and D100 were examined. Subsequently, GCMS analysis was conducted on diesel and algae biodiesel, while FTIR analysis was performed on both. Different ratios of biodiesel (10, 20, 30, 40, and 100%) blended with petroleum products were tested along with pure diesel (D100) powered diesel engines without algae biodiesel. For improvement purposes, algae biodiesel B20 blends were examined with the addition of Al_2O_3 and CeO_2 nanoparticles. B20 was identified as the optimal blend due to its superior performance in combustion and emissions. Tests of Al_2O_3 and CeO_2 nano additives at levels of 25, 50, 75, and 100 ppm, for each B20 test. Emission characteristics like carbon monoxide and Carbon dioxide were analyzed in the diesel engine for each biodiesel test. Significant advancements were observed in heat release and pressure evolution data, dependent on the nano additives added.

Table 3: Cerium oxide (CeO_2) Nano-additive specification

Item	Specification
Manufacturer	Apex Innovation, Maharashtra, India
India Chemical name	Cerium oxide (CeO_2)
Ppm size	25, 50, 75, 100
Specific surface area	$>40m^2/g$

2.6 Experimental Set-up

In this reading, experiments were carried out on a naturally aspirated water-cooled diesel engine. The experimental setup of the VCR engine is illustrated in Fig. 6, with load applied through an eddy current dynamometer.

Fig. 6: Experimental VCR diesel engine

Crank angle sensors were employed to collect combustion parameters, and a P-V graph was obtained and displayed using a high-speed data capture system. A Particle Size Analyzer was used; an AVL Di Gas Analyzer was used to monitor hydrocarbon and nitrogen oxide emissions, while the smoke value level was determined using AVL smoke meters. The reading was approved on a variable compression ratio engine speed of 1500 rpm and engine power. Various loads were applied to the VCR engine using an eddy current dynamometer. Quick data acquisition was employed to obtain pressure vs crank angle data and displayed on a computer. Fig. 6 illustrates the VCR diesel engine setup.

Table 4: Technical specifications of the test engine

Engine specification	
Make	Kirloskar
Number of cylinders	1
Stroke	110 mm
Connecting rod length	234 mm
Piston bowl shape	Hemispherical
Piston bowl diameter	52 mm
Bore	87.5 mm
Compression ratio	12 to 18
Type of cooling	Water cooled
Injection Timing	23° bTDC
Rated power	3.5 kW
Cylinder head curvature	Flat
Fuel injection opening pressure	200 bar

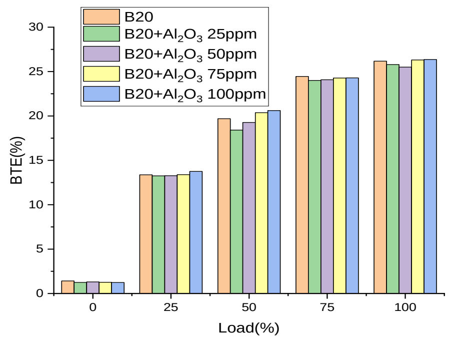
Engine specifications are listed in Table 4. A piezoelectric pressure level transducer was used in the engine to calculate net heat release and cylinder pressure. Fuel flow rate, engine stability, and exhaust gas temperature were measured for each operating mode. The AVL 437C was used to determine emissions of hydrocarbons, carbon monoxide, carbon dioxide, and nitrogen oxides. Smoke levels of blends were determined using the AVL 437C and exhaust gas temperature was calculated at various tailpipe positions. The hydrocarbon and oxide of nitrogen emissions were calculated using an AVL Di gas analyzer and smoke intensity was determined using an AVL smoke meter.

3. RESULTS AND DISCUSSION

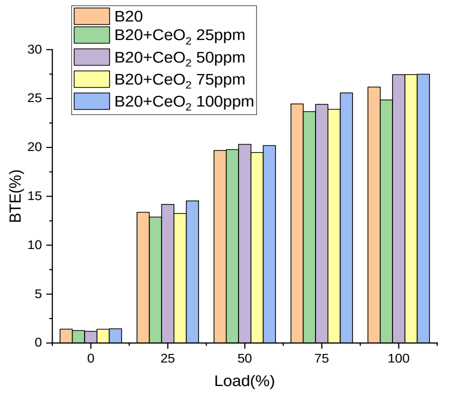
3.1 Performance

3.1.1 Brake Thermal Efficiency

Fig. 7a shows B20 and B20 with aluminum oxide nano-additive at different concentrations under load to measure brake thermal efficiency (BTE). The majority of the findings indicate a significant improvement in BTE (Ansari *et al.* 2023). This increase in thermal efficiency is linked to an increase in brake power. At full load, the BTE of B20 with the addition of 75 ppm Al_2O_3 is comparable to that of pure diesel. Additionally, the inclusion of metal oxide microparticles improved combustion efficiency compared to algae biodiesel blends. In comparison to B20, the addition of Al_2O_3 nano-additive to B20 improves brake thermal efficiency. B20 added aluminum oxide (Al_2O_3) nano-additive brake thermal efficiency value is 26.36.



(a) Al_2O_3 Brake Thermal Efficiency



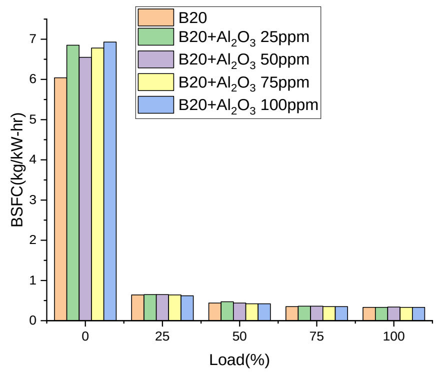
(b) CeO_2 Brake Thermal Efficiency

Fig. 7: Variation of BTE with load

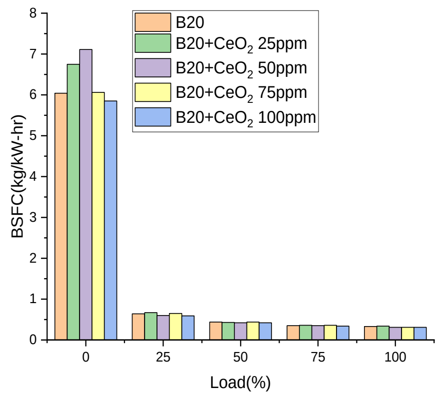
Fig. 7b illustrates B20, cerium oxide (CeO_2) B20, and B20 with CeO_2 nano-additives at concentrations of 25, 50, 75, and 100 ppm under different load conditions for BTE. Additionally, CeO_2 nano-additives were introduced to B20 algae biodiesel blends, leading to a rise in brake thermal efficiency (BTE) in this experimental research. This improvement is accredited to the larger surface area ratio of nanoparticles (Mani *et al.* 2009). Despite the initially lower BTE of B20, the addition of CeO_2 nanoparticles aims to enhance BTE and improve combustion efficiency. The better surface area of the fuel promotes better interaction with oxygen molecules, facilitated by better air-fuel mixing from nanoparticle atomization and rapid evaporation. Due to the influence of both engine operating temperature and load, higher load conditions result in greater BTE. Compared to B20, the inclusion of CeO_2 nano-additive in B20 enhances brake thermal efficiency. B20 added CeO_2 nano-additive brake thermal efficiency value is 27.49. Brake Thermal Efficiency (BTE) indicates how much thermal energy is converted into braking power, and its enhancement signifies an increase in the system's available energy. Algae biodiesel blends have a higher cetane number than diesel, leading to a quicker ignition response. The diesel engine demonstrated improved brake thermal efficiency due to the biodiesel blends.

3.1.2 Specific Fuel Consumption

In Fig. 8a, the Brake Specific Fuel Consumption (BSFC) for B20 is shown along with B20 containing Al_2O_3 nano-additives at concentrations of 25, 50, 75, and 100 ppm, across various load conditions. Fuels perform well within the optimal BSFC range. The addition of nanoparticles affects injection timing, resulting in faster combustion and reduced ignition delay. Diesel is compared to B20 with varying levels of Al_2O_3 nano additives in terms of BSFC and brake pressure. When adding nanoparticles, the Specific Fuel Consumption (SFC) full load value for B20 increases to 0.20 kg/kWh, while the SFC for diesel decreases by 10% to 0.4 kg/kWh. Rich air-fuel mixtures lead to inefficient fuel combustion, resulting in incomplete burning of fuel within the engine under specific load conditions. When compared with B20 the B20-added Al_2O_3 nano-additive gives better brake specific fuel consumption with better efficiency. B20 added Al_2O_3 nano-additive brake specific fuel consumption value is 0.33.



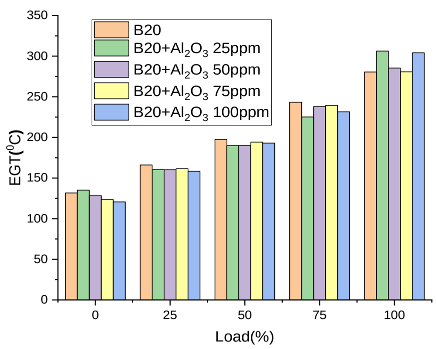
(a) Al_2O_3 brake specific fuel consumption



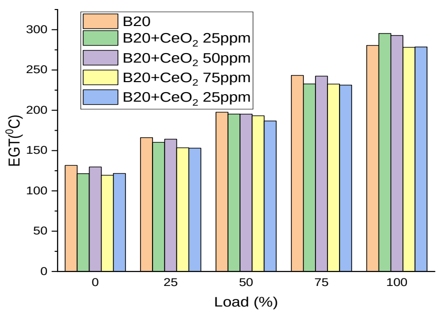
(b) CeO_2 brake specific fuel consumption

Fig. 8: Variation of BSFC with load

Fig. 8b shows the Brake Specific Fuel Consumption (BSFC) at various loads for B20 and B20 containing CeO_2 nano additives at concentrations of 25, 50, 75, and 100 ppm. Adding CeO_2 nano-additives is intended to reduce fuel consumption (Sree *et al.* 2020). Comparing B20 with CeO_2 nano-additives to fuel blends containing CeO_2 nanoparticles, the BSFC of the latter was reduced. B20-added cerium oxide (CeO_2) nano additive gives better brake specific fuel consumption and better efficiency. B20 added cerium oxide (CeO_2) nano additive brake specific fuel consumption value is 0.31. Improved combustion led to a decrease in BSFC when compared to B20. The power was also enhanced in this testing. CeO_2 nano additives at concentrations of 25 ppm, 50 ppm, 75 ppm, and 100 ppm were introduced to reduce fuel consumption. For better combustion, BSFC was reduced while power increased, attributed to the increasing ppm of CeO_2 nano additive added to the B20 fuel blend. The BSFC decreases as the CeO_2 nanoparticle concentration rises. Suitable to the high viscosity and density of algal biodiesel blends, they tend to consume somewhat more fuel than diesel in terms of Brake Specific Fuel Consumption (BSFC). The Specific Fuel Consumption (SFC) measurements for blends containing nano additives at standard compression ratios were 0.32 and 0.34 kg/kWh, respectively. Due to its lower heating value, the blend shows a slightly higher Specific Fuel Consumption (SFC) compared to diesel.



(a) Al_2O_3 Exhaust gas temperature



(b) CeO_2 Exhaust gas temperature

Fig. 8: Variation of EGT with load

3.1.3 Exhaust Gas Temperature

In Fig. 9 a, the exhaust gas temperatures (EGT) for B20 and B20 with Al_2O_3 nano-additives at concentrations of 25, 50, 75, and 100 ppm are shown under load conditions. The testing was carried out at a speed of 1500 rpm for the B20 nano fluid-fueled test engine, and the collected data were analyzed for EGT characteristics (Örs *et al.* 2018). The experimental results indicate that as load conditions and the Al_2O_3 and Al_2O_3 mix ratios in nanofluids containing B20 increase, the exhaust gas temperature also increases. The increase in exhaust gas temperature is due to the burning of carbon atoms and hydrocarbon molecules after the controlled combustion period and thermal breakdown. The specific exhaust gas temperature value for B20 with added Al_2O_3 nano-additive is 304.15 °C.

Fig. 9 b illustrates the exhaust gas temperature (exhaust gas temperature) at different loads for B20 and B20 with CeO_2 nano additives at concentrations of 25, 50, 75, and 100 ppm. As the load increases over the testing time, the EGT varies correspondingly. The graph illustrates that with an increase in load, the EGT shows a noticeable increase. Biodiesel, having a lesser calorific value than diesel, results in correct EGT (Kalaimurugan *et al.* 2020). The graph demonstrates that fuel mixtures with added CeO_2 nanoparticles exhibit higher EGT levels than those in B20 blends. The addition of CeO_2 nanoparticles to the fuel blends promotes combustion, leading to an increase in the highest temperature reached and enhancing the EGT. The exhaust gas temperature for biodiesel blends is higher than diesel, mainly because of the higher temperature of the air resulting from complete combustion. The higher air temperature helps break down the fuel into smaller particles, aiding in complete combustion. The exhaust gas temperature value for B20 with added cerium oxide (CeO_2) nano-additive is 278.601 °C.

3.2 Combustion Characteristics

3.2.1 Cylinder Pressure

Figures 10 a to 10 d show how cylinder pressure changes for B20 algae biodiesel and diesel, with different amounts of Al_2O_3 nano additive, as the engine turns. Cylinder pressure indicates how well the fuel and air mix together for combustion. Higher cylinder pressure leads to higher temperatures in the combustion chamber. Due to the D80-B20 blend's characteristics like high viscosity, low volatility, and large fuel droplets, fuel atomization is reduced, causing poor mixing and lower pressure. The findings indicate that a particular blend of biodiesel made from used cooking oil, n-butanol, and nano additives is suitable for diesel engines, with these additives enhancing cylinder pressure (Chen *et al.* 2018).

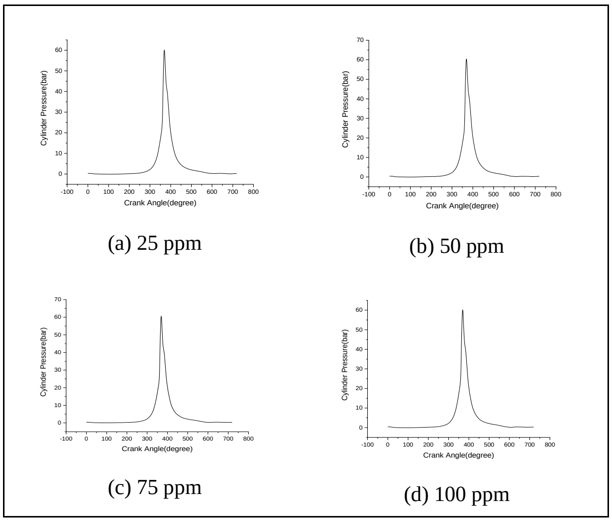


Fig. 10: B20 + Al_2O_3 variation of cylinder pressure with crank angle

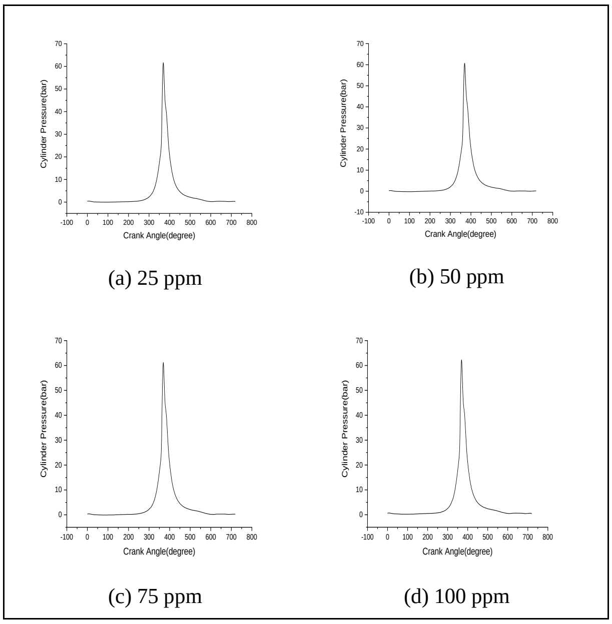


Fig. 11: B20 + CeO_2 Variation of Cylinder Pressure with Crank Angle

The nanoparticles have improved features, a larger surface area, and faster heat transfer. Various factors play a role in this, such as increased peak pressure and temperature, smaller fuel droplets, better fuel-air mixing efficiency from faster nano fuel evaporation, and a higher cetane number. The cylinder pressure improves when B20 and the aluminum oxide (Al_2O_3) nano-additive are used together.

Figures 11 a to 11d illustrate graphs of cylinder pressure values for B20 algae biodiesel and diesel, with various concentrations of CeO_2 nanoparticles, plotted against crank angle. Diesel fuel blends with nanoparticles significantly improve cylinder pressure and ignition delay (Piloto-Rodríguez *et al.* 2017). These nanoparticles contribute to more peak pressure compared to blends without nano additives, ensuring good combustion and a better heat release rate. When B20 is added, CeO_2 nanoparticles added to B20 give better cylinder pressure.

B20 operation is cleaner when compared to combustion without nano-additives, and the pressure is attained after a few crank angles. An efficient B20 operation, with a longer delay, experiences a later peak pressure onset in the power stroke, reducing power production. Higher injection pressures lead to more successful atomization of the fuel. Consequently, smaller, finer biodiesel droplets are formed, resulting in better fuel dispersion and penetration. The highest cylinder pressure values (Cp) were recorded at load and standard compression ratio for diesel and the B20 blend, respectively. The CeO_2 nanoparticle increases ignition delay, leading to fuel accumulation for the duration of the premixed combustion phase. The heat release increases with the inclusion of CeO_2 nanoparticles, due to the rapid injection velocity and high momentum of liquid droplets, leading to a more efficient fuel-air mixture.

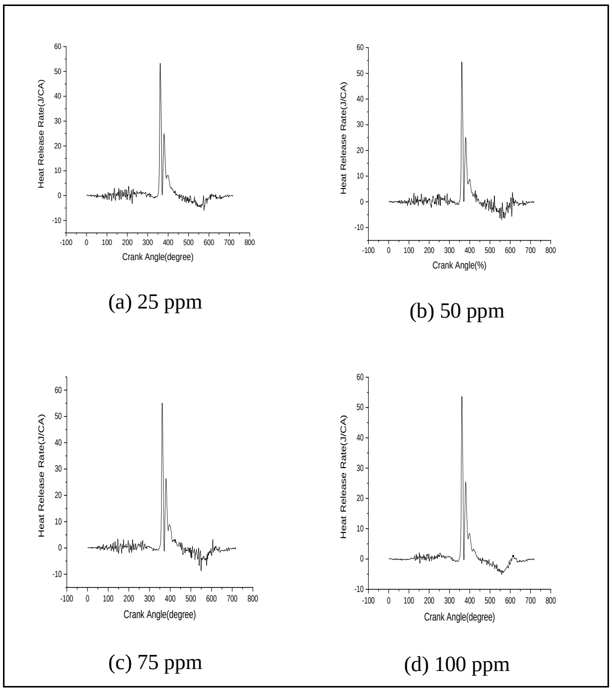
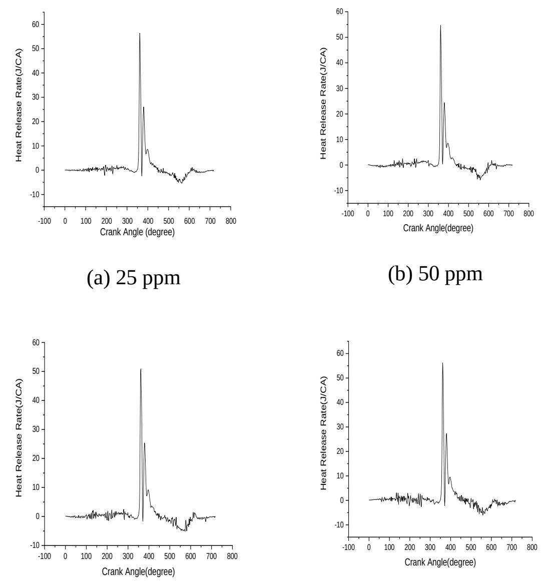


Fig. 12: B20 + Al_2O_3 Variation of Heat Release Rate with Crank Angle

3.2.2 Heat Release Rate

Figures 12 a to 12 d show the heat release rates for B20 biodiesel and diesel at different Al_2O_3 nano additive concentrations, plotted against crank angle. The Heat Release Rate (HRR) of Al_2O_3 blends increases with higher concentrations(Soudagar *et al.* 2020). The higher viscosity of the D80-B20 blend leads to poor atomization and incorrect mixing, resulting in a decrease in HRR. The addition of Al_2O_3 nano-additive to B20 improves the heat release rate. The peak points of other gasoline blends fall between the peak points of B20 biodiesel and diesel blends. Nanoparticles greatly enhance the heat release rate of biodiesel blends. This enhancement is attributed to the ignition and catalytic properties of nanoparticles, along with a faster mixing rate, leading to improved heat release and counteracting the negative effects of diesel and biodiesel mixture thickening. This highlights the importance of ignition delay and a faster mixing rate in understanding the effects of nanoparticles on heat release rates.

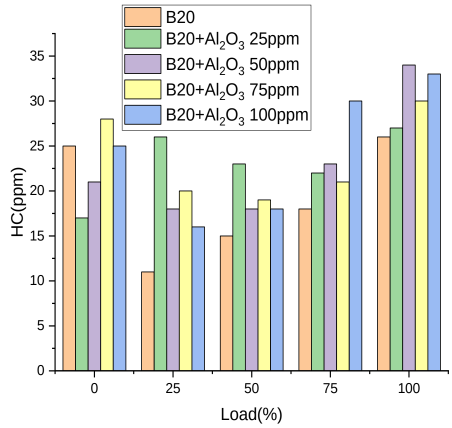


(a) 25 ppm (b) 50 ppm

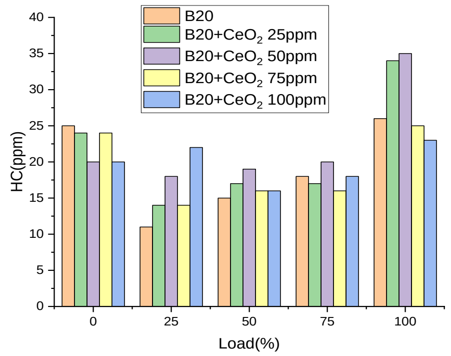
(c) 75 ppm (d) 100 ppm

Fig. 13: B20+CeO_2 variation of heat release rate with crank angle

Figures 13a to 13d show how quickly heat is released by a mix of 20% biodiesel and 80% diesel, with different amounts of CeO_2 nano-additive, displayed on a graph that tracks the engine's rotation. The B20 blend contains 20% biodiesel and 80% diesel. CeO_2 nano additives are included in concentrations of 25, 50, 75, and 100 parts per million (ppm). The heat release parameter shows the combined energy of the fuels. CeO_2 nano-additives are meant to boost the heat release rate (Manimaran *et al.* 2023). This happens when more fuel is injected as the load increases, leading to a rise in the number of carbon particles in the fuel. A higher Heat Release Rate (HRR) is caused by more fuel particles, representing greater energy in the fuel. Furthermore, the data trends indicate that biodiesel blends show a higher Heat Release Rate (HRR) when the injection pressure is increased, signaling a faster blending of air and fuel. Studies have shown that with increased pressure, fuel with CeO_2 releases heat more rapidly. The addition of CeO_2 nano-additive to B20 results in a particular heat release rate. The higher energy content of the blend increases the heat release rate in both blends and diesel, allowing fuel accumulation in the combustion chamber. CeO_2 at 75 ppm triggers rapid combustion in the premixed phase. Comparing B20 with 75 ppm of CeO_2, there is a longer ignition delay leading to changes in the heat release rate.



(a) Al_2O_3 Hydrocarbon emission



(b) CeO_2 Hydrocarbon emission

Fig. 14: Variation of HC emission with load

3.3 Emission Characteristics

3.3.1 Hydrocarbon (HC)

Fig. 14 a shows how HC emissions decrease with B20 algae blends containing Al_2O_3 nano additives at various ppm levels, tested under different load conditions (0%, 25%, 50%, 75%, and 100%). In general, as the ppm of nano additives increases, hydrocarbon emissions tend to decrease. Al_2O_3 nano-additions, with their superior thermal conductivity, enhance combustion, preventing the formation of a rich mixing zone and ultimately reducing HC emissions (Ghanbari *et al.* 2021). This phenomenon occurs when a significant concentration of Al_2O_3 nanoparticles promotes combustion, generates oxygen, and aids in decreasing hydrocarbon emissions at various ppm levels. The B20 algae blend with Al_2O_3 nano additive shows improved hydrocarbon emission performance. The hydrocarbon emission value for the B20 algae blend with Al_2O_3 nano additive is 34.

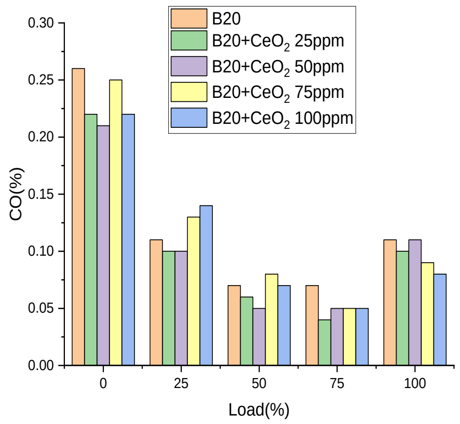
Fig. 14 b shows how adding B20 algae blends with CeO_2 nano additives at various levels reduces Hydrocarbon (HC) emissions in a variable compression engine under different loads. Comparatively, B20 + 75 ppm exhibits the most significant decrease in HC emissions compared to other blends. Higher HC emissions in the B20 blend occur because of lower oxygen levels during combustion, leading to a prolonged air-fuel mixing time. The presence of CeO_2 nano additives, especially at 75 ppm, enhances combustion by increasing oxygen levels, leading to a more effective reduction in hydrocarbon emissions compared to using B20 fuel alone(Hirkude *et al.* 2018). The addition of CeO_2 nano-additive to B20 improves hydrocarbon emissions. The hydrocarbon emission value for the B20-added CeO_2 nano-additive is 35 units. To sum up, incorporating CeO_2 nano-additives enhances combustion and decreases HC emissions, particularly at higher concentrations.

3.3.2 Carbon Monoxide (CO)

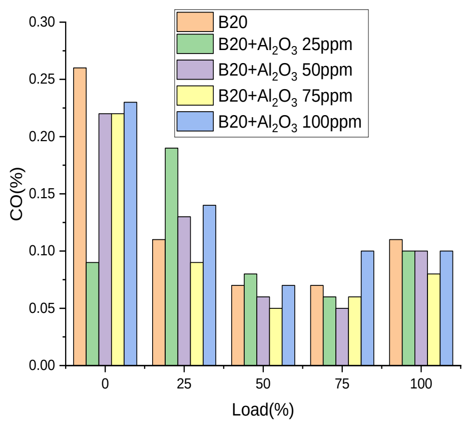
Fig. 15 a shows how adding B20 algae blends with Al_2O_3 nano additives at various ppm levels, tested under different loads, reduces CO emissions. The main reason for carbon monoxide formation is insufficient oxygen during combustion (Shaisundaram *et al.* 2021). The Al_2O_3 nano-additive helps reduce carbon monoxide emissions by enhancing CO_2 conversion speed when Al_2O_3 nanoparticles are added at 25 ppm and 50 ppm, leading to decreased CO emissions. The carbon monoxide emission value for B20 with added aluminum oxide (Al_2O_3) nano additive is 0.1.

Fig. 15 b illustrates the CO emissions due to B20 algae blends added with CeO_2 nano additives at different ppm levels, tested at 0%, 25%, 50%, 75%, and 100% load in a variable compression engine. Carbon monoxide is a colorless and dangerous gas that, when inhaled, can prevent oxygen transport to various parts of the body, posing a risk to human health. Incomplete combustion is a factor in CO production, and in this study, CeO_2 has a lower CO concentration compared to B20. Previous studies have investigated the impact of cerium oxide nanoparticles on greenhouse gas emissions from biofuels(Rao *et al.* 2021). The carbon monoxide emission value for the B20-added CeO_2 nano-additive is 0.08.

There is a correlation between load conditions and CO emissions as they initially rise and then decrease by 60% of the load. Lower engine loads result in partial gas phase combustion and higher CO emissions due to lower gas temperatures. Higher loads lead to more CO oxidation, which decreases CO emissions due to the higher gas temperature in the cylinder. The carbon monoxide emission value for B20 with added cerium oxide (CeO_2) nano additive is 0.08.



(a) Al_2O_3 Carbon monoxide emission



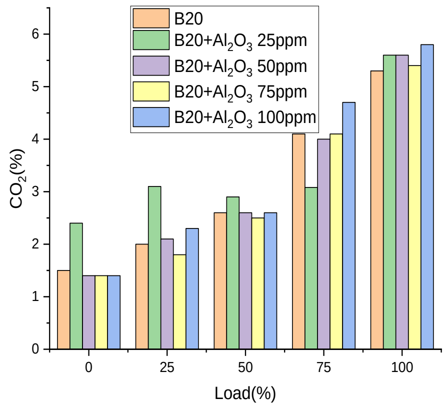
(b) CeO_2 Carbon monoxide emission

Fig. 15: Variation of CO emission with load

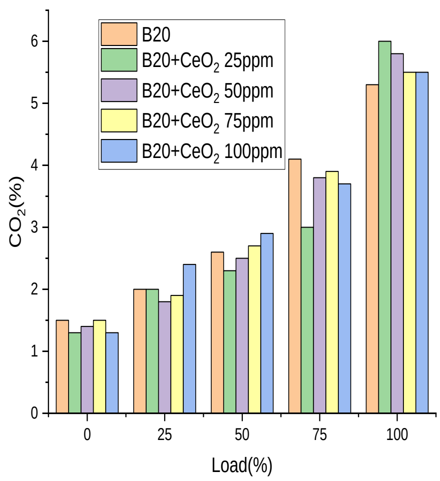
3.3.3 Carbon Dioxide (CO_2)

In Fig. 16 a, the graph shows the levels of Carbon Dioxide (CO_2) emissions resulting from B20 algae blends mixed with Al_2O_3 nano additives at various concentrations (0%, 25%, 50%, 75%, and 100%) and tested under different loads on a variable compression engine. The experimental results indicate an increase in both NO_x and CO_2 emissions. The primary finding from the experiments indicates that higher concentrations of Al_2O_3 nanoparticles lead to increased CO_2 content (Mohapatra *et al.* 2023). During this experiment, the performance, combustion, and emissions of the engine were affected by the higher energy content, heat conductivity, and surface area to volume ratio of nanoparticles in comparison to pure biodiesel and biodiesel-diesel mixtures. The addition of B20-Al_2O_3

nano additive results in improved carbon dioxide emissions, with an emission value of 5.8.



(a) Al_2O_3 Carbon dioxide emission



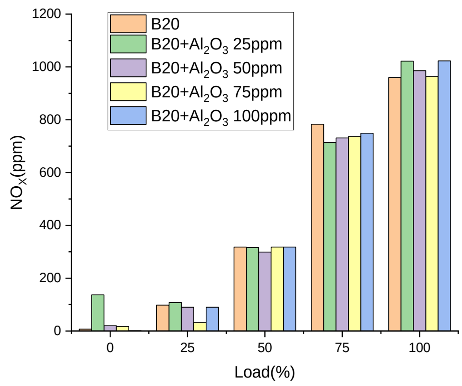
(b) CeO_2 Carbon dioxide emission

Fig. 16: Variation of CO_2 emission with load

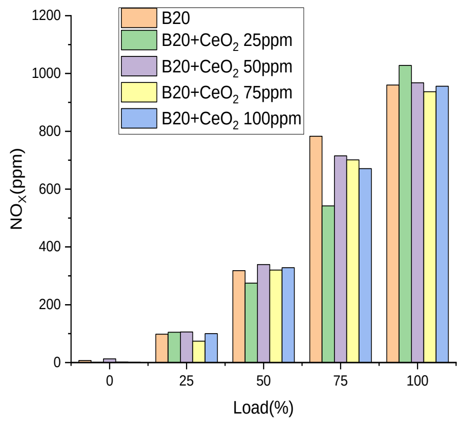
In Fig. 16 b, the graph depicts the Carbon Dioxide (CO_2) emissions resulting from B20 algae blends mixed with CeO_2 nano-additives at varying concentrations (0, 25, 50, 75, and 100%) and tested under different loads on a variable compression engine. The results demonstrate an increase in CO_2 emissions, suggesting that higher loads lead to a richer mixture. CO_2 emissions were higher (Saxena *et al.* 2017). This experimental study on B20-CeO_2 blends includes an analysis of viscosity, density, energy content, and ignition properties, confirming that the emission levels are within the correct range for the tested values, including the addition of B20 CO_2 blends. The study examines exhaust emission characteristics, with a specific focus on CO_2. When compared to pure biodiesel and mixes of biodiesel and gasoline, the nanoparticles improve engine performance, combustion, and emissions due to their higher calorific value, thermal conductivity, and surface-to-volume ratio characteristics. The inclusion of B20-CeO_2 nano-additive results in improved carbon dioxide emissions, with an emission value of 5.5.

3.3.4 Nitrogen Oxide (NO_x)

In Fig. 17 a, the graph shows how NOx emissions change at different load levels (0%, 25%, 50%, 75%, and 100%) when using B20 algae blends with Al_2O_3 nano additives at various concentrations. The experiment shows that, even though NO_x levels increase, diesel values are lower under load than all blends with nanoparticles, demonstrating reduced NOx emissions at various concentrations (Venu *et al.* 2020). The nitrogen oxide emission value for B20 with Al_2O_3 nano-additive is 1023.



(a) Al_2O_3 Nitrogen oxide emission



(b) CeO_2 Nitrogen oxide emission

Fig. 17: Variation of NO_x emission with load

In Fig. 17 b, the graph displays NO_x emissions at different load levels (0%, 25%, 50%, 75%, and 100%) for B20 algae blends with CeO_2 nano additives at varying concentrations. Throughout the experiment, as combustion increases, NOx emissions also increase, reaching the maximum level during electricity outputs. The B20 blend achieved the most significant decrease in NOx emissions. Temperature has a significant impact on the amount of nitrogen oxide (NOx) released impacting the quantity of oxygen during premixed combustion. Because of the high cylinder pressure under load, the NOx rose under heavier loads, leading to higher combustion temperatures. B20-added CeO_2 nano-additive oxides of nitrogen emission value is 1028. When B20 blend is mixed with nano additive at 75 ppm, it shows enhanced thermal efficiency, resulting in higher temperatures and pressure, leading to increased NOx emissions.

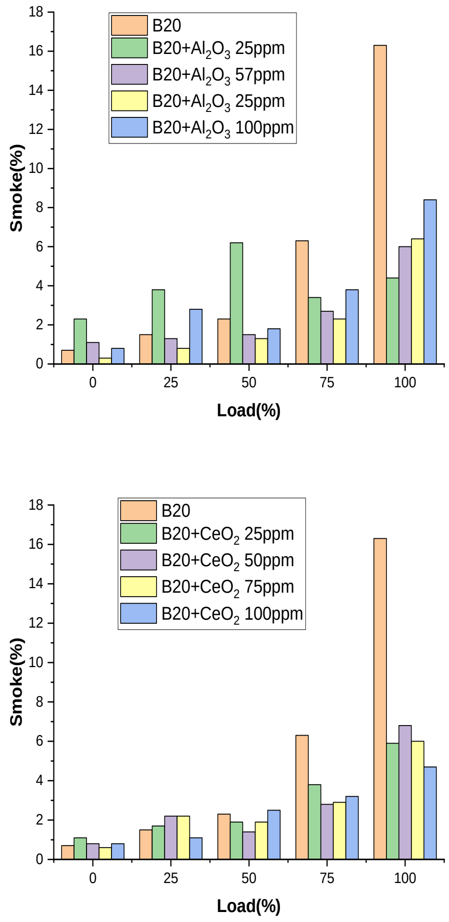


Fig. 18: Variation of Smoke emission with load

3.3.5 Smoke

Fig. 18a shows how adding B20 algae blends with Al_2O_3 nano additives at various ppm levels reduces smoke emissions during load testing at 0, 25, 50, 75, and 100%. Smoke is reduced for all increasing loads with different ppm levels. When B20 fuel blends are combined with Al_2O_3 nano additives at 25, 50, 75, and 100 ppm, smoke emissions increase as engine load levels rise. This excess fuel results in varying degrees of smoke, incomplete combustion, and rich mixture zones. These factors mainly include the excess fuel, incomplete combustion, and rich mixture zones, leading to the rapid oxidation of soot particles. Adding Al_2O_3 nano-additives is intended to reduce smoke emissions during combustion. The B20-added Al_2O_3 nano-additive results in a smoke emission value of 8.4.

Fig. 18 b illustrates smoke emission reduction due to B20 algae blends added to CeO_2 nano additives at different ppm levels with 0, 25, 50, 75, and 100% load testing. Compared to the B20 fuel, the blended fuels containing CeO_2 nanoparticles emit less smoke overall. Smoke density decreases, improving combustion and formation, due to factors like fuel mixture regions and oxygen content. This outcome is attributed to the improved air-fuel mixing achieved with diesel fuel. Biodiesel enhances combustion and reduces levels of hydrocarbons, carbon monoxide, and smoke opacity. Under full load conditions, the smoke opacities of B20 blends and pure diesel are measured at the standard compression ratio. Due to the higher oxygen content in the blend, the fuel exhibits reduced smoke emissions, emitting less smoke than diesel fuel overall. The addition of B20 with CeO_2 nano additive results in a lower smoke emission value of 4.7. Compared to other blends, the tested B20 blend shows lower smoke emissions. This describes the clean combustion of the B20 mix when the CeO_2 nano-additive at 75 ppm is included, leading to reduced smoke emissions.

4. CONCLUSION

Several sectors prefer alternate sources, and the biodiesel blending procedure for diesel engines has undergone thorough testing.

This research examines the advantages of biodiesel blends for automobiles and machinery, investigating different amounts of blending and variations in load.

Algal biodiesel blends, ranging from B10 to B40, were produced by combining diesel with algal biodiesel and using 100% algae biodiesel. These blends were compared to diesel in terms of their result characteristics. Among the entire range of algae biodiesel options, B20 stands out as the most efficient, generating minimal amounts of pollutants. This mixture possesses the capacity to decrease pollution levels and improve overall performance.

In addition, we incorporated aluminum oxide and cerium oxide nano-additives into B20 algae blends at varying quantities for the purpose of conducting engine testing. The fuel quality of algal biodiesel is assessed using tests that adhere to ASTM criteria. During testing, the introduction of two nano-additives, aluminum oxide and cerium oxide nanoparticles, effectively reduces the fuel consumption for brakes.

To summarize, the thorough analysis of these different factors provides significant knowledge for attaining improved outcomes at all levels that were examined.

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