

# Combined Effects Of Thermal Barrier Coating And Blending With Nanoparticles On Usability Of Algae Biofuel In Diesel Engines

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## Abstract

The present study explores the combined influence of thermal barrier coating (500 $\mu$ m of YSZ + Al<sub>2</sub>O<sub>3</sub>) and higher compression ratios (18, 19, and 20) on the performance, combustion, and emissions of a diesel engine using diesel and algae biofuel blends with cerium oxide nanoparticles (BD20CeO<sub>2</sub>200 and BD100CeO<sub>2</sub>200). Increasing compression ratio (CR) with thermal barrier coating significantly boosts in-cylinder pressure, temperature, and density of air-fuel charge, leading to improved spray characteristics and more efficient combustion of the blended fuel. These improvements are also attributed to the nanoparticles' catalytic effect and high surface-to-volume ratio. A peak brake thermal efficiency of 28.38% was achieved at the lowest brake specific fuel consumption of 0.22 kg/kWh for BD20CeO<sub>2</sub>200 at higher CR (20) with thermal barrier coating (500 $\mu$ m). For all the test fuels, at higher CR with thermal barrier coating resulted in a notable reduction in the HC (5.45%), CO (12.6%), and NO<sub>x</sub> (8%) emissions. Furthermore, engine modification with a thermal barrier coating at higher compression ratios showed superior results compared to the uncoated engine, with a 7% increase in peak pressure, a 6.8% rise in heat release rate, and an 11.36% reduction in ignition delay for BD20CeO<sub>2</sub>200. The experimental findings indicate that adding 200 ppm of cerium oxide (CeO<sub>2</sub>) nanoparticles as a fuel additive into a small volume (BD20) of the algae biofuel blend, combined with a high CR ( $\geq 18$ ) with thermal barrier coating (500 $\mu$ m), significantly enhanced overall engine performance. This fuel blend emerges as a sustainable and practical alternative to conventional fuels.

**Keywords:** Algae biofuel, Cerium oxide. Performance Combustion Emission

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## 1. INTRODUCTION

Among the various alternatives explored for the conventional petrodiesel, biofuels provide improved performance and reduced exhaust emissions without any modifications. Several countries, including India, are partially replacing the conventional petrodiesel with a small content of biofuels. Being the most capable biological producer of oil on the Earth and a resourceful biomass, algae is a promising substitute energy source. Based on the species, algae can produce varying proportions of different types of lipids, carbohydrates, and other complex oils in large quantities over a short time [1]. Thus, algae-based biofuels are a practical solution for the global energy crisis and future climate change due to their potentially high yield, high growth rate, biodegradability, nontoxicity, carbon neutrality, and low emission profile. Moreover, algae use nonarable land and nonpotable water [2].

Being a renewable substitute, biofuel has disadvantages such as poor atomisation, high NO<sub>x</sub> emission, carbon deposition, and high viscosity, which result in incomplete combustion. To address these disadvantages, researchers have suggested that algae biofuels should be modified by blending nanoparticles and emulsified fluids into them [3–11]. Cerium oxide (CeO<sub>2</sub>) is one of the most crucial metal oxide additives. CeO<sub>2</sub> nanoparticles act as antioxidants, have a low cost, are corrosion inhibitors, and have an anti-wear property. Shaafi et al., Subramanian et al., and Tomar et al. [18–20] reviewed the influence of the dispersal of different nano-additives on the diesel engine characteristics operated with diesel, biofuel, and diesel-biofuel blends. They reported that nano-additives enhanced the test fuel attributes such as flash point, fire point, viscosity, and density depending on their dosage. Thus, the evaluation of the optimum dosage of nano-additives is crucial. Ashok et al., Javed et al., and Kumar et al. [21–23] determine the advantages, and complexity of using nanoadditives in biofuel for CI engines. They prefer nanoparticles of metal and metal oxides for enhancing the overall engine performance with reduced emissions. Such enhancement would enable the conservation of fossil fuels and the reduction of air pollution. These enhancements occur because of the catalytic effect of the nanoparticles, improved heat transfer rate, and evaporation of water particles present in the blend. Boutonnet et al., Basha et al., and Anand et al. [24–26] reported that the use of metal-based nanoparticles in

blends has increased surface energy because of its enhanced surface to volume ratio, reactivity, and cetane number along with lower viscosity attributed to promoting clean and complete combustion.

Selman et al. [22] investigated the waste cooking biodiesel usage in a coated ( $ZrO_2$ ,  $MgO$  and  $Al_2O_3$ ) diesel engine. Such modification of the engine resulted in better performance with decreased fuel consumption. Also, engine emissions were lowered excluding the nitrogen oxides emission. Hanbey et al. [23] applied the thermal barrier coating material ( $MgO-ZrO_2$ ) on engine parts for canola biodiesel blends. He noted increment in engine power and decrement in specific fuel consumption, along with major enhancements in emissions and smoke for all test fuels employed in the coated engine compared to the uncoated one. Prasath et al. [24] compared the outcomes of experimental data with prediction model for LHR engine using partially stabilized zirconia coating and *Jatropha* biodiesel. They found that the presented model includes Wiebe's heat release model and extended Zeldovich mechanism can predict the overall engine characteristics in good agreement with the experimental results. Aydin et al. [25] experimentally investigated the usage of vegetable biofuels in a coated ( $ZrO_2$ ) CI engine. Major enhancements in performance parameters along with slight declines in emissions with coated engine was noted. Taymaz et al. [26] investigated the heat losses at various engine loads and speeds with as well as without ceramic-coated multi-cylinder CI engine. They observed reduced heat losses to the coolant, improved thermal efficiency, and increased exhaust energy across all load conditions. Jaichandar et al. [27] reviewed the outcome of insulation on overall engine characteristics. They found conflicting results are probably due to the different LHR engine configurations, operating test conditions, and the analysis techniques used. Musthafa et al. [28] compared the outcomes of coated as well as uncoated engines at similar operating conditions. Waste material, fly ash, was employed as a thermal barrier coating material. Test results confirmed major enhancements in performance characteristics, along with a slight decline in emissions for the coated engine. Azadi et al. [29] reviewed the outcomes of thermal barrier coatings on diesel engine performance and its components. They conclude that NiCrAlY with 150 microns thickness and another layer made of  $ZrO_2-8\%Y_2O_3$  with 300 microns thickness by using the plasma thermal spray method gives overall better engine performance parameters and fatigue lifetime of engine components. Shabir et al. [30] reviewed the influences of thermal barrier coatings on LHR engine characteristics. They conclude that the decrement of heat losses in LHR engines is more beneficial in turbocharged engines than the naturally aspirated engines. Ramu et al. [31] investigated the combined impact of thermal barrier coating and fuel additives, revealing enhanced engine performance along with a simultaneous reduction in smoke and  $NO_x$  emissions.

The objective of this study is to examine the combined effects of thermal barrier coating (500 $\mu$ m) and higher CR (18, 19, and 20), on the overall engine characteristics of a DI diesel engine using diesel and algal biofuel blends with  $CeO_2$  nanoparticles. The blends were examined for their suitability as substitutes to the conventional fuel.

## 2. Experimental setup

The experimental setup consisted of a single-cylinder, four-stroke, direct-injection (DI), variable compression ratio (VCR), and compression ignition (CI) engine, coupled with an eddy current dynamometer for applying load. The setup was equipped with crucial instruments such as an in-cylinder pressure transducer, a crank angle encoder, a fuel flow measurement system, thermocouples, and a strain gauge load cell interfaced with a computer through a prompt data acquisition device. A Kistler piezoelectric pressure transducer was positioned at the center of the cylinder head to minimize errors. The sensor's output was amplified, digitized, and recorded at intervals of every 1° crank angle (CA). To account for cycle-to-cycle variations, in-cylinder pressure data were collected over 10 consecutive cycles, and the average pressure was utilized for analysis. Hence, combustion parameters, such as the in-cylinder pressure, net heat release, ignition delay, peak pressure, and crank angles, were measured with an accuracy of 0.1 [6]. A specially designed tilting cylinder block arrangement allowed the compression ratio (CR) to be varied without shutting down the engine or modifying the combustion chamber geometry. The fuel consumption was determined by employing a calibrated burette, while the air volume flow rate was determined with the help of an airbox and a U-tube manometer. A mechanical fuel injection pump was used to inject the test fuels at a pressure of 210 bar with an injection advance of 23° top dead centre. Exhaust gas emissions were analyzed using a five-gas analyzer, while the engine performance monitoring system utilized EngineSoft, a LabVIEW-based software package.

The detailed engine specifications are provided in Table 1, and the schematic of the experimental setup is shown in Fig. 1. The engine was run at a steady speed of 1500 rpm with a constant air intake and cooling water flow rate under various loading conditions. Prior to actual engine testing, all the instruments, sensors, and thermocouples were calibrated to obtain accurate results. Standard diesel was utilized for initiating and warming up the engine. Additionally, all tests were conducted, and parameters measured under steady-state conditions. The experimental test matrix is presented in Table 2.

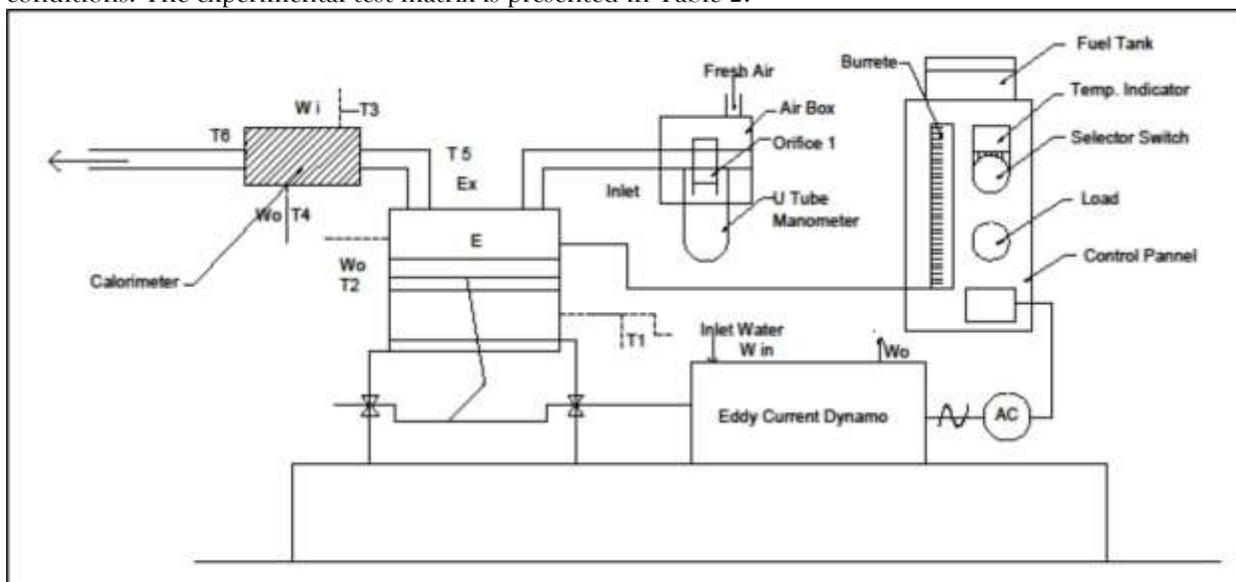


Fig.1. Schematic of engine setup.

Table 1 Engine specifications.

Make	KirloskarTAF1
Orientation	Vertical
Type	Direct injection, Singlecylinder,4-Stroke
Arrangement of valves	Overhead
Bore &Stroke(mm)	87.5 & 110
Compression ratio	18:1
Engine capacity	0.661 lit
Rated power	3.5 KW
Rated speed	1500 rpm
Start of injection	23 <sup>o</sup> b TDC
Dynamometer	Eddy current
Cooling system	Water cooling
Injection pressure	200 bar

Table 2 Test matrix of experimentation.

Parameters	Levels				
	1	2	3	4	5
Load (%)	0	25	50	75	100
Speed (rpm)	1500	~	~	~	~
Biofuel blends (%)	BD0	BD20+ CeO <sub>2</sub> 200	BD100+ CeO <sub>2</sub> 200	~	~
Compression ratio	18	19	20	~	~

### 2.1 Blending of algae biofuel blend with CeO<sub>2</sub> nanoparticles as a fuel additive

Ceria is a naturally occurring rare earth material, derived from the element cerium (Ce). It is highly stable and is most commonly utilized in the form of cerium dioxide (CeO<sub>2</sub>). The fuel samples are prepared in two stages for the experiment (Figure 2-4). Initially, the transesterification technique was used so that the raw biofuel oil attained diesel-like properties. Nano-emulsion is prepared with the algae biofuel. The nanofluid comprised nanoparticles and distilled water.

Due to the insoluble nature of CeO<sub>2</sub> nanoparticles, CeO<sub>2</sub> is first dispersed in distilled water, and then dispersed in biofuel through ultrasonication. In this method, 200 ppm of CeO<sub>2</sub> is weighed using a precise weighing balance. The CeO<sub>2</sub> is then scattered in distilled water, which constitutes 5% of the total volume of the fuel sample, through ultrasonication of the liquid at 50 kHz for 30 minutes. The prepared nanofluid is added to the algae biofuel, and the mixture is stirred with a mechanical stirrer at an optimal speed of 1500 rpm to prepare the emulsified fuel.

Physico-chemical properties of algae biofuel blends with CeO<sub>2</sub> nanoparticles as fuel additive and standard diesel.

Sr. No.	Property	Unit	Ref. Std. ASTM 6751	Diesel	BD20+	BD100+
					CeO <sub>2</sub> 200	CeO <sub>2</sub> 200
1	Density	Kg/m <sup>3</sup>	D1448	830	839	858
2	Calorific Value	KJ/Kg	D6751	42500	42190	41880
3	Cetane Number	~	D613	49.5	50.5	51
4	Viscosity	mm <sup>2</sup> /s	D445	2.7	2.94	3.17
5	Flash Point	°C	D93	64	75	82



Figure 2 Mechanical stirrer for mixing



Figure 3 Mixing of solution in an ultrasonic homogenizer



Figure 4 Final prepared sample for testing (AOME BD100 + 200PPM  $\text{CeO}_2$ )

### 2.2 Thermal barrier coating of engine components

The piston, valves and cylinder head of the test engine were coated with  $500\mu\text{m}$  material of thermal barrier coating that includes  $100\mu\text{m}$  of NiCrAl,  $350\mu\text{m}$  of YSZ and  $50\mu\text{m}$  of  $\text{Al}_2\text{O}_3$ , by employing the plasma spray method. Prior to applying the coating, the surfaces of the chosen engine components were grinded and removed an equal amount of base material and then the coating material is applied uniformly. After the coating was deposited, the piston surface underwent sandblasting to enhance surface roughness and improve the adherence of the coating to the substrate. Thus, the CR of the test engine was remaining same.

The  $100\mu\text{m}$  coating of NiCrAl was applied to the top of the piston crown as a bond coat and then the  $350\mu\text{m}$  of YSZ and  $50\mu\text{m}$  of  $\text{Al}_2\text{O}_3$  as a ceramic coating. YSZ and  $\text{Al}_2\text{O}_3$  were chosen as thermal barrier coating materials due to their exceptional thermo-material properties, including low thermal expansion, low thermal conductivity, high resistance to thermal shock, and stability at elevated temperatures. Figure 8 displays photographs of the coated components of the test engine.



**Figure 8** Coated piston, valves and cylinder head

### 2.3 Error and uncertainty analysis

In any equipment-based analysis, there is always a possibility of metrological errors and uncertainties arising from factors such as calibration, incorrect selection, observational inaccuracies, and ambient conditions. Therefore, conducting an uncertainty analysis is essential to validate the accuracy of the experiment. This analysis aims to establish a relationship between input variables and the uncertainties encountered during testing. The overall uncertainty in the process was determined by applying the RMS method to the percentage uncertainties of individual equipment, as outlined in Table 4. To reduce measurement errors, three readings were taken for all parameters, and the average values were used for reporting. The following equations were applied to acquire the value of total uncertainty in the process where,

Total uncertainty (TU) =  $\sqrt{\{(\text{uncertainty of BP})^2 + (\text{uncertainty of SFC})^2 + (\text{uncertainty of brake thermal efficiency})^2 + (\text{uncertainty of CO})^2 + (\text{uncertainty of HC})^2 + (\text{uncertainty of NOx})^2 + (\text{uncertainty of EGT})^2 + (\text{uncertainty of pressure pick up})^2\}}$

$TU = \sqrt{\{(0.2)^2 + (1.5)^2 + (0.2)^2 + (0.15)^2 + (0.2)^2 + (0.2)^2 + (0.15)^2 + (1.0)^2\}}$

$TU = \pm 1.8587\%$

**Table 4** Accuracy and uncertainty of equipment

Sr. no.	Instruments	Calibration Range	Accuracy	Uncertainty (U)(%)
1.	Exhaust Gas Analyzer	CO: 0-10%	$\pm 0.02$	$\pm 0.2$
		CO <sub>2</sub> : 0-20%	$\pm 0.03$	$\pm 0.15$
		HC: 0-10,000ppm	$\pm 20$ ppm	$\pm 0.2$
		NO <sub>x</sub> : 0-5000ppm	$\pm 10$ ppm	$\pm 0.2$
2.	Exhaust gas temperature	50 to 500°C	$\pm 1^\circ\text{C}$	$\pm 0.1$
3.	Speed Indicator	0-5500 RPM	$\pm 10$ RPM	$\pm 0.1$
4.	Load Indicator	0-50 kgs	$\pm 0.1$ kgs	$\pm 0.2$
5.	Burette measurement	0- 500 CC	$\pm 2$ CC	$\pm 0.2$
6.	Manometer	0-50 mm	$\pm 1$ mm	$\pm 1$
7.	Crank Angle Sensor	0-360°	1°	$\pm 1$

## 3. RESULTS AND DISCUSSION

### 3.1 Performance analysis

#### 3.1.1 Brake thermal efficiency

Generally, higher CR enhances the BTE of the engine. Changes in the BTE percentage with higher CRs, uncoated as well as coated engines for diesel, BD20CeO<sub>2</sub>200, and BD100CeO<sub>2</sub>200 are displayed in figure 4. The observation is that the BTE is improved with raising the compression ratio for all test fuels, coated and uncoated engine operation. Increasing the compression ratio (CR) from 18 to 20 led to an approximate 4% improvement in brake thermal efficiency (BTE) for all test fuels. This can be attributed to better mixing of oxygenated biofuel with nanoparticles at higher in-cylinder pressure and temperature causes reduced ignition delay and complete combustion. The graph indicates that the brake thermal efficiency (BTE) increases by up

to 7% for a 500 $\mu$ m coating across all test fuels. This improvement can be attributed to the reduced heat rejection from the walls of the engine's combustion chamber, resulting from the thermal barrier effect, which leads to higher in-cylinder combustion temperature and BTE values.

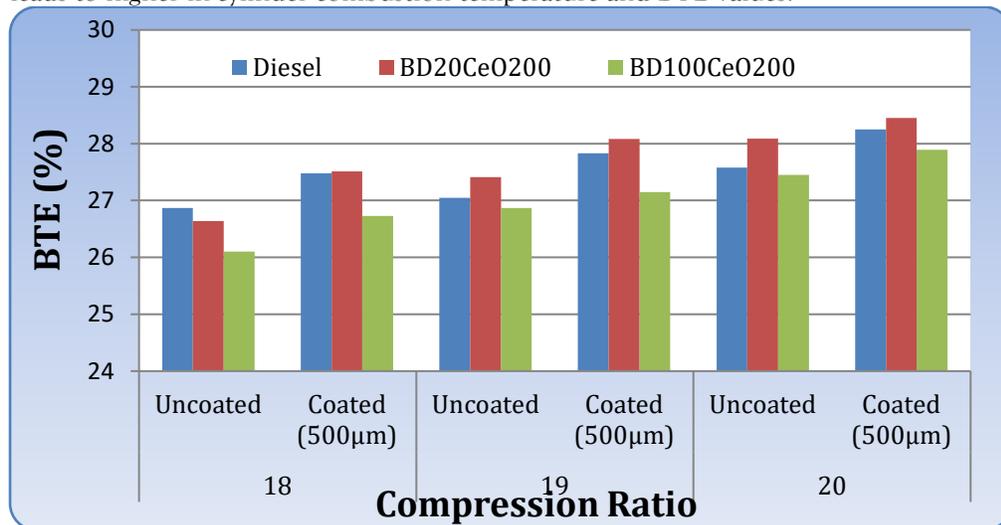


Figure 4 Variation in the BTE for different fuels with higher CRs uncoated as well as coated engines

### 3.1.2 Brake specific fuel consumption

The variations in the BSFC with higher CRs uncoated as well as coated engines for diesel, BD20CeO<sub>2</sub>00, and BD100CeO<sub>2</sub>00 are illustrated in figure 5. The BSFCs of all test fuels decreased on an average by 6% at full load condition, respectively, when the CR was increased from 18 to 20. This illustrates that raising the CR had more beneficial for biofuel blends with nanoparticles than with diesel. Due to their low volatility and higher viscosity, nanoadditive biofuel blends might be performing relatively superior at higher compression ratios. Also, while comparing the coated and uncoated engines, it is found that the coated engine operation resulted in lower BSFC values (approximately 11%) for all the test fuels. Relatively higher in-cylinder combustion temperatures reduced the density while increasing the rate of vaporization and burning of test fuels, which lead in consuming lesser fuel to develop same amount of power.

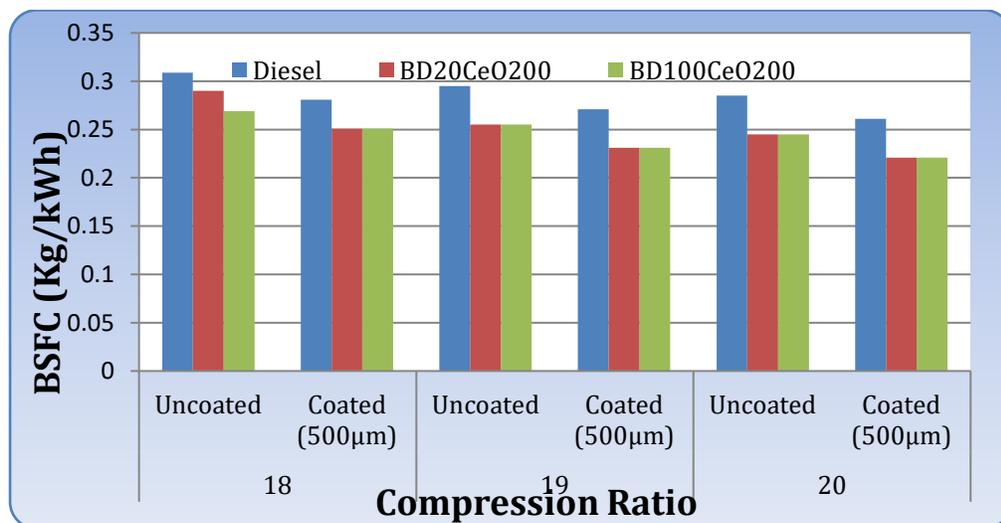


Figure 5 Variation in the SFC for various fuels with higher CRs uncoated as well as coated engines

## 3.2 Combustion analysis

### 3.2.1 Cylinder pressure

Cylinder peak pressure is a key parameter reflecting the efficacy of the combustion process. The change in the peak pressure for the diesel, BD20CeO<sub>2</sub>00, and BD100CeO<sub>2</sub>00 with higher CRs uncoated as well as coated engines is illustrated in Figure 6. Under the full-load condition, the change in the CR from 18 to 20 resulted in approximately 5%, 7%, and 8% increment in the peak pressure for the diesel, BD20CeO<sub>2</sub>00,

and BD100CeO<sub>2</sub>200, respectively. This can be attributed to the higher CR, which increases the air pressure and temperature inside the cylinder consequently reducing the ignition lag, causing better and more complete burning of the fuel. While comparing with LHR engines, a minor reduction in peak pressure was noted for the conventional engine for all test fuels. It can be attributed to the reduction in in-cylinder combustion temperature and total heat release than LHR engines. The maximum peak pressure values were obtained for the diesel (73.1 bar), BD20CeO<sub>2</sub>200 (73.9 bar), and BD100CeO<sub>2</sub>200 (72.89 bar) in coated engine operation at full load condition.

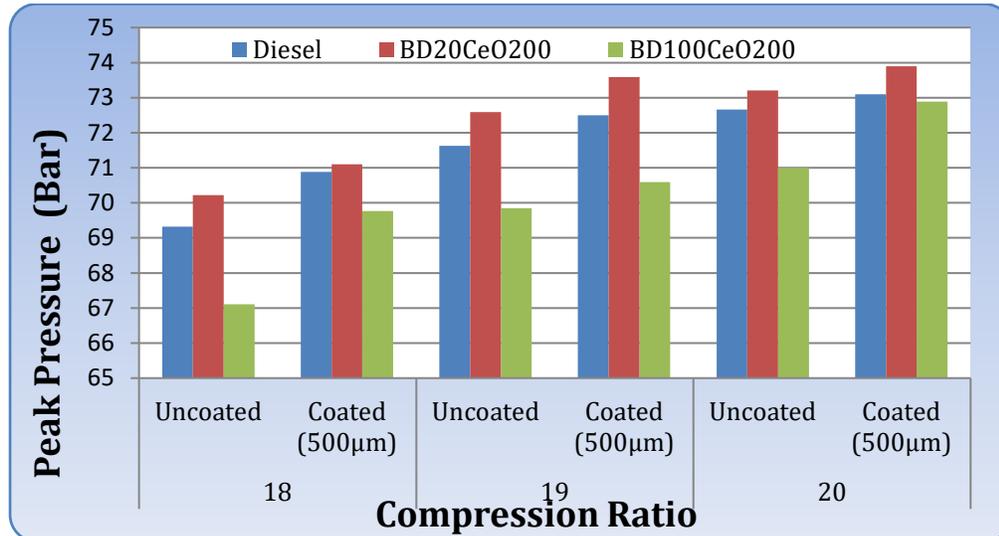


Figure 6 Variation in the CP for various fuels with higher CRs uncoated as well as coated engines

### 3.2.2 Ignition delay

Figure 7 displays the change in the ignition delay (ID) with higher CRs uncoated as well as coated engines for the diesel, BD20CeO<sub>2</sub>200, and BD100CeO<sub>2</sub>200. Under the full-load condition, the delay period decreased by 7%, 8.5%, and 11% on average for the diesel, BD20CeO<sub>2</sub>200, and BD100CeO<sub>2</sub>200, respectively, when the CR was increased from 18 to 20 along with the thermal barrier coated engine. The addition of CeO<sub>2</sub> nanoparticles to the biofuel blend likely served as heat carrier media, enhancing heat transfer between the fuel droplets and air. This increased heat flow may have accelerated the evaporation of fuel droplets, thereby shortening the delay period. Also, the comparable cetane number, oxygenated nature and higher in-cylinder combustion temperature of BD20CeO<sub>2</sub>200, and BD100CeO<sub>2</sub>200 are thought to reduce ignition delay significantly.

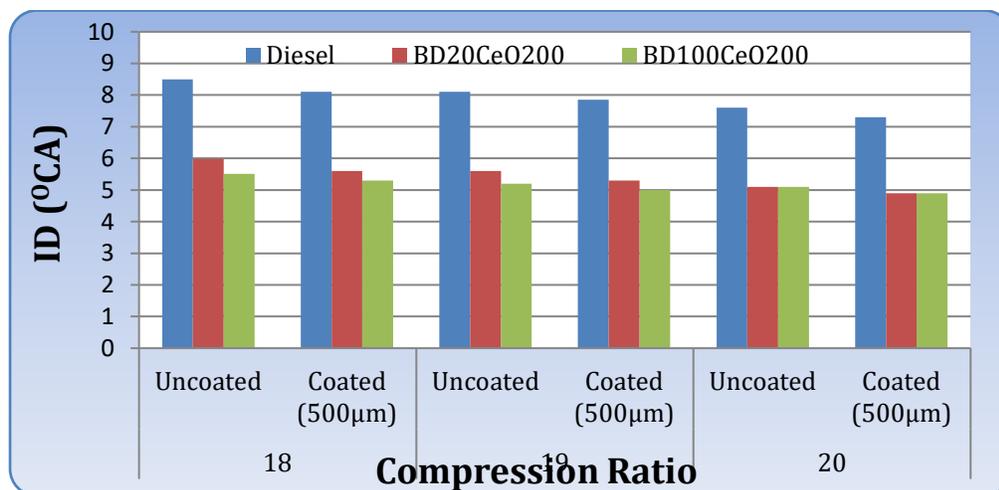


Figure 7 Variation in the ID for various fuels with higher CRs uncoated as well as coated engines

### 3.2.3 Net heat release

Figure 8 depicts the net heat release with respect to the crank angle for the diesel BD20CeO<sub>2</sub>200, and BD100CeO<sub>2</sub>200 at higher CRs uncoated as well as coated engines. Under the full-load condition, the change in the CR from 18 to 20 along with the thermal barrier coating resulted in a 5.15%, 5.85%, and 6.8% increment in the heat release rate (HRR) for the diesel, BD20CeO<sub>2</sub>200, and BD100CeO<sub>2</sub>200, respectively. This occurs due to a shorter ignition delay and higher in-cylinder combustion temperatures induced by thermal barrier coating, resulting in a lowering of the higher viscosity and density of the test fuels leads to better combustible mixture formation and burning. At the full-load condition, the HRRs of the algae biofuel blends exhibited a decreasing trend than the HRRs of diesel. However, during the controlled combustion phase, an improved calorific value, a high surface-area-to-volume ratio of the nanoparticles, and the oxidising nature of the biofuel blends accelerated hydrocarbon combustion. Furthermore, continued combustion during the late phase contributed to enhanced energy release and minimized unburnt hydrocarbon losses in the exhaust.

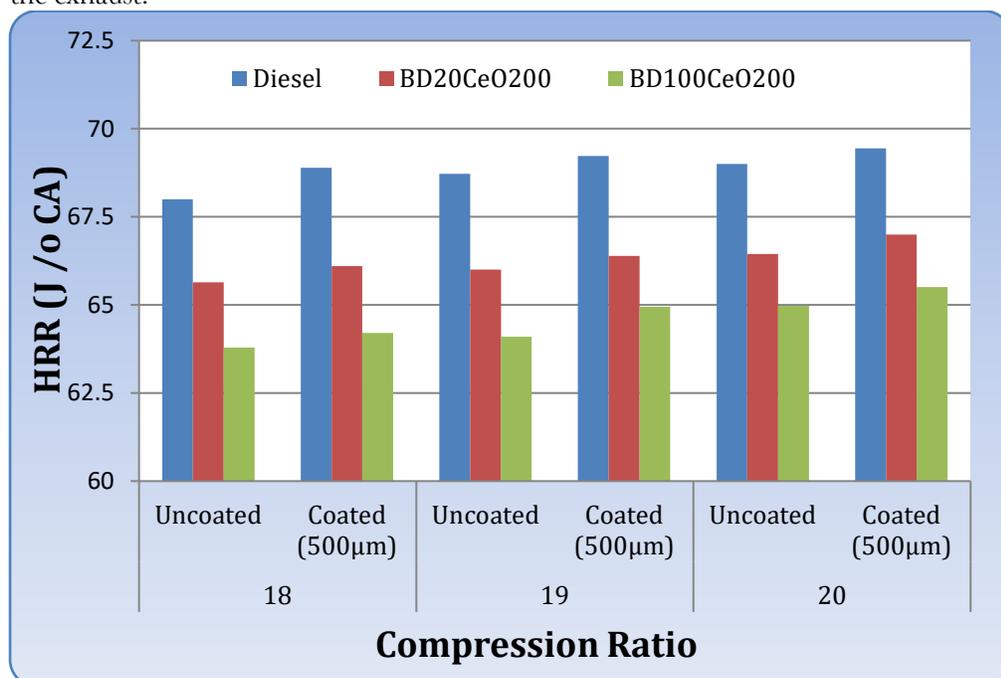


Figure 8 Variation in the HRR with the crank angle for different blends at higher CRs uncoated as well as coated engines

### 3.3 Emission analysis

#### 3.3.1 Hydrocarbon

Changes in the HC emission with higher CRs uncoated as well as coated engines for diesel, BD20CeO<sub>2</sub>200, and BD100CeO<sub>2</sub>200 are displayed in figure 9. HC concentration generally decreases with the addition of oxygenated biofuels, along with the catalytic action of nanoceria. Such oxygen enrichment with higher in-cylinder combustion temperature is favorable to the oxidation of HC in the later phases of combustion, which results in complete and clean combustion, henceforth decreasing the HC emissions. For the algae biofuel blends with nanoparticles, the HC emission reduced by approximately 5.45% when increasing the CR from 18 to 20 for a low heat rejected engine. At lower compression ratios (CR), inadequate heat of compression delays ignition, resulting in increased hydrocarbon (HC) emissions. Figure 9 clearly illustrates that the average HC emissions were slightly reduced during the operation of the coated diesel engine. The Low Heat Rejection (LHR) concept plays a crucial role in raising in-cylinder combustion temperatures, enhancing the evaporation of test fuels, and promoting oxidation of unburnt hydrocarbons.

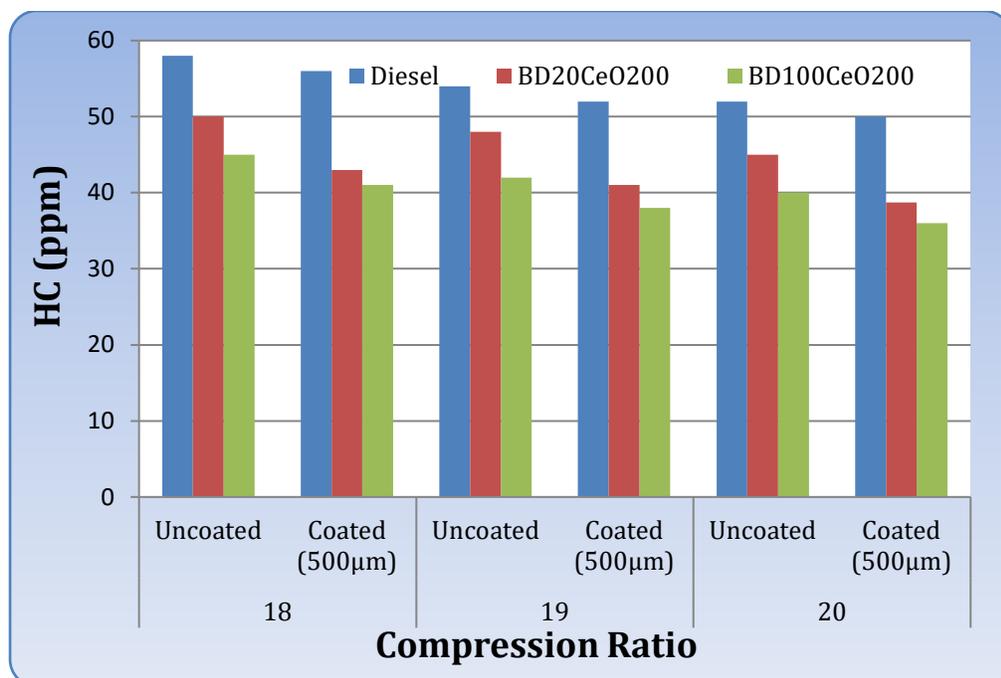


Figure 9 Variation in the HC emissions for various fuels with higher CRs uncoated as well as coated engines

### 3.3.2 Carbon monoxide

Carbon monoxide (CO) is primarily formed due to insufficient oxygen available for complete oxidation. Figure 10 illustrates the variation in CO emissions for diesel, BD20CeO<sub>200</sub>, and BD100CeO<sub>200</sub> fuels at higher compression ratios (CRs) in both uncoated and coated engines. At elevated CRs, the combustion rate increases due to the higher in-cylinder temperatures induced by the thermal barrier coating, reduced pre-mixed combustion, oxygen enrichment, and enhanced turbulence within the combustion chamber contribute to more complete and cleaner combustion. As a result, CO emissions decrease. In the coated engine, the average CO emissions for the test fuels are observed to be 12.6% lower than those of diesel at a CR of 20 under full load conditions.

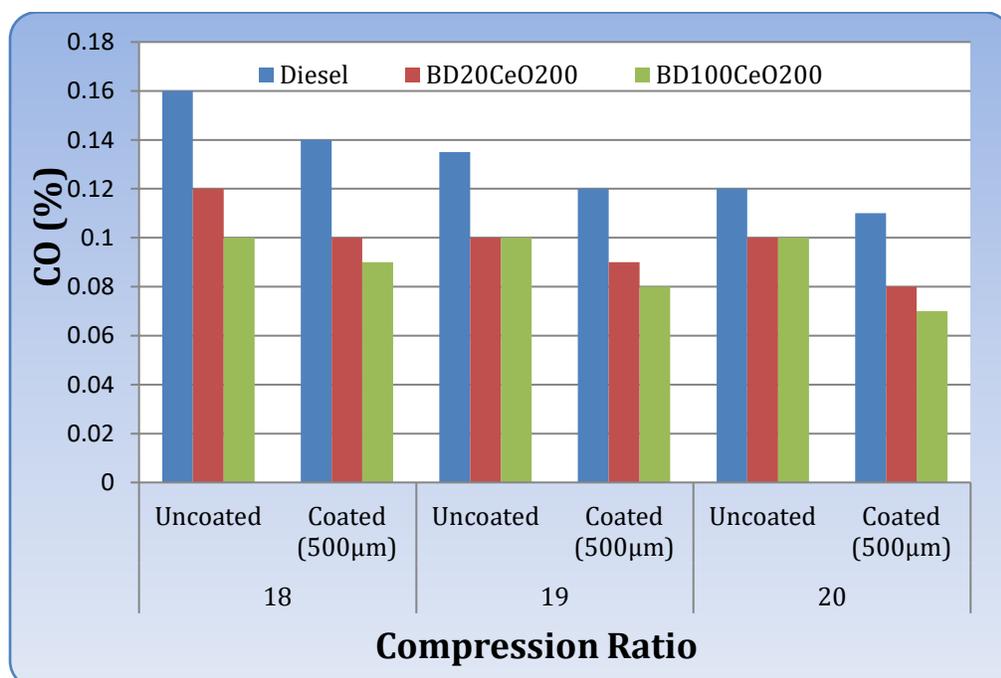


Figure 10 Variation in the CO emissions for various fuels with higher CRs uncoated as well as coated engines

### 3.3.3 Nitrogen oxide

Figure 11 shows the variation in NO<sub>x</sub> emissions for diesel, BD20CeO<sub>2</sub>200, and BD100CeO<sub>2</sub>200 at higher compression ratios (CRs) in both uncoated and coated engines. It was observed that NO<sub>x</sub> emissions increased with rising CR, both with and without coating, across all test fuels and load conditions. On average, NO<sub>x</sub> emissions were 10% higher in coated engines and 8% higher in uncoated engines when the CR increased from 18 to 20. This rise is attributed to the homogenization of the oxygenated, denser combustible mixture, lower oxidation stability, longer reaction times, and thermally rich conditions, including elevated peak combustion temperatures and pressures.

However, cerium oxide (CeO<sub>2</sub>) plays a crucial role in the reduction of NO<sub>x</sub> emissions due to its excellent redox properties. Initially, CeO<sub>2</sub> reacts with hydrocarbons, leading to its partial reduction to cerous oxide (Ce<sub>2</sub>O<sub>3</sub>). This reduced form subsequently interacts with nitrogen oxides (NO<sub>x</sub>), facilitating an oxidation reaction that converts Ce<sub>2</sub>O<sub>3</sub> back to CeO<sub>2</sub>. During this process, NO<sub>x</sub> is reduced to molecular nitrogen (N<sub>2</sub>), effectively lowering harmful emissions. The overall transformation and formation of nitrogen are represented in Equations 1 and 2.

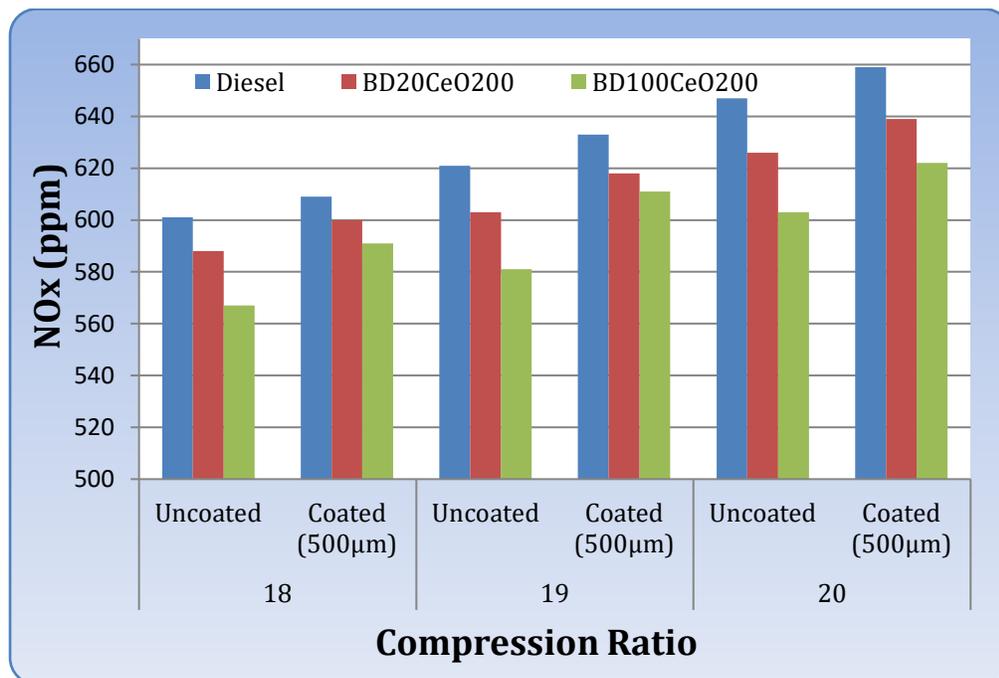


Figure 11 Variation in the NO<sub>x</sub> emissions for various fuels with higher CRs uncoated as well as coated engines

## 5. CONCLUSION

The present study was conducted to investigate the combined influence of thermal barrier coating (500µm) and higher CR (18, 19, and 20), on the performance, combustion and emissions of a DI diesel engine using diesel and algal biofuel blends with CeO<sub>2</sub> nanoparticles. Measures were undertaken to improve combustion and performance characteristics while minimizing emissions. The conclusions of this study are summarised as follows:

- The addition of CeO<sub>2</sub> in the form of emulsified nanofluid as a fuel additive is a promising approach for efficiently improving the overall fuel properties of the algae biofuel blends.
- An increase in compression ratio (CR) combined with thermal barrier coating boosts in-cylinder pressure, temperature, and the density of the air-fuel mixture, thereby improving spray characteristics and complete combustion of blended fuels. Additionally, the observed enhancements in overall engine characteristics were attributed to the catalytic effect, the high surface-to-volume ratio of nanoparticles, and the micro-explosion phenomenon of water particles within the fuel.

- As indicated by the experimental results, adding 200 ppm of cerium oxide (CeO<sub>2</sub>) nanoparticles as a fuel additive into a small volume (BD20) of the algae biofuel blend, combined with a high CR ( $\geq 18$ ) with thermal barrier coating (500 $\mu\text{m}$ ), significantly enhanced overall engine characteristics. This fuel blend emerges as a sustainable and practical alternative to conventional fuels.

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