Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Enhancement of engine performance by nano-coated pistons fuelled with nano-additive biodiesel blends

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Biodiesel
Diesel engine
Nano-additive
Optimization
Thermal barrier coating

ABSTRACT

Researchers have been interested in making a more energy-efficient engine for a long time. This is because the use of fossil fuels like diesel has grown along with the need for more electricity, industry, and transportation. Thermal barrier coating (TBC) on engine parts has become more popular in recent years because it improves thermal and mechanical efficiency, reduces emissions, and saves fuel. In a similar way, biodiesel, which is safe and made from renewable sources of bioenergy, has been suggested as a good alternative to diesel. The present study aims to increase the efficiency of the diesel engine while simultaneously lowering emissions using a piston with a thermal barrier coating, engine operates on biodiesel blends, and a dosage of nano-additives to minimize emissions,. The engine efficiency of nano additives was found to be about 5.4% higher than that of base diesel, and with 6.5% better fuel consumption. Additionally, nano additives reduced carbon monoxide emissions in the range of 6.1–11% and hydrocarbon emissions in the range of 5.2–9.5%. The results were further analysed using the design of experiment tool to determine the influential parameters.

1. Introduction

Energy is a significant part of manufacturing expenses, thus conserving and managing it has become a critical industrial activity. As a result of this positive approach, worldwide patterns of energy usage have been altered. This has led to an increase in productivity, but a decrease in energy use, in wealthy countries. Finally, in today's rapidly expanding world, local and low-emission sources of renewable energy are just as important. Reducing pollution by fully using these resources might be very beneficial [1]. Research on internal combustion engines is being done with the goal of lowering fuel and operating costs and consumption. By decreasing heat rejection, upgraded ceramic coatings might boost engine performance and cut emissions. In addition, it's important to convert as much fuel energy as possible into usable mechanical energy. The combustion chamber of the engine has to be coated with high-tech ceramics that have a low heat transmission rate if these goals are to be realized [2].

Thermal barrier coating (TBC) on engine components has gained popularity recently due to improved thermal and mechanical efficiency, lower harmful pollution, and lower energy consumption. The waste heat from the engine's insulation may be used to oxidise soot precursors in hydrocarbon combustion, lowering emissions [3]. Ceramic materials excel in high temperature applications because of their high melting point, adhesion, and wear resistance. Ceramics may cover combustion chamber components due to their properties. A covered engine maintains heat better in the combustion chamber. So fewer emissions and fuel are created [4].

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https://doi.org/10.1016/j.matpr.2023.02.231
2214-7853/

An uncoated piston was tested against two coated pistons of varying thicknesses. The influence of biofuel was revealed by comparing results from studies utilising diesel for coated and non-coated pistons. A thicker layer reduces thermal efficiency, fuel use, and pollution [5]. Grey relational analysis improved the efficiency and pollution levels of a diesel engine covered with copper alloy. The copper-chromium-zirconium-coated piston is more efficient and produces less emissions [6]. Coatings made of zirconia are effective in reducing heat conduction. Glow plugs used with ethanol as a fuel reduce pollution while improving fuel efficiency. The thermal efficiency of the engine improves when the injection time is prolonged [7]. With a higher combustion temperature, pollutants like carbon monoxide (CO) and unburned hydrocarbons (UHC) are less likely to be decreases, whereas nitrogen oxide (NO) emissions increases [8]. A thermal barrier coating of aluminum silicate and zirconia with a nickel layer was tested in experiments with diesel and palm oil biodiesel to see how it would affect engine performance and emission levels. Their low emissions from fuel and biodiesel made them the greenest option [9].

Recent advancements in nanotechnology have opened the door for the development of nanoscale energetic materials, which provide significant benefits over materials that are just a few microns in size or larger. For a diesel engine to function well and emit low emissions, ignition temperatures and ignition delay are crucial characteristics to measure [1011]. Using the hot experiment, researchers aimed to enhance the igniting qualities of diesel fuel by incorporating aluminium oxide nano-particles (AONP) into the fuel. It was discovered that the ignition possibility for the nanoparticle combination was greater than the ignition probability for pure diesel in all of the scenarios investigated [12].

A novel low-cost feedstock for biodiesel manufacturing is being investigated in this study i.e.pumpkin seed oil. Pumpkin seeds have an astonishingly high oil content, according to the research. Pumpkin oil has been shown to be a suitable feedstock for biodiesel manufacturing, notwithstanding the study's findings [13]. Except for NO_x emissions, significant reductions in exhaust emissions such as CO, HC, and smoke were seen under high engine running conditions. Pumpkin seed biodiesel was shown to have excellent performance, combustion, and emission properties, making it a viable alternative to regular fuel provided the operating parameters of the engine are modified [14]. The alkali-catalyzed conversion of pumpkin seed oil into biodiesel resulted in a boron coated engine with enhanced performance characteristics, including a greater brake thermal efficiency and a lower brake specific energy consumption [15]. The study was carriedout to analysis the impact of alumina nanoparticle added biodiesel blend on engine behaviour, stability enhancement, and characterisation techniques to determine chemical bonding, nanoparticle form, and size, nano-additives in liquid fuel, health implications, and automotive applications [16]. Nanoparticle helps to boost the combustion and enhance the performance and minimize emissions [17].

The purpose of this research is to measure the performance and emissions of a single-cylinder diesel engine under varying loads. The purpose of this study is to investigate what happens when regular diesel is blended with pumpkin seed biodiesel at concentrations of 15% and 30% using AONP as a nano-additive. Based on the results of a "Full Factorial Design" experiment, the optimal ratios of biodiesel to AONP nano-additive dosage were determined, resulting in reduced fuel use, less UHC, and fewer carbon monoxide (CO_2) emissions.

2. Material and methods

Compared to other alternative fuels, biodiesel's many advantages stem from its chemical similarity to diesel fuel made from petroleum. Since biodiesel is competitive with conventional petroleum fuels in terms of engine efficiency, power production, climbing, and hauling, it is being increasingly adopted by the oil industry as a diesel replacement. Biodiesel behaves similarly to regular diesel in freezing temperatures, fogging up and gelling. In developing nations like India, diesel engines are increasingly vital for transporting people and products. Diesel engines are more efficient than gasoline engines because of their greater compression ratios, leaner air–fuel combinations, and less pumping losses [18]. Foreign financial outflows and environmental issues are exacerbated by this. Biofuels that are both renewable and have the same properties as diesel may be the answer to these problems [19].

Ceramics have weak thermal conductivity and expansion coefficient at high temperatures. Consequently, combustion chamber components are less effective in dissipating heat than metal or metal alloys. Only a few ceramic compounds have the necessary characteristics to serve as thermal barrier materials for covering components in the combustion chamber. The coated engine can retain the greatest heat at high combustion chamber temperatures because heat loss is reduced. High temperatures help complete combustion, limit pollutants, and save fuel [20]. The melting points, transition temperatures, minimum temperatures, thermal expansion coefficients, chemical composition, and compatibility with metallic substrates all played a role in the selection of these materials. In this test, a thermal barrier for an internal combustion engine was constructed out of a 200-μm layer of Yttria-stabilized zirconia (YSZ). There are several methods for insulating a surface. YSZ is coated by plasma spraying, and the powdered YSZ is sprayed onto the cylinder wall, where it melts and flows toward the piston to create a substantial coating [3].

In order to come closer together, nanoparticles are being pushed to the liquid surface as their concentration rises. Nanoparticles have a greater surface tension because of the strong cohesive force between the molecules. The nanoparticles' average distance from the fuel molecules is shrinking [21]. The surface tension of nanoparticles is raised by using the Van der Waals force instead of electrostatic repulsion. When the nanoparticle size and number vary, the surface tension of nanoparticles changes. When the bulk density of nanoparticles varies, so does the attraction force between the nanoparticles and the fuel's surface tension. As the size of the nanoparticles grows, so does their surface tension in nanoparticles. The surface charge density of bigger nanoparticles is increased by the presence of smaller nanoparticles [22]. Due to their high heat conductivity and mechanical qualities, AONP nanoparticles may influence biodiesel combustion. AONP is toxicologically volatile and irritating to the respiratory system. It quickly interacts with water to form hydrogen. The size and form of AONP nanoparticles affect the combustion of blended nanoparticle fuels. In this way, water molecules can be split into hydrogen and oxygen [23]. Table 1 displays the properties of pumpkin seed biodiesel.

3. Experimental details

The performance of a combination of pumpkin seed biodiesel and AONP was tested using a single-cylinder, constant-speed, direct-injection engine. Fig. 1 shows the test engine photograph.

Table 1
Properties of pumpkin seed biodiesel.

Sl.No	**Property**	**Diesel**	**Pumpkin seed Biodiesel**
1	Lowest heating Value (kJ/kg)	42,500	38,820
2	Viscosity at 40 °C (cSt)	2.72	4.41
3	Density at 15 °C (kg/m^3)	842	883
4	Flash Point (°C)	60	120
5	Cetane Index	54	56

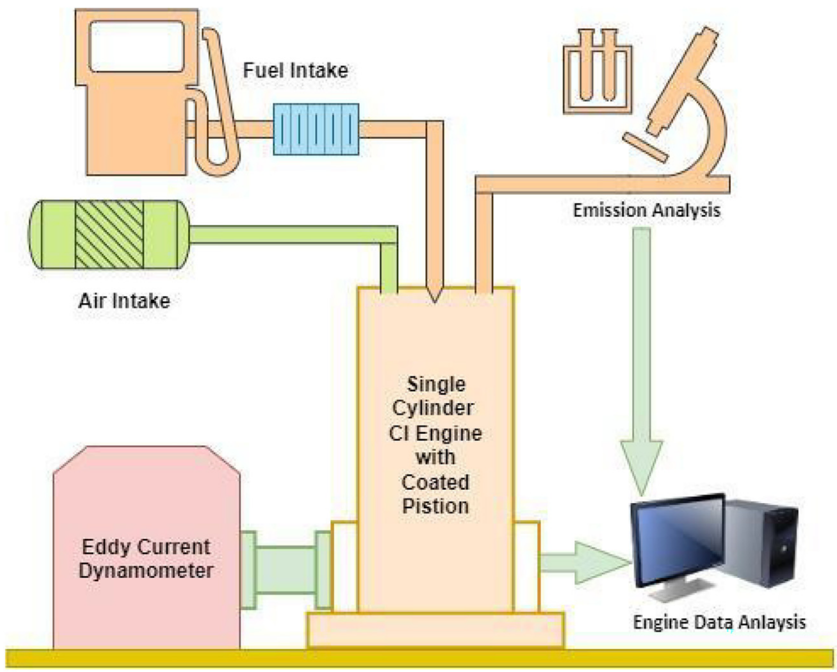

Fig. 1. Experimental engine setup.

The eddy current dynamometer applied varying loads to the engine, starting at zero and going all the way up to one hundred. At 1500 rpm, the engine produces 4.2 kW of power, which is used to raise the load on each testing mixture by 25%. An eddy current dynamometer is used to manually vary engine loads. The fuel consumption of both diesel and a blend of esterified pumpkin seed biodiesel and AONP was recorded. During the course of the inquiry, several readings and data may be recorded using the AVL software installed on the test equipment. Table 2 represents the experimental measurements and its parameters.

Pumpkin seed biodiesel was transesterified in order to create biodiesel, and this biodiesel was then combined with diesel. The fuel mix is created using varied ratios of pumpkin seed biodiesel, ranging from 15% to 30% on a volumetric basis as BD15 and BD30 along with standard diesel of 85% and 65% respectively, along with nano-additives of AONP with 50 ppm and 100 ppm. Biodiesel blends are named as BD15AONP50, BD15AONP100, BD30AONP50 and BD30AONP100 respectively with their blend ratios.

4. Results and discussion

4.1. Engine performance characteristics

4.1.1. Brake thermal efficiency

Low thermal conductivity coating on the combustion chamber surface prevents heat from escaping into the coolant and environment, as well as controlling temperature distributions and heat flow. When tested under maximum load, BD15AONP100′s brake thermal efficiency (BTE) was found to be roughly 5.4% greater than that of pure diesel. Increased thermal performance may be achieved by increasing AONP's content of oxygen [24]. Fig. 2 shows that the 10% of BTE is lower than that of BD30AONP100 due to the increased viscosity and, as a consequence, reduced combustion rate induced by the high AONP component in the mixture. Due to the higher in-cylinder temperature as a result of trapped heat energy, This suggests that the increased BTE may be due to the coated engine's combustion chamber being hotter than normal [20]. The inclusion of nanoparticles improves the burning of fuel and the transfer of energy from fuel into useful work [25]. The enhanced surface to volume ratio of nanoparticles, which enhances heat transfer, is the most important factor contributing to the

Table 2
Experimental measurements and its parameters.

S. No.	Measurement	Accuracy	Range
1	Fuel quantity	± 0.1 cm^3	0–50 cm^3
2	Engine load	+0.1 kg to – 0.1 kg	–
3	Crank speed	± 10 rpm	0–10000 rpm
4	Nitrogen oxides	± 10 ppm	0 to 5000 ppm
5	Hydrocarbon	± 10 ppm	0 to 20000 ppm
6	Carbon Monoxide	± 0.05%	0 to 15%

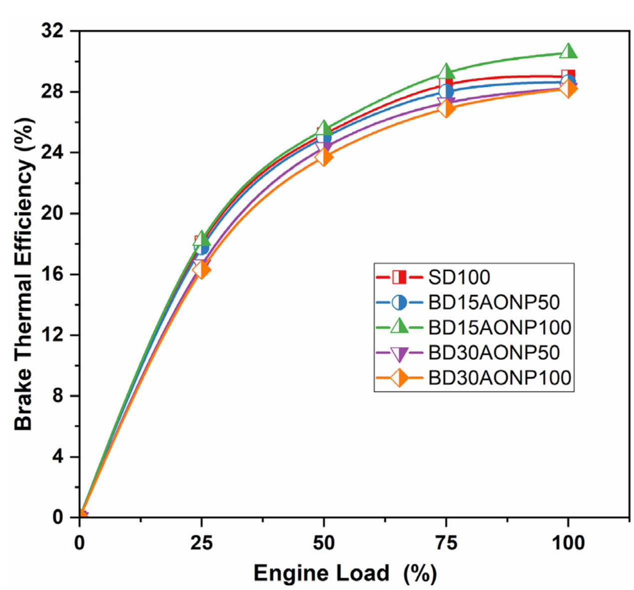

Fig. 2. Effect of AONP on brake thermal efficiency.

increase in power. AONP additions reduce the time it takes for the fuel to ignite and burn, resulting in higher peak cylinder pressure and a faster rate of heat release. Nanoparticles aid in the dispersion of fuel droplets and the spreading of injected fuel.

4.1.2. Specific energy consumption

As a result of this investigation, it was concluded that the higher amount of injected biodiesel to produce same amount of heat produced by diesel was the reason for higher specific energy consumption (SEC) [26]. It can be seen in Fig. 3, that as the AONP ratio is increased, engine load rises and SEC falls. Blends of BD15AONP50 and BD15AONP100 achieved 3.8% and 6.5% lower SEC than diesel, whereas blends of BD30AONP100 used 6% more energy than diesel. Reduced ignition delay time as a function of nanoparticles on fuel physical parameters is one of the reasons. Nanoparticles with a smaller size and homogeneous dispersion caused blockage and fuel atomization issues. The inclusion of nanoparticles improved fuel air mixing and combustion properties. To assist reactivity as a catalyst, nano-sized particles have reactive surfaces. There is less need for fuel since the surface area-to-volume ratio of biodiesel blends has been improved by adding nanoparticles. As the nanoparticle dosage increased, so did the required amounts of certain fuels [27].

4.2. Engine emission characteristics

4.2.1. Carbon monoxide emission

Lower CO emissions were created when BD15 was used in the engines. Engine CO emissions are influenced by the volume of oxygen in the fuel structure. An increase in oxygen concentration in the biodiesel increased the pace at which oxidation processes occurred during combustion, which resulted in a more efficient use of the fuel. As a consequence, CO emissions were significantly reduced in both engines due to the high oxygen concentration of the biodiesel [28]. CO emissions were lowest in a coated engine that ran on BD15 blend. Combustion efficiency was improved by the combination of a higher in-cylinder temperature and an excess supply of oxygen. Local conditions in the combustion chamber improved as a result of coatings. There was an increase in the rate of CO oxidation, which resulted in a decrease in CO emissions. Fig. 4 shows that BD15AONP50 and BD15AONP100 blends reduced CO emissions by 6.1% and 11%, respectively, compared to diesel, while BD30 blends produced 4% more CO than diesel. Thermal barrier coatings reduced CO emissions in engines. Late-phase combustion and CO oxidation occurred after compression due to nano-coated thermal insulation. With rising speed, CO emission declined to almost nothing while the engine was operating at its ideal speed. This test also reveals that piston coating has no effect on CO emission [29].

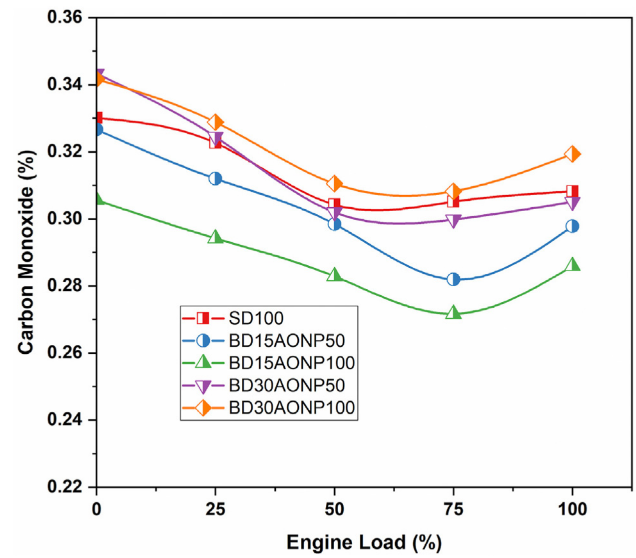

Fig. 4. Effect of AONP on carbon monoxide emission.

4.2.2. Hydrocarbon emission

This is due to a variety of factors that affect the full combustion of the hydrocarbon fuels. For example, increased viscosity and surface tension, as well as the presence of fatty acids, are additional factors that affect HC emissions in biodiesel as compared to clean diesel, as well as oxygen in the fuel. The BD15 blend has greater viscosity and lesser compressibility owing to increased surface tension, however the inclusion of AONP nanoparticles in the BD15AONP50 mix improves the surface area exposure for the fuel droplets, which promotes the combustion and results in lower HC than the BP20 blend. BD15AONP50 and BD15AONP100 blends

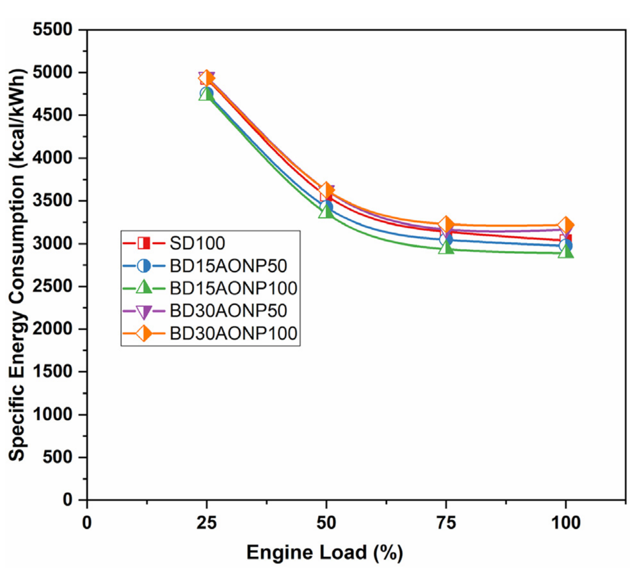

Fig. 3. Effect of AONP on fuel energy consumption.

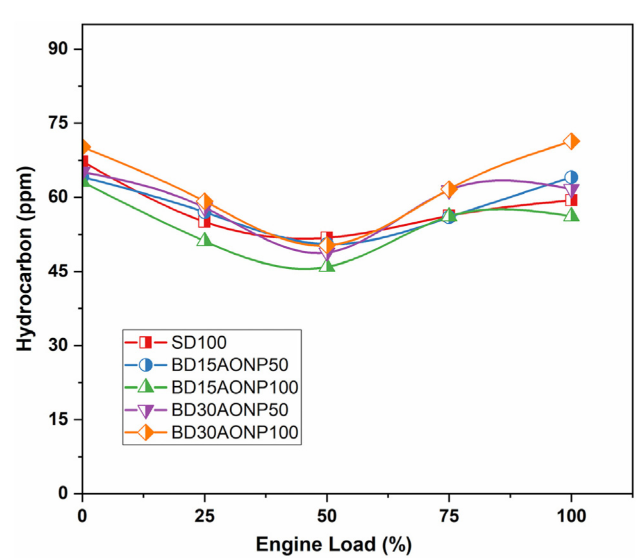

Fig. 5. Effect of AONP on hydrocarbon emission.

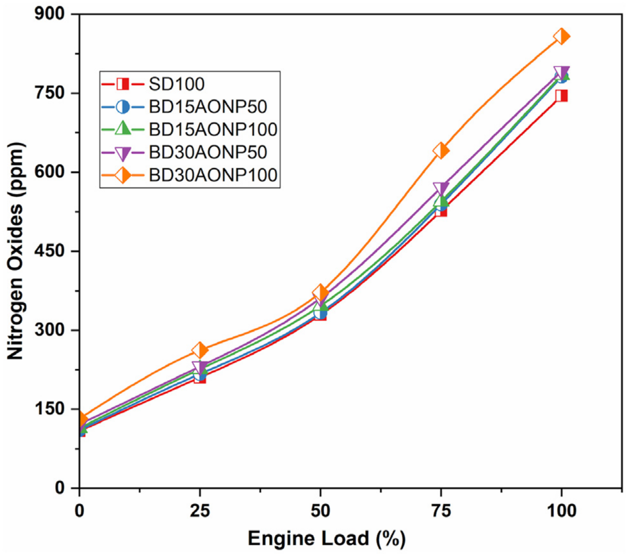

Fig. 6. Effect of AONP on nitrogen oxides emission.

reduced HC emission by 5.2%, and 9.5% than pure diesel and B30E15 blends reached 12.5% increased hydrocarbon emission than diesel as shown in Fig. 5. When compared to diesel engines, TBC engines produce less hydrocarbons owing to the higher quantity of heat generated within the combustion chamber and the ramifications of having a lower value than an uncoated engine, as opposed to the latter. Aside from that, since the fuel spray has a greater probability of impinging on the wall and surviving the combustion process because of the longer ignition delay time [30].

4.2.3. Nitrogen oxides emission

The load increases, NO_x emissions proportionally. A higher flame temperature increased thermal NO_x production when the engine ramped up to full load [31]. Rising flame temperatures cause greater oxygen dissociation, resulting in NOx. However, because of its oxygen content, biodiesel emits higher NO_x. AONP nanoparticles in biodiesel reduced NO_x production. As a result, the in-cylinder temperature dropped and the thermal NO_x generation decreased. As can be shown in Fig. 6, NO_x emissions from BD15AONP50, BD15AONP100, BD30AONP50, and BD30AONP100 blends are 4.6%, 5%, 6.3%, and 15% higher than those from diesel respectively at peak load. Increasing combustion chamber temperature and covering the piston crown increased fuel evaporation rates. The use of a thermal barrier layer improves and speeds up the combustion process. As a result of the thermal barrier coating increasing the rate at which hydrocarbons are broken down into hydrogen and oxygen in the combustion chamber, hydrocarbon emissions are reduced for coated pistons [32].

4.3. AONP influence on engine performance and emission

The design of experiment method is frequently employed in the field of process improvement to arrive at the most comprehensive answer. It's the go-to method for optimizing results using numbers. Many process parameters and gradations of difficulty were needed to create a comprehensive factorial model for the study under inquiry. A significant number of process parameters and

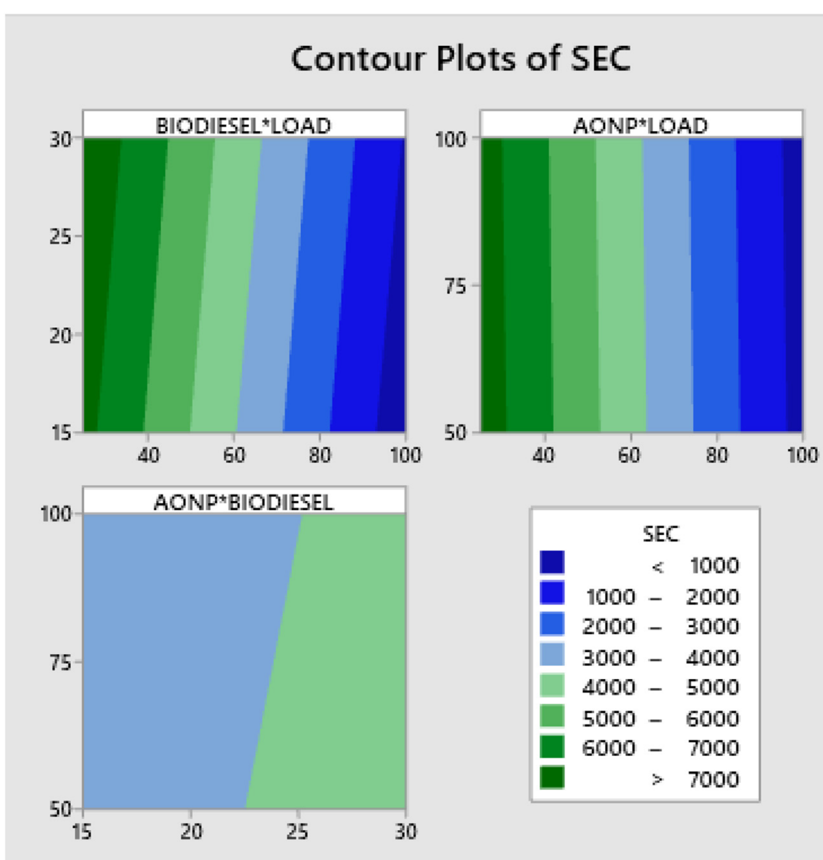

Fig. 7. Effect of AONP on SEC.

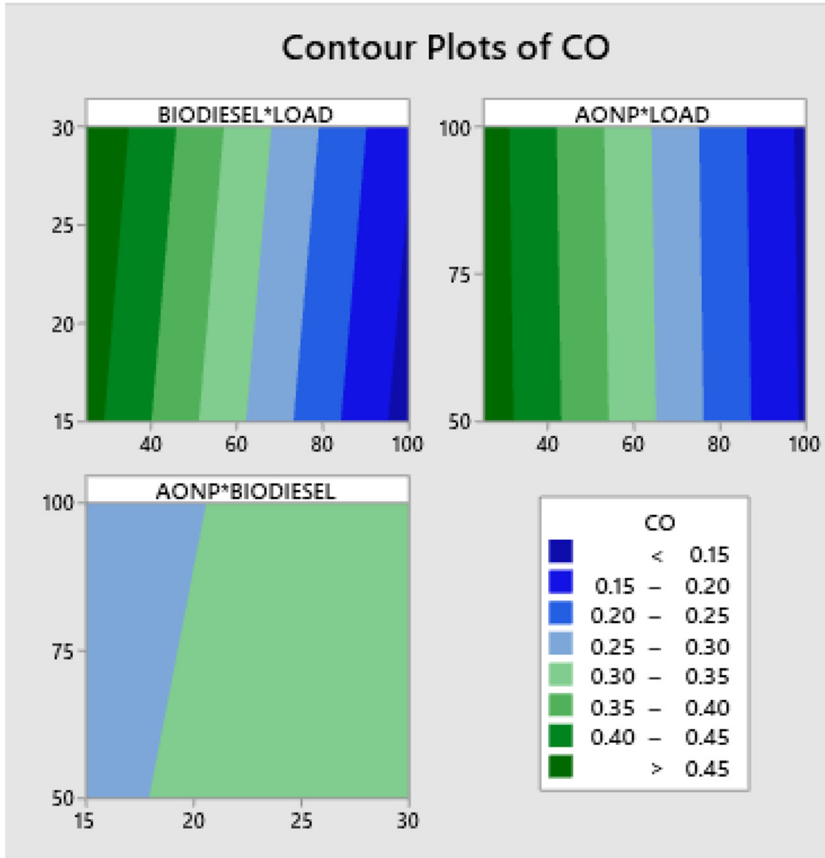

Fig. 8. Effect of AONP on CO emission.

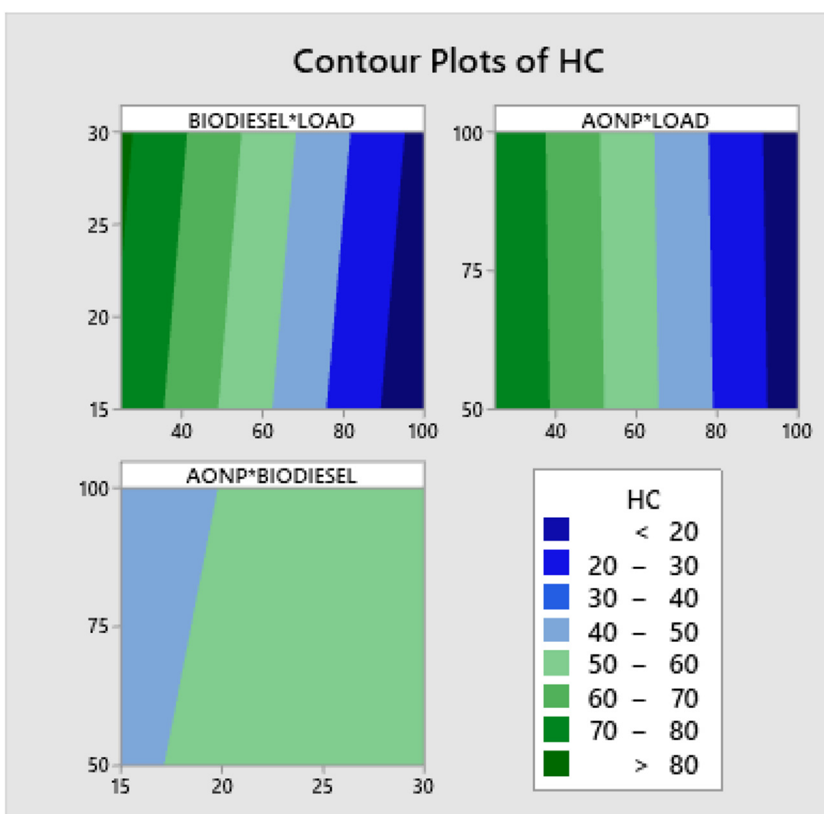

Fig. 9. Effect of AONP on HC emission.

levels were needed for the study's inquiry. Emissions of carbon monoxide and hydrocarbons, as well as fuel consumption, were analyzed in relation to various biodiesel and AONP blends. Researchers looked at how blending biodiesel and AONP affected fuel efficiency, carbon monoxide, and hydrocarbon emissions [32].

Fig. 7 contour plots for specific energy consumption reveal that increasing nano AONP dose and decreasing the biodiesel mix had the greatest impact on engine energy consumption. Also, at maximum load, a concentration of 100 ppm AONP results in the lowest values for fuel consumption, which is likely related to a quicker combustion rate due to the increased oxygen content.

Figs. 8 and 9 show contour plots for CO, HC, and NOx emissions, respectively, illustrating the greatest influence of increasing or decreasing the AONP dose and biodiesel mix, respectively, on the engine's ability to run at the lowest practicable CO, HC, and NO_x emissions. The lowest values for emissions were obtained at a concentration of 100 ppm, which is likely attributable to a faster combustion rate due to the increased oxygen content. When the mix ratio was raised, emissions increased because of the higher viscosity of biodiesel, and the fuel's burning capacity was reduced as a result. Complete combustion of biodiesel is achieved with higher oxygen content blends as those containing 15% biodiesel, reducing emissions of CO and HC. Emissions of carbon monoxide and hydrocarbons decrease with increasing AONP ratio, with the lowest levels seen at 100 ppm AONP dose, in part because of the faster rate of combustion at this level.

5. Conclusion

Energy management and conservation have become more important in the industrial sector in recent years, as the cost of energy constitutes a significant portion of the overall cost of production. Through the utilization of a thermal barrier coated piston that runs on biodiesel blends and the addition of a dosage of AONP nano-additives, the current investigation intends to improve the performance of a diesel engine. This will be accomplished by reducing emissions. It was discovered that the braking thermal efficiency of the BD15AONP100 was approximately 5.4% greater than that of pure diesel when it was tested under maximum load conditions. The SEC of BD15AONP50 and BD15AONP100 blends was reduced when compared to diesel by 3.8% and 6.5%, respectively. Both the BD15AONP50 and BD15AONP100 blends reduced CO emissions by 6.1% and 11%, respectively, when compared to those of pure diesel. When compared to pure diesel, the HC emissions from BD15AONP50 and BD15AONP100 blends were reduced by 5.2% and 9.5%, respectively. The greatest influence on the engine's capacity to function with the fewest amount of CO, HC, and NO_x emissions conceivable is exerted by the AONP dose that is the highest and the biodiesel mix that is the least. Biodiesel take advantage of the planet's natural carbon cycle to lessen the impact of transportation and other industries on global warming. Greenhouse gas emissions are reduced by one gallon for every gallon of biofuel used.

CRediT authorship contribution statement

S. Padmanabhan: Investigation, Writing – original draft. **M. Selvamuthukumar:** Methodology. **B. Gopi Krishna:** Conceptualization, Formal analysis. **Manoj Kumar:** Writing – review & editing. **K. Sudheer:** Supervision, Formal analysis. **S. Baskar:** Supervision, Writing – review & editing. **Rahul Mishra:** Formal analysis. **Y. Anupam Rao:** Writing – review & editing.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

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

References

[1] S. Sparsh, C.S. Ramakrishna, R. Sahu, R.S. Narain, J.K. Sohal, M. Sahu, N. Sharma, V. Kumar, A. Sharma, Future prospects of biodiesel production from jatropha in India, Mater. Today Proc. 63 (2022) A22–A26.

[2] P. Sambandam, H. Venu, B.K. Narayanaperumal, Effective utilization and evaluation of waste plastic pyrolysis oil in a low heat rejection single cylinder diesel engine, Energy Sources, Part A Recover, Util. Environ. Eff. (2020) 1–17.

[3] H. Venu, P. Appavu, Analysis on a thermal barrier coated (TBC) piston in a single cylinder diesel engine powered by Jatropha biodiesel–diesel blends, SN Appl. Sci. 1 (2019) 1669.

[4] V. Dananjayakumar, M.B. Sanjeevannavar, S.M. Golabhanvi, M.A. Kamoji, Experimental analysis of CI engine using zirconia ceramic powder coated piston fuelled with Karanja biodiesel, Mater. Today Proc. 42 (2021) 1387–1392.

[5] A.M. Narad, M.P. Joshi, Experimental analysis of CI engine using titanium oxide and aluminum oxide alloy coated piston fuelled with biofuel made up of agricultural waste, Results Mater. 8 (2020).

[6] S. Yessian, P.A. Varthanan, Optimization of performance and emission characteristics of catalytic coated ic engine with biodiesel using grey-taguchi method, Sci. Rep. 10 (2020) 2129.

[7] Abhishek Sharma, S. Murugan, Experimental Evaluation of Combustion Parameters of a DI Diesel Engine Operating with Biodiesel Blend at Varying Injection Timings, (2016) 169–177. https://doi.org/10.1007/978-81-322-2773-1_13.

[8] A. Sharma, S. Murugan, Investigation on the behaviour of a DI diesel engine fueled with Jatropha Methyl Ester (JME) and Tyre Pyrolysis Oil (TPO) blends, Fuel. 108 (2013) 699–708, https://doi.org/10.1016/j.fuel.2012.12.042.

[9] N. Ramasamy, M. Abul Kalam, M. Varman, Y.H. Teoh, Comparative studies of piston crown coating with YSZ and Al2O3· SiO2 on engine out responses using conventional diesel and palm oil biodiesel, Coatings. 11 (2021) 885.

[10] A. Sharma, S. Murugan, Combustion Analysis of a Diesel Engine Run on Non-conventional Fuel at Different Nozzle Injection Pressure, in: Innov. Energy, Power Therm. Eng., Springer, 2022: pp. 109–118.

[11] A. Sharma, S. Murugan, Influence of fuel injection timing on the performance and emission characteristics of a diesel engine fueled with Jatropha methyl ester-tyre pyrolysis oil blend, Appl. Mech. Mater. 592–594 (2014) 1627–1631, https://doi.org/10.4028/www.scientific.net/AMM.592-594.1627.

[12] K. Logesh, M. Karthick, S. Baskar, A. Sharma, Performance and Emissions Characteristics of Diesel Engine Run on Citrullus Colocynthis Biodiesel with Zinc Oxide Additive, in: Adv. Mater. Manuf. Energy Eng. Vol. II, Springer, 2022: pp. 513–520.

[13] P. Schinas, G. Karavalakis, C. Davaris, G. Anastopoulos, D. Karonis, F. Zannikos, S. Stournas, E. Lois, Pumpkin (Cucurbita pepo L.) seed oil as an alternative feedstock for the production of biodiesel in Greece, Biomass and Bioenergy. 33 (2009) 44–49.

[14] S. Wang, V. Karthickeyan, E. Sivakumar, M. Lakshmikandan, Experimental investigation on pumpkin seed oil methyl ester blend in diesel engine with various injection pressure, injection timing and compression ratio, Fuel. 264 (2020).

[15] U. Öztürk, H. Hazar, Y.S. Arı, Investigation of using pumpkin seed oil methyl ester as a fuel in a boron coated diesel engine, Energy. 186 (2019).

[16] S.S. Kumar, K. Rajan, V. Mohanavel, M. Ravichandran, P. Rajendran, A. Rashedi, A. Sharma, S.A. Khan, A. Afzal, Combustion, Performance, and Emission Behaviors of Biodiesel Fueled Diesel Engine with the Impact of Alumina Nanoparticle as an Additive, Sustainability. 13 (2021) 12103.

[17] G.N.V. Siddartha, C.S. Ramakrishna, P.K. Kujur, Y.A. Rao, N. Dalela, A.S. Yadav, A. Sharma, Effect of fuel additives on internal combustion engine performance and emissions, Mater Today Proc. (2022).

[18] A. Sharma, G. Gupta, A. Agrawal, Utilization of Waste Lubricating Oil as a Diesel Engine Fuel, IOP Conf. Ser. Mater. Sci. Eng. 840 (2020), https://doi.org/10.1088/1757-899X/840/1/012015.

[19] A.S. Yadav, P. Singh, R. Sahu, P. Thangamuthu, R.S. Narain, Y.A. Rao, A. Balu, B.P. Panda, A. Sharma, Potential utilization of turpentine oil as an alternative fuel, Mater Today Proc. (2022).

[20] S. Padmanabhan, K. Giridharan, B. Stalin, V. Elango, J. Vairamuthu, P. Sureshkumar, L.T. Jule, R. Krishnaraj, Sustainability and environmental impact of ethanol and oxyhydrogen addition on nanocoated gasoline engine, Bioinorg. Chem. Appl. 2022 (2022).

[21] M. Ghanbari, L. Mozafari-Vanani, M. Dehghani-Soufi, A. Jahanbakhshi, Effect of alumina nanoparticles as additive with diesel–biodiesel blends on performance and emission characteristic of a six-cylinder diesel engine

using response surface methodology (RSM), Energy Convers. Manag. X. 11 (2021).

[22] M.S. Gad, S. Jayaraj, A comparative study on the effect of nano-additives on the performance and emissions of a diesel engine run on Jatropha biodiesel, Fuel. 267 (2020).

[23] D. Khatri, R. Goyal, A. Sharma, Effects of silicon dioxide nanoparticles on the combustion features of diesel engine using water diesel emulsified fuel, in: Energy Syst. Nanotechnol., Springer, 2021: pp. 119–130.

[24] K.A. Sateesh, V.S. Yaliwal, M.E.M. Soudagar, N.R. Banapurmath, H. Fayaz, M.R. Safaei, A. Elfasakhany, A.I. EL-Seesy,, Utilization of biodiesel/Al2O3 nanoparticles for combustion behavior enhancement of a diesel engine operated on dual fuel mode, J. Therm. Anal. Calorim. 147 (2022) 5897–5911.

[25] M. Nagappan, A. Devaraj, J.M. Babu, N.V. Saxena, O. Prakash, P. Kumar, A. Sharma, Impact of additives on Combustion, performance and exhaust emission of biodiesel fueled direct injection diesel engine, Mater Today Proc. (2022).

[26] M. Karthick, K. Logesh, S. Baskar, A. Sharma, Performance and Emission Characteristics of Single-Cylinder Diesel Engine Fueled with Biodiesel Derived from Cashew Nut Shell, in: Adv. Mater. Manuf. Energy Eng. Vol. II, Springer, 2022: pp. 521–529.

[27] A. Devaraj, M. Nagappan, D. Yogaraj, O. Prakash, Y.A. Rao, A. Sharma, Influence of nano-additives on engine behaviour using diesel-biodiesel blend, Mater Today Proc. (2022).

[28] L. Urtekin, S. Bayaşoğlu, Investigation of the wear characteristics of thermal barrier coating in a biodiesel engine, Surf. Rev. Lett. 27 (2020) 1950158.

[29] N. Ramasamy, M.A. Kalam, M. Varman, Y.H. Teoh, Effect of thermal barrier coating on the performance and emissions of diesel engine operated with conventional diesel and palm oil biodiesel, Coatings. 11 (2021) 692.

[30] S. Padmanabhan, C. Joel, L. Joel, O.Y. Reddy, K.G.D. Harsha, S. Ganesan, Evaluation of waste plastic pyrolysis oil performance with diethyl ether additive on insulated piston diesel engine, Nat. Environ. Pollut. Technol. 20 (2021).

[31] A. Sharma, S. Murugan, Effect of nozzle opening pressure on the behaviour of a diesel engine running with non-petroleum fuel, Energy. 127 (2017) 236–246, https://doi.org/10.1016/j.energy.2017.03.114.

[32] M. Selvam, S. Shanmugan, S. Palani, Performance analysis of IC engine with ceramic-coated piston, Environ. Sci. Pollut. Res. Int. 25 (2018) 35210–35220.