Hindawi
Journal of Nanomaterials
Volume 2023, Article ID 7341542, 8 pages
https://doi.org/10.1155/2023/7341542

Research Article

Rice Bran Oil-Fueled IC Engine Performance and Emission Characteristics Improved by Nanoadditives

J. Renuraman ,[1] K. Yoganand,[1] P. V. Arunraj ,[1] M. Subramanian,[2] and Elangomathavan Ramaraj [3]

[1]*Department of Mechanical Engineering, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Ramapuram, Tamilnadu, India*
[2]*Adithya Institute of Technology, Coimbatore, Tamilnadu, India*
[3]*Department of Biology, College of Natural and Computational Sciences, Debre Tabor University, Debre Tabor, Amhara Region, Ethiopia*

Correspondence should be addressed to Elangomathavan Ramaraj; elanmath@dtu.edu.et

Received 10 August 2022; Revised 24 September 2022; Accepted 30 September 2022; Published 12 May 2023

Academic Editor: N. Senthilkumar

In day-to-day life, fossil fuels play an important role in transportation and power generation. The consumption of fossil fuels increasing rapidly with increase in emission from engines. Due to habituation over fossil fuel, both the economy and environment are suffering. The researchers are in the position to find the best alternative for fossil fuels. The employment of biodiesel is taken to be the classy replacement for this snag. According to scores of research, using additions of nanoparticle is the greatest way to control emissions and improve engine performance. Here the assessment was employed though rice bran (RB) oil, rice bran oil blended with aluminum oxide (RB Al_2O_3), and rice bran oil blended with cerium oxide (RB CeO_2). Rice bran oil is extracted and converted into biodiesel by transesterification process. And the nanoadditives are prepared using the two-step method. The addition of nanoadditives showed an improved performance in the engine as well as emission parameters. The congruent assessment clearly demonstrates the improvement of brake thermal efficiency by around 28% for RB-Al_2O_3 and an improved brake-specific fuel of 16%. Both the blends exhibit good part loading traits.

1. Introduction

The rapid expansion of industrialization and motorization completely relies on petroleum products. But all petroleum-based products are available from limited sources. Only certain regions of the world have access to these finite resources. Countries without petroleum resources are experiencing economic problems. In addition to that emission is a major issue that suffers both human beings and environment. It is necessary to find the alternate to the existing petroleum-based products. Biodiesel obtained from animal fats, vegetable oil, and waste cooking oil are found to be a better replacement, and it is a clean burning alternative fuel that is a 100% renewable resource [1]. The experts encourage biodiesel as an alternative fuel in light of the present environmental changes and the devaluation of rising fossil fuel prices. Biodiesel can be obtained from vegetable oils like rice bran, sunflower oil, soya bean, palm oil, orange oil, etc.

This fuel is characterized by a high cetane number and sulfur content, as well as the absence of toxic chemicals and aromatics such as xylene and benzene [2, 3]. Because of this advantage, biodiesel is expected to have a lower environmental impact and a lower human impact.

2. Rice Bran Oil—Extraction and Synthesis

Husk or chaff, the outside brown coating of rice, is used to extract oil. It is available in every piece of rice. The extracted oil gives a gentle flavor and taste. Rice bran oil has been attracting a lot of attention among waste-oriented feedstock and nonedible oil feedstocks due to its potential to reduce biodiesel production costs [4]. Several countries, including Bangladesh, Vietnam, India, China, and Indonesia, primarily use rice bran as animal feed or the use of solid fuel as a low-cost source of energy [5, 6]. Rice bran can contain up to 32 wt% oil depending on the type of rice and method of milling.

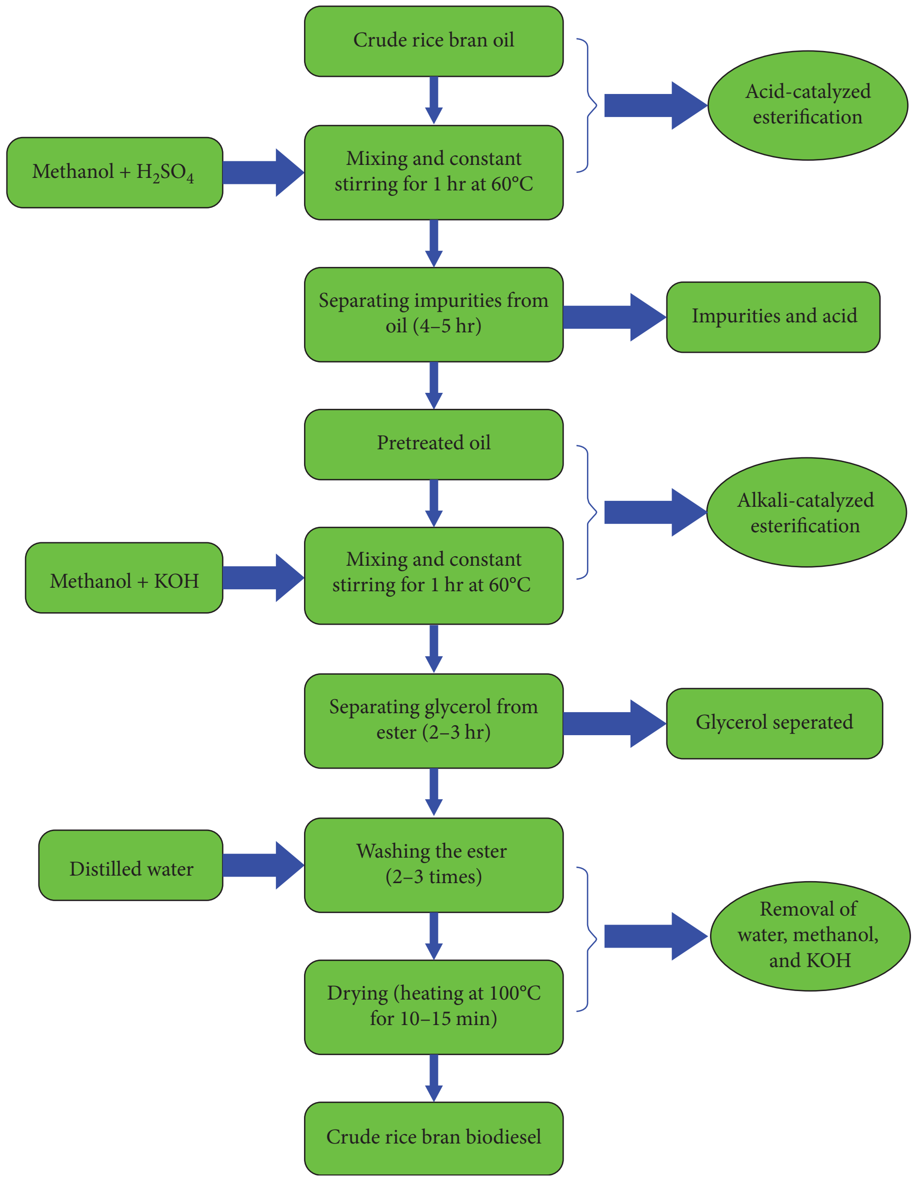

Figure 1: Methodology of extraction and synthesis of rice bran oil.

However, due to the presence of an active lipase, rice bran oil has substantially larger free fatty acid content than the bran oil of other cereals. As a result, up to 70% of the rice bran oil produced worldwide is unfit for human consumption [7, 8].

In areas where rice bran production is significant, nonedible rice bran oil can be made into biodiesel. Rice bran can differ in fatty acid composition depending on its type and quality. The amount of monounsaturated, polyunsaturated, and saturated fatty acids in rice bran oil are 39.3%, 35.0%, and 19.7%, respectively [9]. First, rice bran oil must be extracted from rice bran. A biodiesel's quality criteria are evaluated by its acid value (AV), which usually measures the quality of the extraction process. Additionally, rice bran includes a lot of protein [10]. A variety of techniques, including lipase- and acid-catalyzed transesterification, base-catalyzed transesterification, and noncatalytic techniques, have been purportedly utilized to produce biodiesel [11–14]. Due to its rapid reaction time and great efficiency, base-catalyzed alcoholysis is typically regarded as the most favorable of these techniques [15, 16].

Figure 1 displays the methodology of extraction and synthesis of rice bran oil. Transesterification of rice bran oil was carried out in two steps because of its high free-fatty-acid content [17]. For the first stage of transesterification, which is known as acid-catalyzed transesterification, small amounts of oil are placed in a conical flask and heated for 30 min at 60°C. A mixture of methanol and sulfuric acid was mixed with heated oil. An hour of shaking at a constant temperature inside the water bath shaker preceded the separation of the oil in the separating funnel.

The leftover oil that was collected from the separation funnel was measured and preheated to 60°C for the base-catalyzed

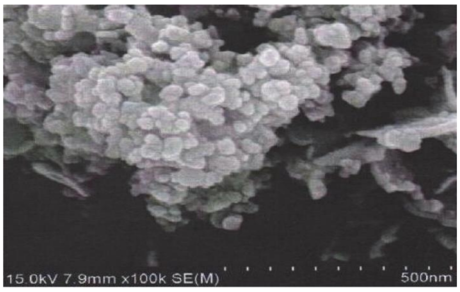

Figure 2: Analysis of CeO_2 using TEM.

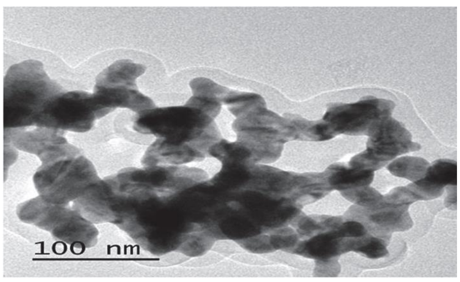

Figure 3: Analysis of Al_2O_3 using TEM.

procedure, which comes next. Then, some methanol and potassium hydroxide were added to the heated oil. The same approach used in the first section was used again. For an hour, the mixture was continuously mixed at a steady temperature. The remaining residue (methyl ester-biodiesel), which was acquired after the mixture was separated in a separating funnel to remove the glycerol, was obtained. The methyl ester was purified from this residue using washing and drying to get rid of any extra KOH, methanol, and water.

3. Nanoadditives—Materials Characterization and Synthesis

By using advanced nanotechnology, it is possible to create nanoparticles with enhanced properties. Increased brake thermal efficiency is achieved by adding nanoparticles to fuel [18, 19]. The addition of nanoparticles can increase cetane number, resulting in decreased viscosity and flash point [20]. SiO_2, CeO_2, $NiFeO_3$, Al_2O_3, MgO, ZnO, Fe_2O_3, NiO, and TiO_2 studies were performed with varying dispersion levels of 25, 50, and 100 ppm. As soon as nanoparticles are added to clean diesel fuel, the results are satisfactory [21–23]. Here we analyzed with CeO_2 and Al_2O_3 for our experiment.

Cerium oxide has a grid-like structure that can provide oxygen iotas to catalyze burning reactions [24–26]. By incorporating cerium oxide into biodiesel, unburned hydrocarbons and residue can be broken down, reducing the amount of these toxins released as fumes, NO_x emissions, and fuel consumption. Figure 2 displays the SEM analysis of cerium oxide nanoparticles.

Due to its high energy combustion, aluminum increases engine power, and it has been found that nanoscale aluminum particles perform better than microscale aluminum particles. As shown in Figure 3, aluminum oxide nanoparticles were analyzed by TEM.

Table 1: Measured fuel properties.

Fuel	Gross calorific value (kJ/kg)	Density (gm/ml)	Viscosity (cSt)
Rice bran oil	39,520	0.865	5.320
Rice bran oil + CeO_2	40,850	0.871	5.311
Rice bran oil + Al_2O_3	40,221	0.889	5.302

4. Examination of Fuel Properties

Table 1 lists the fuel qualities of rice bran oil and rice bran oil with nanoadditives as determined by IS: 1448 PART-6 & IS: 1448 PART-16 techniques. The gross calorific value of RB CeO_2 is higher than RB and RB Al_2O_3. But the viscosity of RB is higher than the other additive blends.

5. Investigational Setup

Figures 4 and 5 show the layout and the actual tested experimental setup, and Table 2 has a description of the single-cylinder diesel engine that was tested.

6. Results and Discussion

Biodiesel made from rice bran (RB), alcohol made from rice bran with 150 ppm aluminum oxide (RB Al_2O_3), and cerium oxide made from rice bran with 150 ppm (RB CeO_2) indicate the capabilities and emission characteristics of these fuel mixtures. During the experimental process, many factors were investigated, including thermal efficiency, fuel consumption, heat balance, volumetric efficiency, brake power, and other factors that influenced the results. Numerous engine loading conditions were used during the test. A set of blends was assessed for its brake-specific fuel consumption, change in cylinder pressure with crank angle, and change in heat release with crank angle as well as its brake thermal efficiency.

6.1. Performance Characteristics

6.1.1. Brake Power Variation with Brake Thermal Efficiency (BTE). The graph in Figure 6 shows the variation between brake power and brake thermal efficiency. Due to its calorific value, RB Al_2O_3 has been found to have a higher brake thermal efficiency than RB CeO_2. The primary cause may be that RB Al_2O_3 can mix with air to produce mixtures, which improve combustion efficiency and, in turn, brake thermal efficiency. Low ignition timing can be used to explain why RB CeO_2 has a lower brake thermal efficiency than RB Al_2O_3, and biodiesel mix has a significant ignition delay risk if injection occurs before TDC. In this case, more compression effort is performed, resulting in a lower brake thermal efficiency (BTE). The addition of nanoadditives reduced the delay period, and also the secondary atomization of nanoparticle took a longer period to promote its impact on improving brake thermal efficiency.

6.1.2. Brake Power Variation with Brake-Specific Fuel Consumption (BSFC). Since rice bran oil has a greater cetane number and oxygen concentration than RB Al_2O_3 and RB

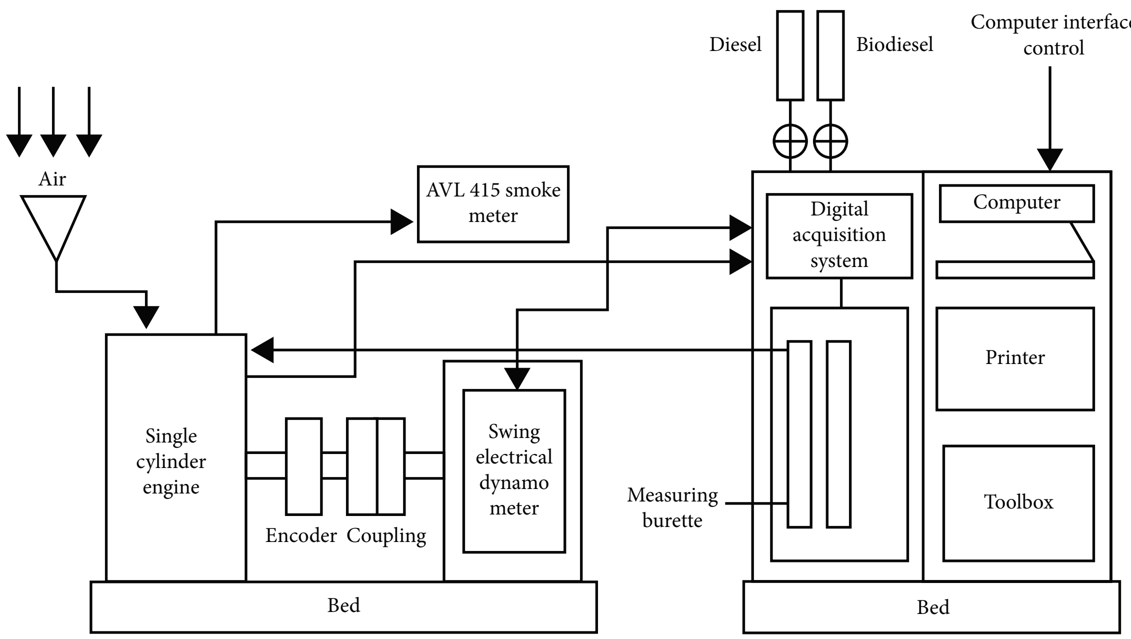

Figure 4: Layout of experimental setup.

Figure 5: Actual tested experimental setup.

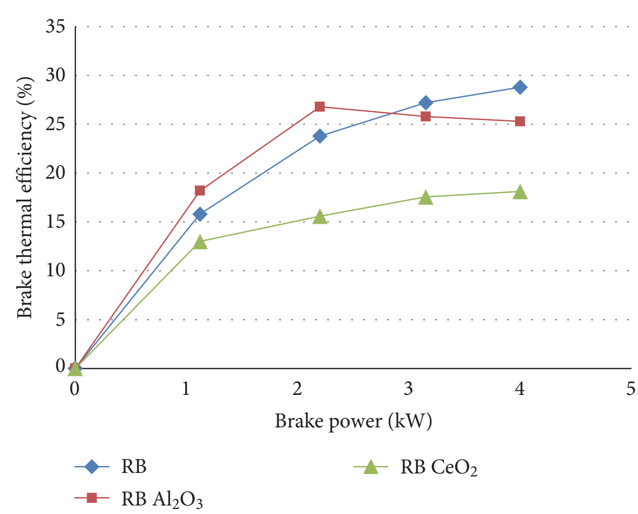

Figure 6: Brake power variation with BTE.

Table 2: Test engine specification.

Rated power	4.4 kW
Rated speed	1,500 rpm
Bore diameter (*D*)	87.5 mm
Stroke (*L*)	110 mm
Compression ratio	17.5 : 1
Orifice diameter	13.6 mm
Coefficient of discharge	0.6
Dynamometer	Swing field electrical
Smoke	AVL 415 smoke meter

CeO_2. it allows for better charge combustion and uses less energy as a result, lowering the brake-specific fuel consumption (BSFC) of rice bran oil. Here insufficient air–fuel mixing ratio may be the reason for the excessive specific-fuel consumption.

An illustration of the variation between brake power and brake-specific fuel consumption can be seen in Figure 7.

6.2. Combustion Characteristics

6.2.1. Crank Angle Variation with Heat Release. Figure 8 illustrates the variation in crank angle with a heat release for RB, RB Al_2O_3, and RB CeO_2. In both full-load and no-load conditions, the RB blend was able to release heat at a higher rate, which resulted in a shorter ignition delay. We saw that the RB oil has a somewhat longer ignition delay when compared with the RB Al_2O_3 and RB CeO_2 blends and expected that the premixed combustion process of the fuel would result in an increase in fuel combustion. As a result, peak pressure rises; however, since RB CeO_2 has less delay, less fuel is burned in the premixed condition at low

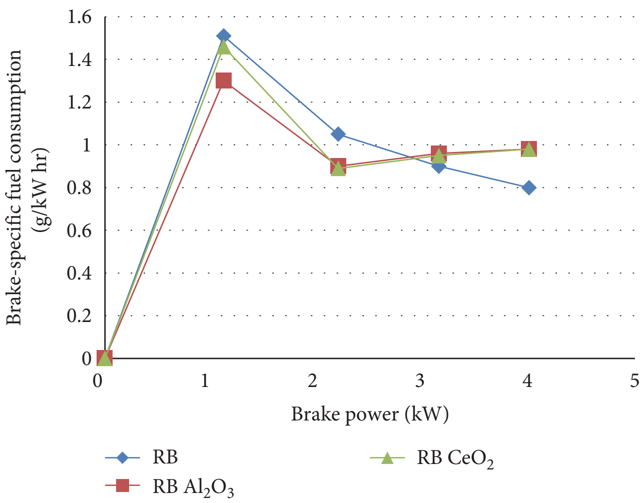

FIGURE 7: Brake power variation with BSFC.

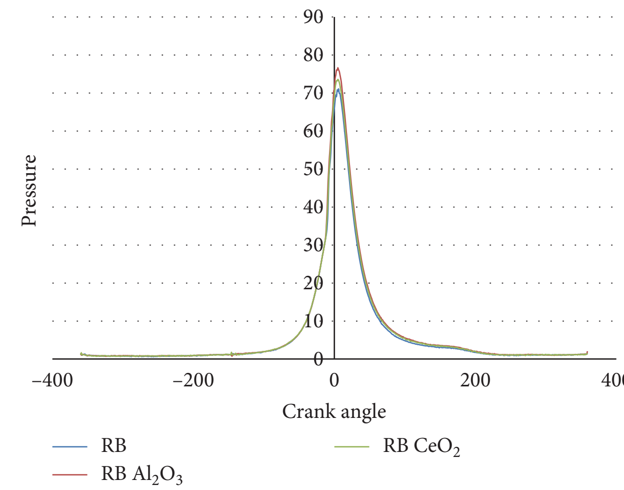

FIGURE 9: Crank angle variations with cylinder pressure.

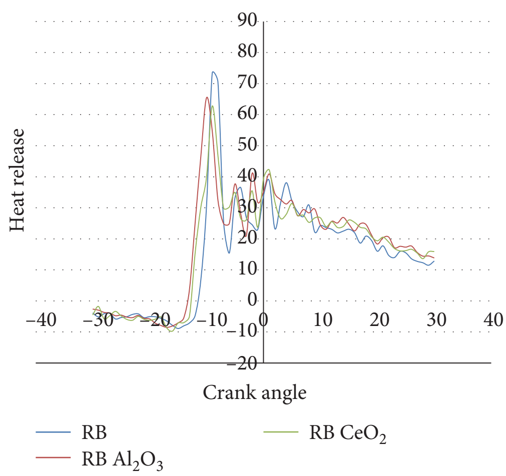

FIGURE 8: Crank angle variation with heat release.

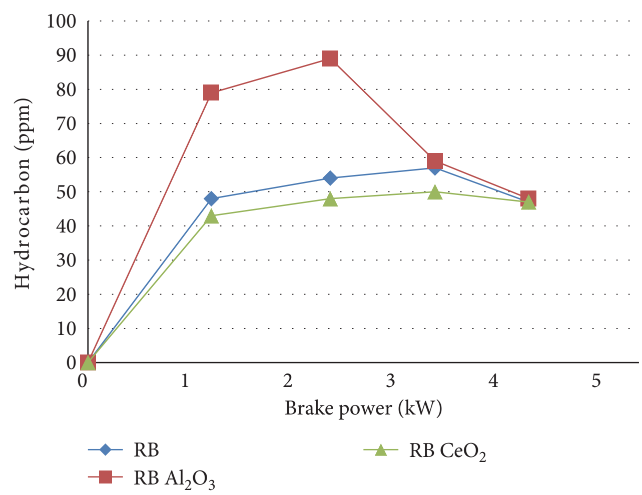

FIGURE 10: Brake power variations with HC.

and high loads. It is also possible that the premixed solution releases heat at a higher maximum rate because RB evaporates better than RB Al_2O_3 and RB CeO_2.

6.2.2. Crank Angle Variation with Cylinder Pressure. RB, RB Al_2O_3, and RB CeO_2 are shown in Figure 9 with their cylinder pressures fluctuating with crank angle. Maximum pressure is nearly the same for all of its mixes; although RB Al_2O_3 has higher pressure consequently aluminum oxide is present, which causes combustion to begin even before TDC.

6.3. Emission Characteristics. Here the emission characteristics are measured with the help of AVL 415S smoke meter. This type of smoke meter is used for measuring the soot content in the exhaust of diesel and GDI engines.

6.3.1. Brake Power Variation with Hydrocarbon (HC). It has been noted that RB Al_2O_3 produces higher hydrocarbon emissions than RB and RB CeO_2. One such explanation for their behavior could be incorrect ignition and fuel mixture ratios. A chart of the variation between brake power and hydrocarbon can be found in Figure 10.

6.3.2. Brake Power Variation with Carbon Dioxide (CO_2). Figure 11 illustrates the relationship between brake power and carbon dioxide. When compared with RB and RB Al_2O_3, the fluctuation in CO_2 emissions for RB CeO_2 is noticeably reduced. One explanation for this would be the high oxygen concentration, which helps better and properly burn fuels even at high temperatures in the engine's cylinder. Because there is less oxygen present under lighter loads than there is under heavier loads, carbon dioxide emissions rise as braking power rises.

6.3.3. Brake Power Variation with Carbon Monoxide (CO). Figure 12 depicts the fluctuation in carbon monoxide for RB, RB Al_2O_3, and RB CeO_2 from zero load to maximum load. Incomplete combustions and a lack of the proper proportionate oxygen fuel combination are the main causes of CO emissions. When the flame temperature is low or the air-to-fuel ratio is high, carbon monoxide emissions take place. Both

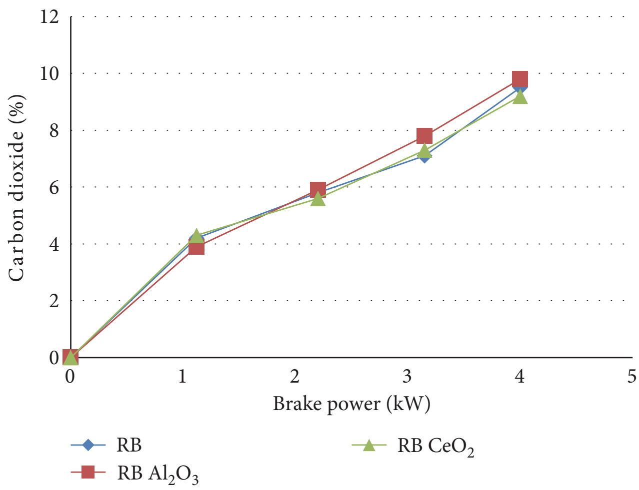

Figure 11: Brake power variations with CO_2.

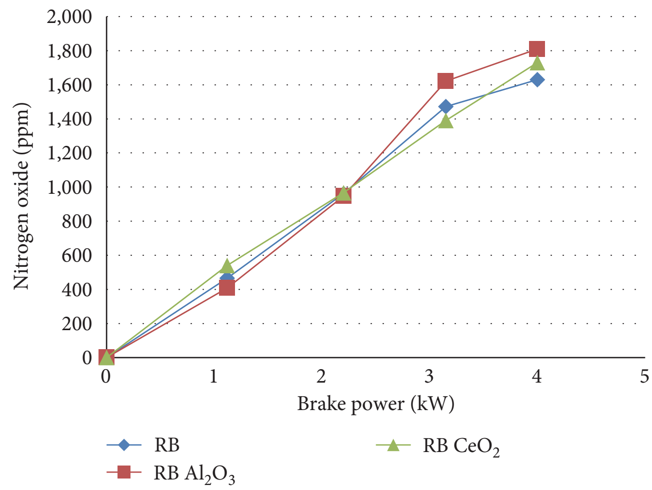

Figure 13: Brake power variations with NO_x.

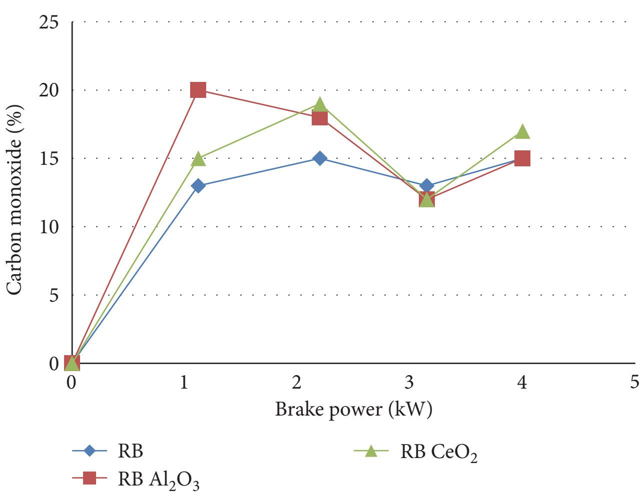

Figure 12: Brake power variations with CO.

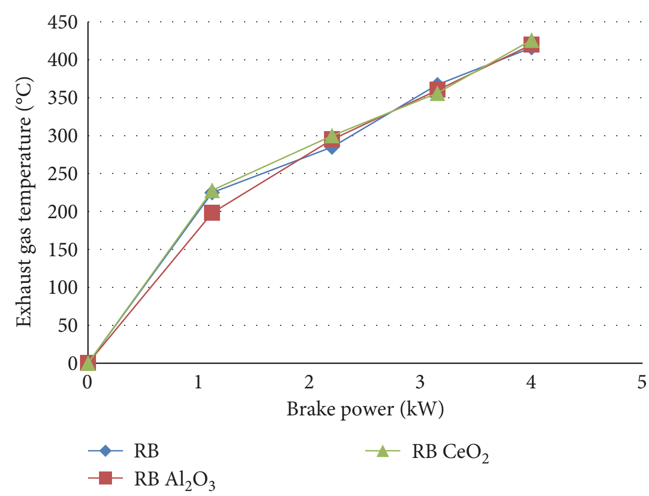

Figure 14: Brake power variations with EGT.

mixes have ups and downs depending on the blend type; rice bran emits less carbon dioxide than RB Al_2O_3 and RB CeO_2. As fuel consumption increases with load, and emissions increase as well.

6.3.4. Brake Power Variation with Nitrogen Oxide (NO_x). An illustration of the relationship between brake power and nitrogen oxide is shown in Figure 13. When compared with RB Al_2O_3 and RB CeO_2, it has been found that RB emits less nitrogen oxide. However, as braking power is increased, the NO_x emission rises. Both RB Al_2O_3 and RB CeO_2 emit nitrogen oxides at near ranges with lower loads. With increasing load, however, a distinct difference becomes apparent, which is attributed to high combustion temperatures. Comparing CeO_2 to Al_2O_3, an oxidation catalyst, reduces NO_x and ultimately increases combustion.

6.3.5. Brake Power Variation with Exhaust Gas Temperature (EGT). As the biodiesel blend increases, exhaust gas temperatures change as shown in Figure 14. It can be shown that, under all maximum loading situations, rice bran oil's exhaust gas temperature (EGT) is lower than that of RB Al_2O_3 and RB CeO_2. According to conventional wisdom, the EGT rises as engine loads rise. A rice bran blend's high oxygen content and low calorific value are other factors that contribute to its lower EGT.

7. Conclusion

In an experimental study, involving rice bran blended engines and compression ignition diesel engines, the following results were reported:

(i) At partial load condition, RB and RB CeO_2 pose similar UBHC emission, but RB Al_2O_3 showed an increased emission of about 46% than RB CeO_2. At peak condition, RB and RB CeO_2 pose similar UBHC emission, but RB Al_2O_3 showed an increased emission of about 3% than RB CeO_2.

(ii) At partial load condition, the BSFC of RB Al_2O_3 is 16% less than RB. At peak load condition, both RB Al_2O_3 and RB CeO_2 consume 18% more than RB.

- (iii) CO_2 and CO emissions are well within the limits and pose no significant changes during the entire operation.
- (iv) At peak load condition NO_x emission of RB Al_2O_3 is 10% higher than the RB.
- (v) At partial load condition, RB Al_2O_3 poses 28% improved BTE than RB CeO_2 and 13% improved than pure blend.

This study recommends that the usage of nanoadditives shall bring a positive influence on engine performance and emission, but the diffusion of nanoparticles plays a vital role. It is also observed that the nanoadditives are well-proven for the part load as well as full load characteristics which make Al_2O_3 and CeO_2 potential additives for rice bran oil.

Data Availability

The datasets obtained and analyzed, related to the present study, are available with the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] A. S. Ramadhas, S. Jayaraj, and C. Muraleedharan, "Use of vegetable oils as I.C. engine fuels—a review," *Renewable Energy*, vol. 29, no. 5, pp. 727–742, 2004.

[2] A. T. Hoang, "Prediction of the density and viscosity of biodiesel and the influence of biodiesel properties on a diesel engine fuel supply system," *Journal of Marine Engineering & Technology*, vol. 20, no. 5, pp. 299–311, 2021.

[3] H. Hosseinzadeh-Bandbafha, E. Khalife, M. Tabatabaei et al., "Effects of aqueous carbon nanoparticles as a novel nanoadditive in water-emulsified diesel/biodiesel blends on performance and emissions parameters of a diesel engine," *Energy Conversion and Management*, vol. 196, pp. 1153–1166, 2019.

[4] S. Zullaikah, C.-C. Lai, S. R. Vali, and Y.-H. Ju, "A two-step acid-catalyzed process for the production of biodiesel from rice bran oil," *Bioresource Technology*, vol. 96, no. 17, pp. 1889–1896, 2005.

[5] L. Lin, D. Ying, S. Chaitep, and S. Vittayapadung, "Biodiesel production from crude rice bran oil and properties as fuel," *Applied Energy*, vol. 86, no. 5, pp. 681–688, 2009.

[6] A. P. Hasan, M. A. Wakil, and M. A. Kafy, "Prospect of rice bran for biodiesel production in Bangladesh," *Procedia Engineering*, vol. 90, pp. 746–752, 2014.

[7] F. T. Orthoefer, "Rice Bran Oil," in *Bailey's Industrial Oil and Fat Products*, pp. 469–485, John Wiley & Sons, Ltd, 2005.

[8] S. A. El Khatib, S. A. Hanafi, Y. Barakat, and E. F. Al-Amrousi, "Hydrotreating rice bran oil for biofuel production," *Egyptian Journal of Petroleum*, vol. 27, no. 4, pp. 1325–1331, 2018.

[9] M. Sohail, A. Rakha, M. S. Butt, M. J. Iqbal, and S. Rashid, "Rice bran nutraceutics: a comprehensive review," *Critical Reviews in Food Science and Nutrition*, vol. 57, no. 17, pp. 3771–3780, 2017.

[10] H. Lei, X. Ding, J. Zhao et al., "In situ production of fatty acid ethyl ester from low quality rice bran," *Fuel*, vol. 90, no. 2, pp. 592–597, 2011.

[11] J. C. Juan, D. A. Kartika, T. Y. Wu, and T.-Y. Y. Hin, "Biodiesel production from jatropha oil by catalytic and non-catalytic approaches: an overview," *Bioresource Technology*, vol. 102, no. 2, pp. 452–460, 2011.

[12] A. Abbaszaadeh, B. Ghobadian, M. R. Omidkhah, and G. Najafi, "Current biodiesel production technologies: a comparative review," *Energy Conversion and Management*, vol. 63, pp. 138–148, 2012.

[13] J. M. Marchetti, "A summary of the available technologies for biodiesel production based on a comparison of different feedstock's properties," *Process Safety and Environmental Protection*, vol. 90, no. 3, pp. 157–163, 2012.

[14] G. Lourinho and P. Brito, "Advanced biodiesel production technologies: novel developments," *Reviews in Environmental Science and Bio/Technology*, vol. 14, pp. 287–316, 2015.

[15] M. Tabatabaei, M. Aghbashlo, M. Dehhaghi et al., "Reactor technologies for biodiesel production and processing: a review," *Progress in Energy and Combustion Science*, vol. 74, pp. 239–303, 2019.

[16] M. Aghbashlo, M. Tabatabaei, S. Hosseinpour, Z. Khounani, and S. S. Hosseini, "Exergy-based sustainability analysis of a low power, high frequency piezo-based ultrasound reactor for rapid biodiesel production," *Energy Conversion and Management*, vol. 148, pp. 759–769, 2017.

[17] D. N. A. Zaidel, I. I. Muhamad, N. S. M. Daud, N. A. A. Muttalib, N. Khairuddin, and N. A. M. Lazim, "Production of biodiesel from rice bran oil," in *Biomass, Biopolymer-Based Materials, and Bioenergy Construction, Biomedical, and other Industrial Applications*, Composites Science and Engineering, pp. 409–447, Woodhead, 2019.

[18] S. Manigandan, P. Gunasekar, J. Devipriya, and S. Nithya, "Emission and injection characteristics of corn biodiesel blends in diesel engine," *Fuel*, vol. 235, pp. 723–735, 2019.

[19] M. Annamalai, B. Dhinesh, K. Nanthagopal et al., "An assessment on performance, combustion and emission behavior of a diesel engine powered by ceria nanoparticle blended emulsified biofuel," *Energy Conversion and Management*, vol. 123, pp. 372–380, 2016.

[20] R. Vigneswaran, K. Annamalai, B. Dhinesh, and R. Krishnamoorthy, "Experimental investigation of unmodified diesel engine performance, combustion and emission with multipurpose additive along with water-in-diesel emulsion fuel," *Energy Conversion and Management*, vol. 172, pp. 370–380, 2018.

[21] T. Ozgur, G. Tuccar, E. Uludamar et al., "Effect of nanoparticle additives on NO_x emissions of diesel fuelled compression ignition engine," *International Journal of Global Warming*, vol. 7, no. 4, pp. 487–498, 2015.

[22] P. Vasanthkumar, A. R. Revathi, G. Ramya Devi, R. J. Kavitha, A. Muniappan, and C. Karthikeyan, "Improved wild horse optimizer with deep learning enabled battery management system for internet of things based hybrid electric vehicles," *Sustainable Energy Technologies and Assessments*, vol. 52, Part C, Article ID 102281, 2022.

[23] P. Vetrivezhan, C. Ayyanar, P. V. Arunraj, P. Vasanthkumar, and D. Ganesan, "Electroless deposition of aluminium alloy LM25 by SiC and Ni-P nano coating," *Materials Today: Proceedings*, vol. 45, Part 7, pp. 6449–6453, 2021.

[24] Y. Kumaravelu, V. Periyathambi, P. Udhayanan et al., "Influence of aluminum silicate and cerium (IV) oxide nanofluid on pool boiling characteristics," *International Journal of Photoenergy*, vol. 2022, Article ID 5357053, 11 pages, 2022.

[25] A. A. G. Dhas, B. Nagappan, K. Yoganand, T. Arvind, S. Varghese, and D. Christopherselvam, "Effect of nano-fluid on reducing the smoke emissions from diesel engine," *Petroleum Science and Technology*, vol. 37, no. 22, pp. 2283–2287, 2019.

[26] V. Arul Mozhi Selvan, R. B. Anand, and M. Udayakumar, "Effects of cerium oxide nanoparticle addition in diesel and diesel-biodiesel-ethanol blends on the performance and emission characteristics of a CI engine," *Journal of Engineering and Applied Sciences*, vol. 4, no. 7, pp. 1–6, 2009.