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A neo emission reduction approach for minimizing atmospheric air pollutants using ternary fuel with pentanol and seaweed anti-oxidant in multi-cylinder diesel engine

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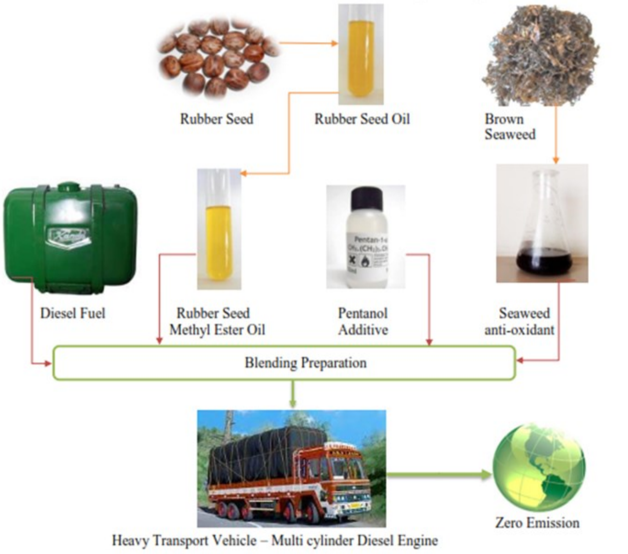
Graphical abstract



Abstract

This research examines the scope for reducing the air pollution caused by the transportation sector through the infusion of biofuel and antioxidants ensuring the partial replacement of conventional fuel. A four-stroke, direct-injection, multi-cylinder and constant-speed diesel engine was employed for the experimental analysis. The ternary fuel blend with a composition of 70% diesel fuel, 20% rubber seed oil and 10% of pentanol and sea weed extract in different ratios were blended to form B20, B20A1, B20A2 and B20A3. The experimental results showed smoke and carbon monoxide reduced by 4.71%, unburned hydrocarbons by 2.2 %. The NOx emission which was slightly higher compared to diesel but not higher than B20 for the blend B20A2 by 5%. The brake thermal efficiency was increased by 3.71% when compared to diesel fuel. Consequently, the B20A2 (5% seaweed and 5% pentanol additive with 70% diesel and 20% of rubber seed methyl ester oil) was found to be an environmentally biodegradable gasoline with the best emission properties. The study findings are quite promising for future which seeks towards zero emission with optimum quantity of biofuel to replace diesel.

Keywords: Multi-cylinder engine, bio-fuel, emission, rubber seed oil, seaweeds

1. Introduction

It has become highly unavoidable for the world nations to augment the road transportation especially heavy vehicles concerning the building up pressure on conserving the environment. But as on date diesel has been the ideal option for the heavy vehicle transportation. Abundant usage of diesel fuel automatically leads to pollution and has its impact in the quality of atmospheric air, climate change, global warming and also affects human health. It becomes imperative to tackle the fuel usage simultaneously focusing quality of air. To cater to this issue, this research attempts to use fuel which emits lesser pollutants and it should be renewable one too. The biofuel that is opted for this research is Rubber seed oil (RSO). Because vegetable oils, which have physical qualities akin to diesel fuel, may be produced from both edible and non-edible oil seeds. Rubber seed oil (RSO), which is cultivated extensively in Asian nations and is categorized as non-edible, demonstrates similar advantageous traits. Only 20%–30% of biodiesel can replace petro-diesel in engines in some situations without decreasing performance, according to experimental investigations [Rakopoulos C.D. *et al.*, (2005)]. Furthermore, it is crystal clear that biodiesel may reduce soot production and greenhouse gas emissions [Rosea R. *et. al.*, (2005)]. Additionally, it regenerates. However, as biodiesel includes more oxygen, it exhibits greater NOx emission, which was supposed to be the researcher's primary goal [Rao G. *et al.*, (2005)]. Exhaust gas recirculation, fuel reformulation, additive approaches, oxidation and anti-oxidation catalysts, diesel particle filters, and exhaust gas recirculation are a few of the solutions that researchers have created to decrease the negative impacts of engine exhaust [Senthil R. *et al.*,

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(2015)]. All of the various technologies used in biodiesel-fueled engines have undergone extensive evaluation [Altin R. *et al*., (2001)]. They found that for reducing NOx and PM emissions, the Low Temperature Combustion (LTC) mode outperforms other technologies, including biodiesel additives, emulsion technology (ET), water injection (WI), exhaust gas recirculation (EGR), modified injection strategies, simultaneous technologies (ST), and modified combustion chamber geometry. The onset of acid rain and ground-level ozone is significantly influenced by NOx emissions. Chronic NO exposure may be the cause of respiratory difficulties, cyanosis, and pulmonary edoema [Vedaraman N. *et al.*, (2011)]. The combustion can be enhanced by combining biodiesel with oxygenated gasoline additives, even though NOx emissions cannot be lowered [Amarnath H. K. and Prabhakaran P. (2012)]. Pentanol, one of the next-generation biofuels, is manufactured from renewable feedstock and includes five carbons in its molecular structure, which may assist to solve the pressing environmental and energy security challenges. Pentanol's increased physical volatility and reduced viscosity may improve its atomizing powers. Pentanol has a higher oxygen content, but it loses ignition quality due to its low cetane number [Anbarasu A. *et al.*, (2013)]. Alcohol is preferred as a fuel addition because it may reduce the viscosity of biodiesel and increase its cold flow characteristic [Sakthivel G. *et. al.*, (2014)]. When biodiesel and alcohol are combined, smoke emission is decreased [Jiaqiang E. *et. al.*, (2017)].

A proportional assessment of the impacts of alcohol on engine exhaust, combustion, and performance parameters when compared to diesel and biodiesel, respectively, was carried out [Innes W. B. (1987)]. Emphasized the benefits and drawbacks of employing alcohol and biodiesel as motor fuels. According to Qi D. H. *et. al.*, (2011), a blend of diesel fuel, biodiesel, and 1-heptanol (C7 alcohol), a next-generation advanced alcohol, was used to study the operation, combustion, and exhaust emission characteristics of a diesel engine. When utilized with diesel fuel and biodiesel-diesel fuel blends, they discovered that the oxygenated addition 1-heptanol boosted CO_2, O_2, and NO_X emissions while lowering CO and unburned HC emissions. The influence of combining biodiesel and anti-oxidants leads to improve the efficiency of the engines and reduced harmful gas emissions. The accumulation of alcohol mix increases NOx generation while reducing CO, HC, and PM emissions. It was evaluated how the increasing oxygen content affected full combustion and the rise in combustion temperature [Wei L. *et al.*, (2014)]. Numerous factors, including sustainability, enviro-economics, exergo economics, exergy, and energy, as well as the features of diesel engines that burn alcohol as an oxygenated fuel, were taken into consideration. Testing has shown that SFC is higher for blends of diesel that contain 20% 1-heptanol, compared to pure diesel [Liu H. *et al.*, (2015)]. In investigations on the effects of ternary safflower-diesel blends on various diesel engine components, it was discovered that there was an improvement in brake thermal efficiency and a decrease in brake-specific fuel consumption [Kanthavelkumaran N. and Kumaresh Seenikannan P. (2015)].

The addition of pentanol also led to a reduction in smoke, hydrocarbon, and carbon monoxide emissions. Antioxidant chemicals will significantly reduce NOx emission when added to biodiesel because they increase antioxidant stability [Sardjono R.E. *et al.*, (2019)]. Carotenoid and chlorophyll, which are typically present in seaweed plants [Yesilyurt M. K. (2020)], fruit, herbs, and medicinal teas [Zaharin M.S.M. *et al.*, (2017)], are able to lessen photo oxidation in addition to other foods. The oxygen structure present in carotenoids and chlorophyll could facilitate better biodiesel combustion and it was also proven the impact of bio based and biodiesel performance was analyzed [Dogan B. *et al.*, (2020)]. The amount and type of phenolic compounds in the feedstock used for the antioxidation effects as well as the freezing point of the feedstock used for the cold flow depressing influence affect the efficiency of the bio-based additives. Evident from the terminology that a thorough analysis of the properties of traditional diesel fuel and biodiesel mix fuel was given. Also discovered at the time was the absence of any evaluations of the effects of biodiesel additives. The major objective of this experiment is to assess the advantageous emission characteristics of a natural aspiration diesel engine using 20% rubber seed biodiesel mixed with diesel and an additive made up of a novel antioxidant derived from seaweeds and pentanol.

2. Materials and methods

A multi-cylinder, direct injection diesel engine was used to evaluate a range of biofuel blends with additives and a special antioxidant made from seaweed. The performance, emissions, and combustion properties of these blends were compared to those of regular diesel fuel. It was bought Rubber Seed Oil (RSO) at Selam, Tamil Nadu, India. KOH, methanol, sulfuric acid, and ethanol utilized in this study were all 99% pure. Transesterification can lower the greater level of unsaturated fatty acids seen in RSO. The transesterification procedures employed methanol (CH_3OH) as the alcohol and KOH and sulfuric acid as the catalysts. 1.5 hours of continuous stirring at 60°C were spent heating raw RSO, methanol, and 1.5 percent concentrated sulfuric acid. The biodiesel was separated from the other by-products by allowing the TRANSESTERIFICATION process' outputs to settle for eight hours in a separating funnel. The process of alkaline transesterification uses the first stage's product. Methanol and the byproducts of the first stage were heated for an hour at 55°C while being agitated constantly in the presence of KOH. The goods were then given time to settle for around 5 to 6 hours in a separating funnel. The surplus alcohol and catalyst were then removed from the biodiesel using distilled water.

2.1. Preparation of antioxidant

Using warm water heated to 50°C for 10 minutes, brown seaweed obtained from Palk Bay was processed. The cleaned leaves were heated to 70°C for 15 minutes in a hot air oven to eliminate the moisture. Then, to weaken the cell walls and enhance the surface area, it was cut into pieces that were between one and two millimeters in size.

20 ml of solvent, which is composed of 15 ml of ethanol and 5 ml of acetone, was combined with 100 g of leaf powder. All night the mixture was stirred often, and in the morning there was a lovely green opalescent liquid floating on top. The sediments were removed from the solution after three hours of being left alone. No. 1 filter paper was used to clean the extract. The filtrate was concentrated in a rotary evaporator at 40°C. The concentrated extract was oven dried at 40°C. for five days before being freeze dried for 2 days. Proteins, fatty acids, carotenoids, and chlorophyll were discovered in the concentrated extract by chemical analysis. This procedure produces an antioxidant supplement that may be administered right immediately. To get rid of the excess solvent, keep the antioxidant component at room temperature and in a dark area. When mixed with ethanol, the additive becomes more miscible with biodiesel.

2.2. TBC coating preparation

Table 1 shows the coating process parameters of piston, cylinder head and valves. Aluminum oxide and lanthanum oxide were employed, both of which were 99% pure. Sigma Aldrich, an Indian company, bought it. were utilized in materials TBC. For bond coat, partially stabilized Zirconia ceramic and aluminum alloy coted parts is acquired from METCO in Mumbai, India. Figure 1 shows the coated parts.

Table 1 Coating Process Parameter

Blast Parameter	Value
Erodent	Alumina grit
Flow rate	450g/min
Nozzle Dia.	3mm
Spray Distance	80mm

Figure 1 shows the PSZ coated engine parts–Cylinder head, Valves and piston crown

2.3. Engine setup and the test procedure

Four stroke diesel engine (direct injection, multi cylinder and 1500 rpm constant speed) was used to test the B20A1 (D70, B20, 7.5 percent pentanol plus 2.5 percent seaweed extract), B20A2 (D70, B20, 5 percent pentanol plus 5 percent seaweed extract), and B20A3 (D70, B20, 2.5 percent pentanol plus 7.5 percent seaweed extract) blends.

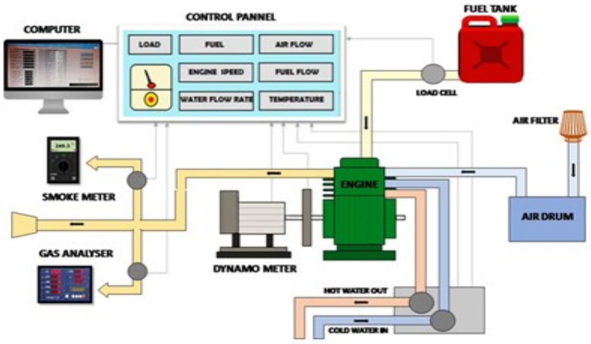

Figure 2 CAD Model for Experimental Setup

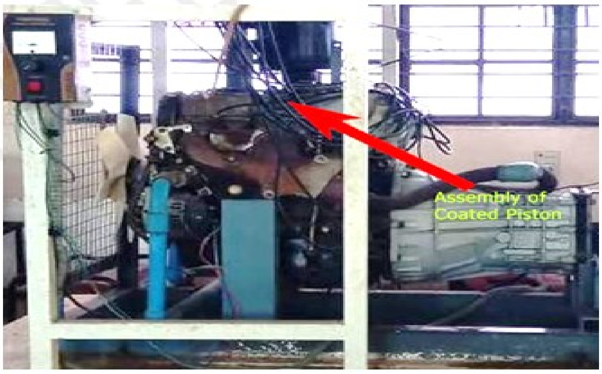

Figure 3 Assembly of coated piston with experimental setup

The above Figure 2 shows the cad model of the experimental set-up and Figure 3 shows the coated piston assembly in multi cylinder diesel engine. Each test fuel that was found has physical characteristics that are listed in Table 2. The engine performance and emission characteristics were examined under various loading conditions (0%, 25%, 50%, 75%, and 100%). After each loading, readings were taken after letting the engine run until it reached a steady state. Average values were taken into consideration while integrating all the data in order to reduce errors and measurement ambiguity. Table 3 shows the detailed information about the instruments used for experimental work. Table 4 gives engine specifications and information.

Table 2 Test Fuel Physical Properties

Properties / Fuel	Specific Gravity 25^{0}C	Kinematic Viscosity 40^{0}C (m^2/s)	Calorific Value (kJ/kg)	Flash Point (^{o}C)	Cetane Number
Methods	ASTM-D 5002	ASTM-D445	ASTM-D240	ASTM-D-93	ASTM D 613
Diesel	0.860	2.97	42000	55	46
B20	0.872	3.04	41168	67	52
B20A1	0.872	3.03	41157	65	51
B20A2	0.872	3.02	41154	63	50
B20A3	0.872	3.02	41151	60	47

Table 3 Detailed Specification of Measuring Equipment's

Measured quality	Instrument	Make
HC, NOx, CO	Gas Analyzer	AVL,Diges-444
Smoke Opacity	Smoke Meter	AVL-437
Cylinder Pressure	Pressure Pickup	PCB Pizotronics, S111A22
Exhaust Gas Temperature	Temp sensor	K-type
Position of TDC, BDC and		
Crank Angle	Angle Encoder	AVL364

Table 4 Test engine Specification

Engine Type	Inline, Four Cylinders
Cycle	4 stroke
Power (kW)	Standby: 18 & Prime 16.2
Speed (RPM)	1500 (Governed)
Firing Sequence	4-2-1-3
Bore (mm)	84
Stroke Length (mm)	100
Compression ratio	23:03:01
Injection Timing – Start	15° before TDC
Inlet / Exhaust Valve lash	/ 0.2 (default)

3. Results and discussions

3.1. Engine performance characterization

3.1.1. BSFC - brake specific fuel consumption

For each test fuel, Figure 4 displays the fuel consumption specific with respect to different engine loads. The BSFC of biodiesel made from rubber seed oil (RSO) and seaweed antioxidant was consistently greater than that of diesel, it is crucial to highlight. For all test fuels, BSFC normally decreases as engine load increases because braking power increases by a bigger amount. The BSFC of the engine observed at maximum rated output brake power of the engine exhibited as 0.395 kg/kWhr, 0.435 kg/kWhr, 0.405 kg/kWhr, 0.409 kg/kWhr and 0.422 kg/kWhr for DF, B20, B20A1, B20A2 and B20A3 respectively. The CV (calorific value) of RSO bio-diesel is overcome in the current study because additional fuel is added to the combustion chamber to provide the same amount of power. The seaweed extract's high antioxidant content and the physical properties of pentanol compensated for the defect and improved fuel economy. The B20A1 and B20A2 blends were outperformed as compared to B20 and B20A3 particularly at full engine load.

3.1.2. Brake thermal efficiency

Figure 5 shows the variance in brake thermal efficiency (BTE) with respect to Brake power (BP) for several test fuels. The three primary elements of BTE were thought to be a decrease in heat loss, an increase in power, and the conversion of fuel energy into mechanical output. The experiments showed that BTE increased with increasing engine load for all of the test fuels. Diesel had a maximum BTE of 27.2 % as opposed to B20, B20A1, B20A2 and B20A3, with 25.6%, 26.9%, 26.8% and 25.9%, respectively. The seaweed-based additive test fuels as a whole outperformed the B20 in terms of thermal efficiency.

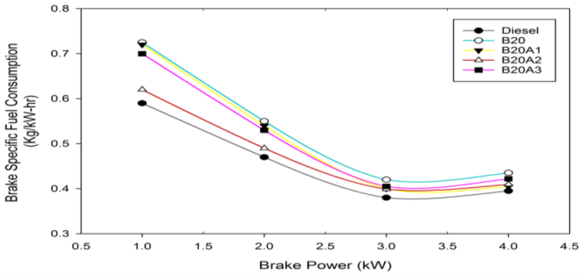

Figure 4 Values of BSFC for various loads and various test fuels

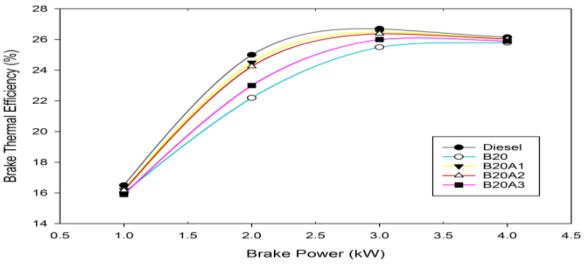

Figure 5 Values of BTE for various loads and various test fuels

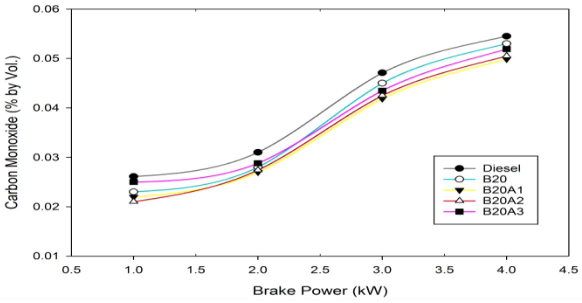

Figure 6 Values of CO Emissions with different load conditions and test fuels

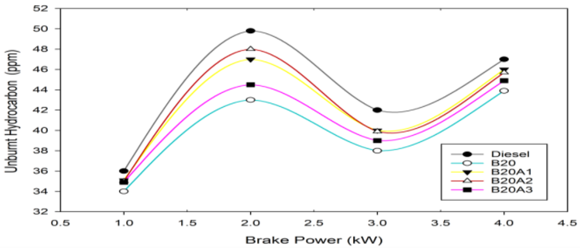

Figure 7 Values of UBHC Emissions with different load conditions and test fuels

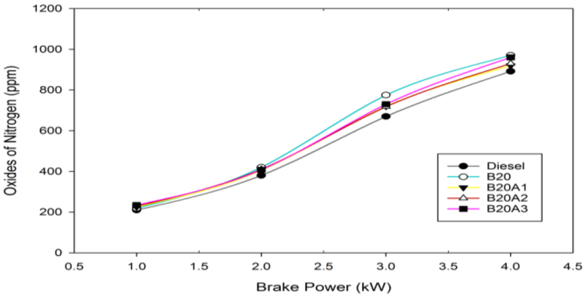

Figure 8 Values of NOx Emissions with different load conditions and test fuels

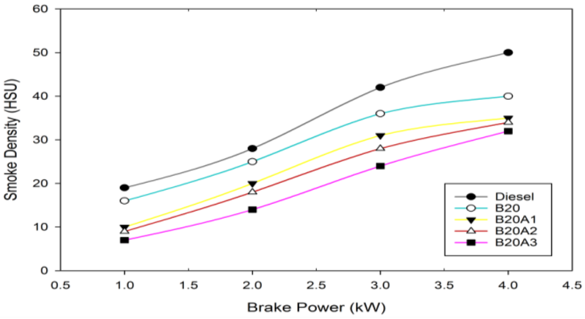

Figure 9 Values of Smoke Density with different load conditions and test fuels

3.2. Emission characteristics

3.2.1. Carbon monoxide emission

Carbon monoxide graphs for the test fuel with respect to various BP are shown in Figure 6 in comparison to the baseline fuel. The CO emissions of a product are the best indicator of its emissions. The test's results show that greater air-fuel ratios cause greater CO emissions. Since CO emission levels rely on the fuel's carbon, oxygen, and combustion efficiency levels, all of the test fuels had extremely low CO emission levels. B20A2 demonstrated a 4.71 percent decrease in CO emissions when compared to base diesel fuel.

3.2.2. Unburned hydrocarbon emission

Figure 7 depicts, for the various test fuels utilized in the experiment, the correlation between unburned hydrocarbon (UBHC) emission and engine load. Base diesel fuel had a higher UBHC of 47 ppm as compared to B20, B20A1, B20A2 and B20A3 respectively. The major cause of UBHC emissions is thought to be incomplete combustion when fuel and air are mixed in excess of the flammability limits. The quality of the gasoline, the conditions under which the engine operates, and the characteristics of the fuel spray all have an impact on UBHC emissions. According to a study of test fuels, biodiesel's viscosity properties led to a slightly higher emission of UBHC. Compared with antioxidants, reduced viscosity of biodiesel and increased its cetane number and oxygen content, resulting in an emission that was more ecologically friendly. When compared to low and high load, medium load showed the lowest UBHC emission. B20A2 produced 4.47 percent lesser emission than DF and outperformed compared with respect to blend B20.

3.2.3. NOx emission

The generation of NOx is facilitated by higher combustion temperatures. Free radicals are anticipated to be able to no longer contribute to NOx-producing events when biodiesel is burned in the flame to antioxidants. Figure 8 illustrates how the three test fuels' NOx emissions are impacted by brake power. All of the test fuels were shown to create more NOx when compared to the basic fuel. By blending chemicals with the biodiesel, the harmful NOx emissions were decreased. When a seaweed-based antioxidant was added to a biodiesel combination, B20A2 test fuel, B20A1 and B20A3 blends are all decreased NOx by around 6.8%, 7.2%, and 2.4% as compared to B20 respectively. The carotenoid's additive and free radical-scavenging effects were amplified by the addition of ethanol, which led to a drop in adiabatic flame temperature. The NOx emissions from B20A2 test fuel were 3.5% greater than those from base diesel fuel.

3.2.4. Smoke density

Figure 9 shows the smoke emission for various test mix fuels at an engine brake power levels. The results show that when engine loading increased, the smoke production of the whole test mix rose. During the peak load period, there was an excess of fuel that could not be burnt off fully, leading to an increase in smoke emissions. This problem can be resolved by using oxygenated fuel additives. The values observed at full load for the smoke density were 50HSU, 40 HSU, 35 HSU, 34 HSU and 30 HSU for DF, B20, B20A1, B20A2 and B20A3 respectively. The experimental study clearly shows that when the seaweed additive percentage in gasoline increases up to the B20A3 threshold, smoke emission reduces considerably.

4. Conclusion

Under the various operating conditions, engine testing, tests utilizing reference diesel fuel, quantity and quality techniques, and engine tests were conducted and analyzed the emission, performance and combustion characteristics as listed below.

1. Even after 100 hours of endurance testing, the coated parts were remained intact.
2. The bilayered coating's surface in the SEM picture exhibited consistently produced grains.

3. The ignition delay was decreased in fuel blends with biodiesel-diesel and seaweed additives.
4. The enhanced oxygen supply and quick combustion rate of the seaweed extract additions resulted in a slight increase in fuel consumption.
5. From the experimental results it was observed that the BSFC of the sea weed antioxidant test blends B20A1, B20A2 and B20A3 were reduced 6.8%, 5.7% and 2.9% lesser than B20 respectively in coated engine. At the same time, it is noted that B20A1 and B20A2 performed similar to diesel fuel.
6. The Carbon monoxide and Smoke emission of blends B20A1, B20A2 and B20A3 were 5.8%, 4.71% and 2.07% lesser respectively as compared to B20 in the coated engine.
7. Also Carbon monoxide and Smoke emission of all the test blends were lesser than the diesel fuel in coated engine. Whereas in case of the UBHC emission, there was slighter increment. It was increased by 4.5%, 2.2% and 1.25% for B20A1, B20A2 and B20A3 respectively compared to B20 but the emission was lesser when compared to base diesel fuel.
8. Contrarily the NOx emission of the sea weed additive biofuel in coated engine is higher than the diesel because of the high operating combustion temperature. This increment was attributed to the inherent physical and additive properties of antioxidant sea weed test fuels B20A1, B20A2 and B20A3. But still the test fuels were 5.1%, 5% and 3.2% lesser NOx as compared to B20 respectively.
9. On the whole, the sea weed antioxidant test blends B20A1, B20A2 and B20A3 had better performance with lower emission levels compared to diesel except the NOx emission. Even in that case too, NOx of the test blends were lesser when compared to that of the B20. The experimental analysis also inferred that the sea weed additive test blends B20A1 and B20A2 had almost the similar performance as the base fuel in coated engine. But between both the blends B20A2 was found to be superior as it assures more biodegradable with 5% composition of seaweed additive which is more ecofriendly than a chemical composition.

The experimental research results are hopeful for future which seeks for environmentally safer fuel. The coating of the engine components with PSZ and aluminum alloy for improving the adiabatic properties and the incorporation of biodegradable additives assured reduced polluting emission and improved efficiency. Also the optimum replacement of the conventional fuel is promising for improving the air quality by reducing the ill effects of greenhouse gases. The aforementioned cutting-edge study was clear that addition of seaweed extract to ternary fuel mixes is essential for increasing engine performance and lowering the emissions.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

Data availability statement

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

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