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Research Article

Nanometal-Based Magnesium Oxide Nanoparticle with C. vulgaris Algae Biodiesel in Diesel Engine

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Many researchers are interested in biofuels because it isenvironmentally friendly and potentially reduce global warming. Incorporating nanoparticles into biodiesel has increased its performance and emission characteristics. The current study examines the influence of magnesium oxide nanoadditions on the performance and emissions of a diesel engine that runs on C. vulgaris algae biodiesel. The transesterification process produced methyl ester from C. vulgaris algae biodiesel.The morphology of nanoadditives was studied using scanning electron microscopy, transmission electron microscopy, and energy-dispersive X-ray spectroscopy. The fuel sample consisted of biodiesel blends with and without magnesium oxide nanoadditives. The fuel properties of the prepared C. vulgaris methyl ester were found to conform with the ASTM standards. The experimental results were determined by running a single-cylinder four-stroke diesel engine at different load conditions. When compared to B20, a B20 blend containing 100 ppm magnesium oxide nanoparticles enhanced brake thermal efficiency while reducing specific fuel consumption, according to the research. When MgO nanoparticles were introduced to B20, engine emissions of HC, CO, and smoke were decreased.

1. Introduction

Depleting fossil fuels, rising fuel consumption, uncertainty in fuel price, and serious environmental concerns have prompted us to research alternative fuels for compression ignition engines [1]. Biodiesel is a feasible alternative fuel for diesel engines compared to other fuels. Biodiesel is an oxygenated fuel that is biodegradable, non-toxic, and environmentally friendly [2]. Many studies have shown that biodiesel is made from various seeds. Blending, pyrolysis, microemulsion, and transesterification have all been suggested as processes for producing biodiesel. Transesterification is the most powerful biodiesel production technology due to its high conversion rate. Biodiesel has a higher viscosity than diesel; using biodiesel alone in current diesel engines will be challenging. As a result, it is preferable to mix biodiesel with diesel to get the required blend properties for present diesel engines. Biodiesel appears to have significant drawbacks, including a low heating value, high density, and higher viscosity. It affects fuel atomization in the combustion chamber, lowering the combustion pressure and temperature [3]. To improve biodiesel's performance and emission characteristics as fuel to CI engines, various researchers promoted the usage of nanoparticles as additives. They resulted in better performance and emission characteristics due to high surface reactivity. Maximum of the studies on nanoparticle additive on the fuel has collective consent that metal additives at nanoscale improved catalytic action during combustion progression, which stimulates and promotes complete combustion [4]. They assessed the performance and emission characteristics of mahua biodiesel that included copper oxide nanoparticles. The CuO blended fuel improved BTE by 2.2% while decreasing BSFC marginally. In addition, CuO nanoadditive blended fuel decreases hydrocarbon, carbon monoxide, and smoke emissions by 5.34, 32, and 12.6%, respectively [5]. They discovered that adding silver oxide nanoparticles to BD100 increased BTE and reduced BSFC in diesel engines. When BD100+ Ag_2O (10 ppm) was utilized to replace BD100, CO, HC, NOx, and smoke emissions were decreased by 16.47%, 14.21%, 6.66%, and 8.34%, respectively [6]. Compared to a blend without copper oxide, the pongamia methyl ester with copper oxide blends reduces HC, CO, NOx, and smoke. Brake thermal efficiency increased by 4.01% during the same period, while specific fuel consumption decreased by 1% [7]. The performance and emission characteristics of mahua methyl ester blends with aluminum oxide nanoparticles were investigated in this study. According to the findings, aluminum oxide nanoparticles incorporated in biodiesel have a significant advantage over mineral diesel in brake thermal efficiency [8]. Mahua oil blended with nanoadditions emits less CO, HC, NOx, and smoke than standard fuel. According to a literature survey, only a few tests have been undertaken in single-cylinder compression ignition engines using algal biodiesel with nanoadditions. Magnesium oxide nanoadditives are incorporated in varying amounts in C. vulgaris algae biodiesel in this study (50 ppm and 100 ppm). The prepared fuel blends' performance and emission characteristics were examined using the CI engine, and the results were compared to B20.

2. Materials and Method

2.1. Biofuel from Microalgae. Microalgae have a less complex structure, comparatively faster growth rate, higher photosynthetic rates, and high oil contents that make them unique over first-generation biofuel feedstock. As algae can be cultivated in shallow water, pond, and bioreactor, it could help in saving the agricultural land to cultivate more food crops. The main reason for selecting C. vulgaris algae is that these photosynthetic microalgae are available as fresh water and marine algae growing in normal climatic conditions. It is a great source of biomass, and the methyl ester extracted from it is seen as a promising alternative to fossil fuel. The high lipid content in the algae makes it suitable for the extraction of methyl ester and its use as an alternate fuel.

2.2. Chlorella vulgaris Algae Biodiesel. C. vulgaris is a prominent source of attraction for biodiesel production since it contains hydrocarbons in 40-75% of its dry mass. C. vulgaris can survive in various kinds of environments. C. vulgaris can grow in various conditions, including calm freshwater with low nutrient content.

Figure 1: After the transesterification process of C. vulgaris methyl ester.

2.3. Transesterification of C. vulgaris Algae Biodiesel. The transesterification method is used to reduce the viscosity of Chlorella vulgaris oil. The 5.3 grams of NaOH and 300 ml of methanol are blended to avoid methanol evaporation in a closed container. The raw C. vulgaris oil is next heated to 40°C with continual uniform stirring. Every 30 minutes, a burette is filled with NaOH and methanol, which is subsequently blended with raw C. vulgaris oil. In addition, the temperature should be between 50 and 60°C. This temperature may be measured using a thermometer. A container containing a mixture of raw C. vulgaris oil, methanol, and NaOH is taken, and the combination is thoroughly mixed using a stirrer. The combination is heated using a heating instrument, and the mixture's temperature is recorded. With raw C. vulgaris oil, a combination of methanol and NaOH is placed in a container and left to settle for 10 hours. Figure 1 depicts the transesterification of C. vulgaris biodiesel. At the end of 10 hours, the ester and glycerol are separated. Figure 2 depicts the chemical process of transesterification.

2.4. Nanoparticle Characterization. The interaction of the high-energy electron beam with the sample enables the scanning electron microscope to obtain information on the topography, morphology, and composition of solids. The detector in SEM observes X-rays, backscattered electrons, and secondary electrons and converts them into a signal to produce a final image. EDX is one of the standard analytic surface techniques used for an unknown sample's elemental detection and composition. EDX technique is generally associated with the SEM instrument. Sometimes, EDX is also used to work in combination with the transmission electron microscope and scanning transmission electron microscope. The X-rays of different wavelengths emitted by the specimen atoms are energy-specific and carry information about a particular atom. The position of the peak in the histogram plot represents the energy correlated with the concerned element, and the area under the peak provides information about the number of atoms irradiated in the

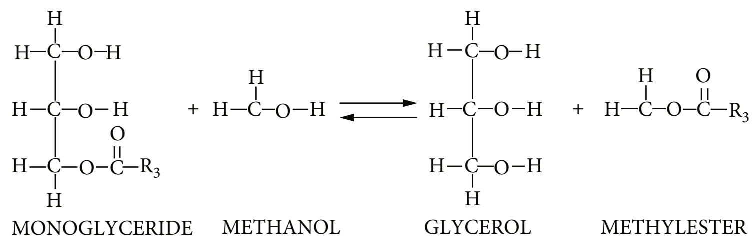

FIGURE 2: The chemical reaction in transesterification.

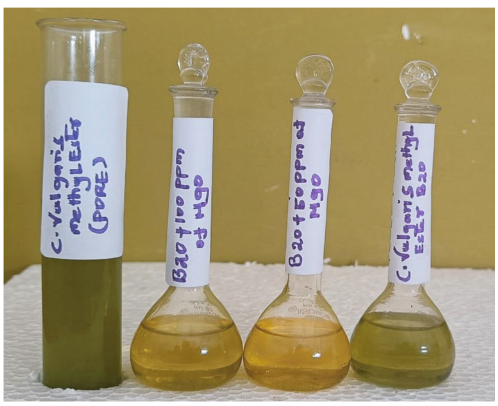

FIGURE 3: Biodiesel with nanoadditive blends.

selected area. The crystalline structure, particle shape, and elemental composition of MgO were investigated morphologically using a JEOL-JSM-IT 200 scanning electron microscope armed with only an Energy-Dispersive X-ray analyzer. The sample was accelerated between 0.5 and 30 kV. The nanoparticle pictures were acquired using a JEOL JEM-1200EX transmission electron microscope.

2.5. Fuel Samples. Figure 3 depicts photographic views of the various biodiesel blends. The C. vulgaris algae methyl ester blend (B20) was produced using a magnetic stirrer by blending 20% biodiesel and 80% diesel on a volumetric basis. Furthermore, using an ultrasonicator, MgO nanoparticles were disseminated into B20 fuel test samples at dose levels of 50 and 100 ppm. B20, B20 + 50 ppm MgO, and B20 + 100 ppm MgO were used in this experiment. Table 1. Properties of these fuels are measured using ASTM D 6751, which is a prescribed method for testing fuel properties.

2.6. Experimental Set-Up. The test rig used for experimental analysis was a one-cylinder four-stroke CI engine (Make: Kirloskar, TV1 model engine with over-head valves controlled by pushrods) with a water-cooled system. The engine can deliver an output power of 5.2 kW at 1500 rpm at full load. The fuel injection pressure and timing were kept at 23° before TDC and 210 bar as recommended by the manufacturer. The coolant was circulated through the water jackets in the cylinder, and the coolant temperature was maintained at 80°C. A piezoelectric transducer was flush-mounted on the cylinder head to measure the in-cylinder pressure. Eddy current dynamometer was fitted to the engine to measure torque. Figure 4 shows the schematic diagram of the experimental set-up.

3. Results and Discussion

3.1. Scanning Electron Microscope. Figure 5 shows an SEM image of magnesium oxide nanoparticles. These findings indicate that particles with flat surfaces were approximately spherical. In certain instances, the particles were found to be evenly dispersed, and in others, they were discovered to be consolidated. The black color in the particles represents the carbon concentration with some oxygen distributed among them. Overall, the distribution of particles is found to be homogeneous. It demonstrates the existence of roughly spherical nanoparticles varying in size from 20 to 38 nm.

3.2. Energy-Dispersive X-Ray Analyzer. The EDX spectrum was used to analyze components quantitatively and qualitatively. The EDX analysis of magnesium oxide nanoparticle samples revealed Mg and O component peaks compared to other elements, as shown in Figure 6. The structure of the remaining elements is relatively insignificant. The elements notified in magnesium oxide nanoparticles are magnesium, oxygen, iron sulfide, silicon dioxide, and sodium. On a weight basis, about 50.74% of oxygen, 45.36% of magnesium, 3.24% of silicon dioxide, and 0.66% of sodium were recorded.

3.3. Transmission Electron Microscope. The transmission electron microscope examination can also elucidate the processed magnesium oxide size, structure, and composition. TEM is an essential technique to extract a clear understanding of particle size distribution and nanoparticle size. After interactions, the electrons transmitted and pass through the nanoparticles provide an image or spectra on the imaging screen. Figure 7 TEM image represents that the magnesium oxide formed takes on unusual forms, with diameters ranging from 9.24 to 14.94 nm.

3.4. Brake Specific Fuel Consumption. Brake-specific fuel consumption is the engine's fuel consumption per unit power generated per unit time and is expressed in kg/kWh. The change in specific fuel consumption as a function of load is seen in Figure 8 for all blends. As the load on the engine increments, the BSFC values decrease. The SFC values for B20, B20 + 50 ppm MgO, and B20 + 100 ppm MgO fuel blends are 0.45 kg/kWh, 0.41 kg/kWh, and 0.38 kg/kWh, respectively. The presence of MgO nanoparticles provides further oxidation and stimulates complete combustion, and hence it results in the reduction of BSFC at a constant speed. This was mainly because of the higher

Table 1: Properties of different fuel blends.

S. no	Properties	C. vulgaris methyl ester (B20)	B20 + 50 ppm of MgO	B20 + 100 ppm of MgO
1	Kinetic viscosity cSt	6.01	6.19	6.21
2	Density kg/m^3	886	891	893
3	Calorific value MJ/kg	39.14	40.23	40.52
4	Flash point °C	91	126	135
5	Fire point °C	116	134	149

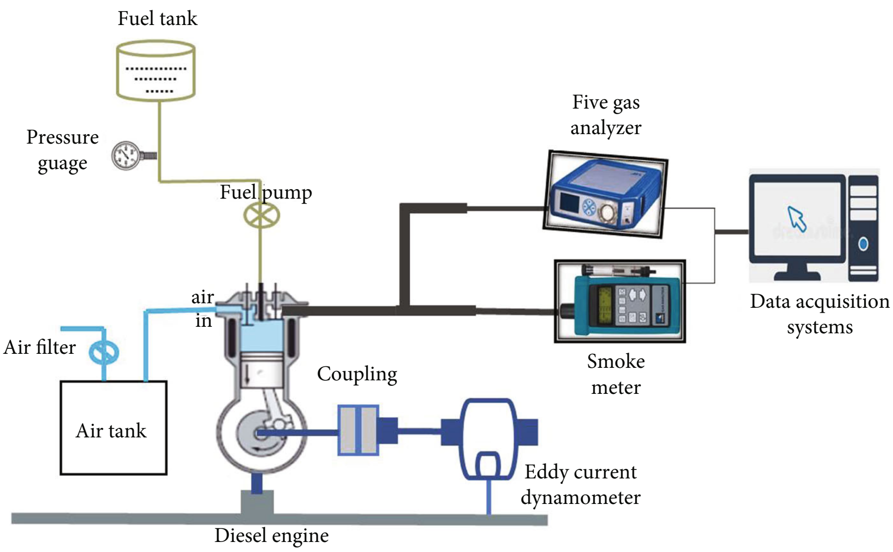

Figure 4: Experimental set-up.

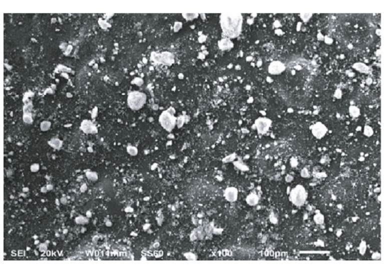

Figure 5: SEM image of MgO.

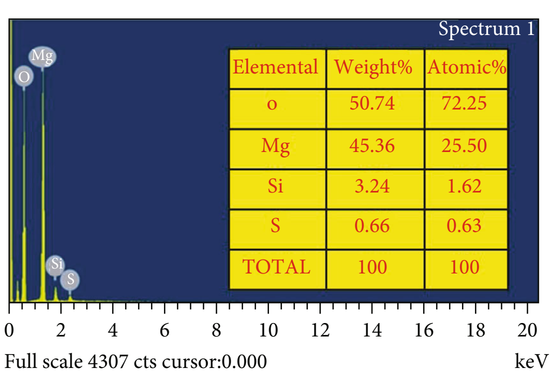

Figure 6: EDX image of MgO.

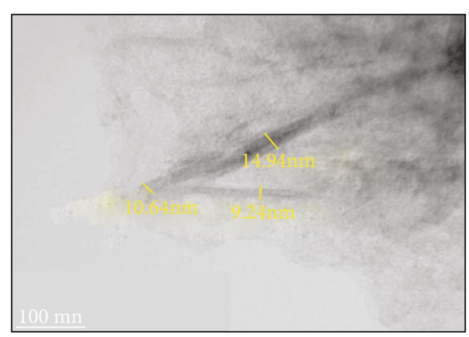

Figure 7: TEM image of MgO.

oxygen content in magnesium oxide nanoadditives, which promotes further combustion and decreases the combustion chamber's fuel-rich region. These results concur with previous research on biodiesel and nano-additives [9].

3.5. Brake Thermal Efficiency. BTE of the engine is the ratio of fuel energy to mechanical energy. Fuel energy depends on many parameters such as fuel blend types, carbon and hydrogen atoms present, cetane number, heating value, and specific gravity. Figure 9 shows the changes in BTE for a variety of blended fuels under different engine loads. The brake thermal efficiency for B20, B20 + 50 ppm MgO, and B20 + 100 ppm MgO fuel blends are 24.9%, 25.8%, and 27.3%, respectively.

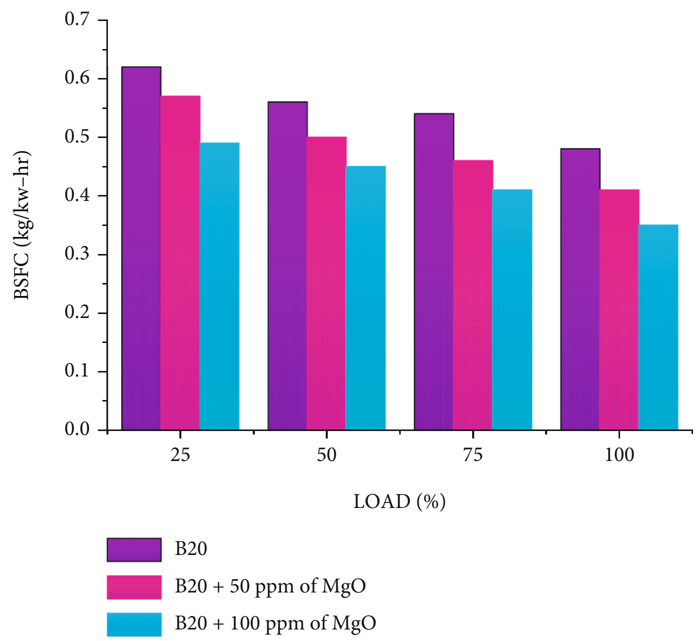

Figure 8: Brake specific fuel consumption vs. load.

B20 + 100 ppm MgO blend increased brake thermal efficiency by 2.4% compared to B20. The inclusion of biodiesel reduces the ignition delay, resulting in longer combustion durations. This is due to a decrease in indicated power, peak in-cylinder pressure, and rate of pressure increase, resulting in decreased biodiesel BTE. The inclusion of magnesium oxide nanoparticles, which improve oxidation, heat release rate, and in-cylinder pressure, is primarily responsible for the increased brake thermal efficiency. Nanoparticles in biodiesel blends have a larger surface area to volume ratio than B20, allowing for more combustion within the combustion chamber. Similar outcomes were obtained in the presence of nanoparticles [10].

3.6. Emission of Carbon Monoxide. CO emission occurred due to partial oxidation of carbon in the fuel. The absence of fuel-borne oxygen in diesel's molecular structure might lead to the production of CO emissions. Due to low flame temperature, fuel combustion with insufficient oxygen leads to increased CO.

Figure 10 depicts the fluctuation of CO emissions with load for all fuel samples. As the engine load incremented, the engine CO emissions generally decreased. Carbon monoxide emissions varied the minimum at low load and the maximum at high load. The CO emissions at maximum load conditions were 0.063%, 0.059%, and 0.051% for B20, B20 + 50 ppm MgO, and B20 + 100 ppm MgO, respectively. Adding 100 ppm of MgO nanoparticles to the B20 reduces CO emissions by 19.02% compared to the B20 at full load. MgO nanoadditive blended fuels have a more incredible oxygen content, allowing for complete combustion. The complete combustion process reduces the CO emission [11, 12].

3.7. Hydrocarbon Emission. Incomplete combustion of fossil fuels in an engine, be it petrol or diesel, which are hydrocarbons, has become the primary sources of emissions of hydrocarbons, and it is expressed in terms of ppm. Figure 11 depicts the variance in HC emissions as a different load function for all the samples. For all test fuels, increasing load showed higher HC emission. The HC emission of B20 + 100 ppm MgO is 27.9% lower than that of B20. The magnesium oxide nanoparticle improves the combustion process within the combustion chamber by enhancing the ignition delay time, increasing the efficiency of the fuel explosion cycle, and boosting the rate of heat escape during fuel combustion. It was concluded that adding magnesium oxide nanoparticles to biodiesel blends decreased hydrocarbon emissions [13, 14].

3.8. Smoke Emission. This was due to a higher amount of fuel with the increasing load, which resulted in rich mixture formation and incomplete combustion. The quantity of unburned hydrocarbons produces ample reasons for smoke emission. Under full load engine conditions, Figure 12 displays the HC emission results for all test fuels. The smoke opacity percentage for B20, B20 + 50 ppm of MgO, and B20 + 100 ppm of MgO test fuels were 28.2%, 26.4%, and 24.5%, respectively. The maximum reduction in smoke opacity is obtained for B20 + 100 ppm of MgO. Compared to B20, the smoke emission of the B20 + 100 ppm MgO blend was reduced by 3.7% at full load. Magnesium oxide nanoparticles accelerate evaporation, and material oxidation ensures complete combustion. The catalytic activity of nanoparticles in biodiesel blends enhanced further oxidation of soot particles, resulting in more reduction of smoke emissions than biodiesel blends without additives [15, 16].

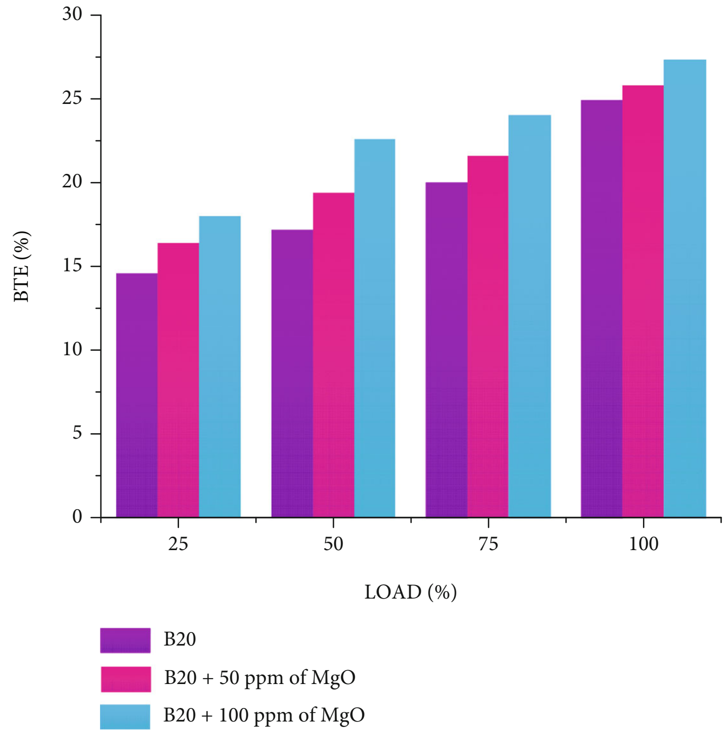

FIGURE 9: Brake thermal efficiency vs. load.

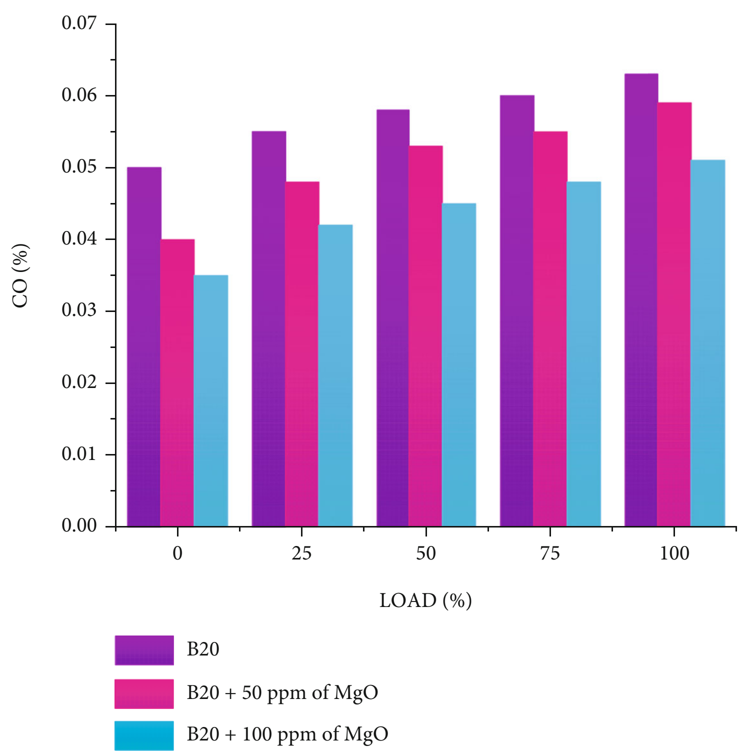

FIGURE 10: Carbon monoxide vs. load.

3.9. Nitrogen Oxide Emission. The emission of oxides of nitrogen takes place from an internal combustion engine when nitrogen present in the air combines with oxygen. This occurs at a high temperature in the engine cylinder. The variation of NO_X formation versus different engine load is shown in Figure 13, for B20, B20 + 50 ppm MgO, and B20 + 100 ppm MgO. The combustion temperature of B20 + 50 ppm of MgO and B20 + 100 ppm of MgO blends

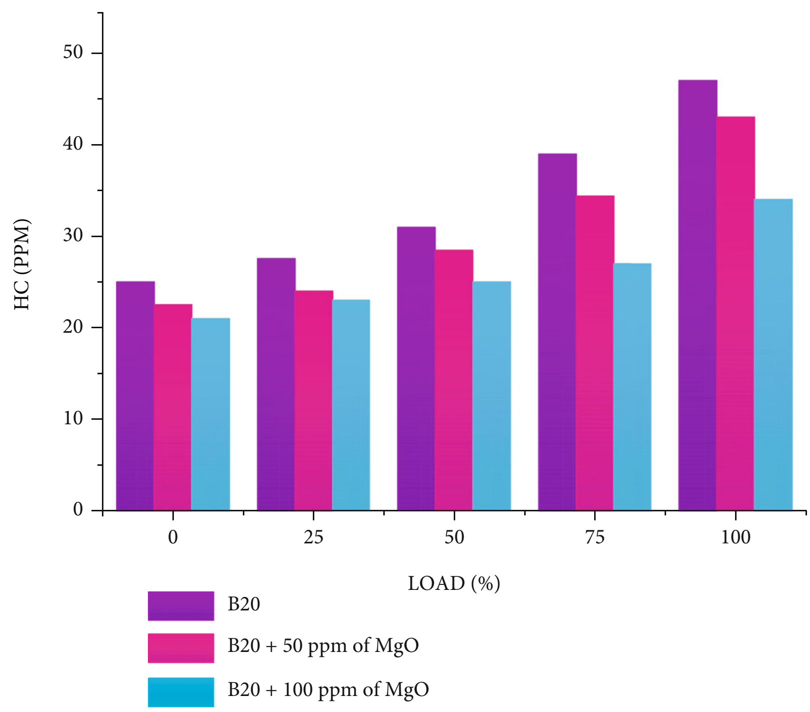

Figure 11: Hydrocarbon emission vs. load.

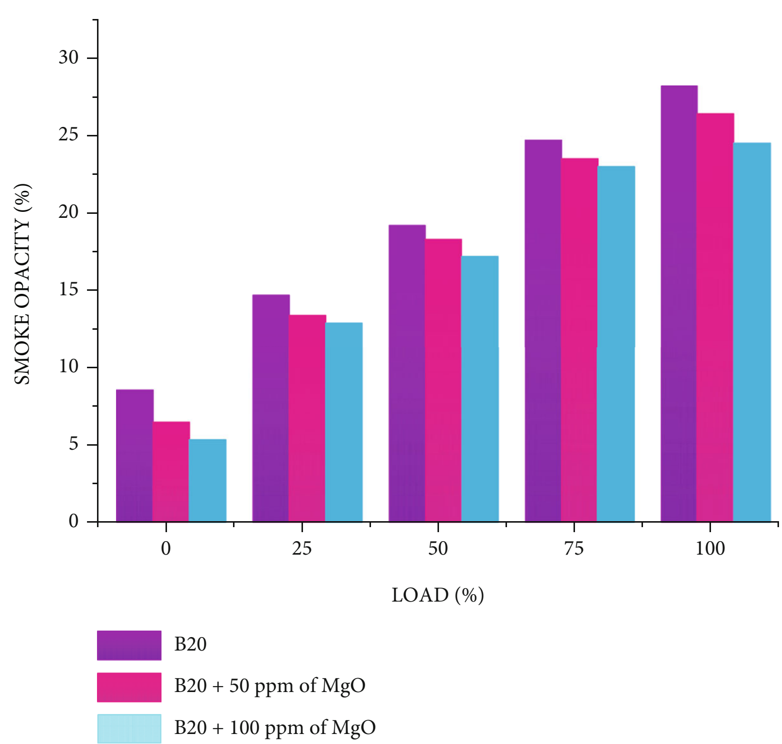

Figure 12: Smoke emission vs. load.

substantially increased due to an increase in O_2, resulting in a high combustion temperature in the cylinder. The B20 + 100 ppm MgO blend emits more NO_x than the B20 blend. This could be due to the presence of oxygen in nanoadditions, causing biodiesel blends with additives to burn entirely than B20. For biodiesel blends with additives, this raises the maximum temperature within the cylinder. Because of the nitrogen oxidation processes in the engine cylinder, biodiesel with additives releases more NO_X [17, 18].

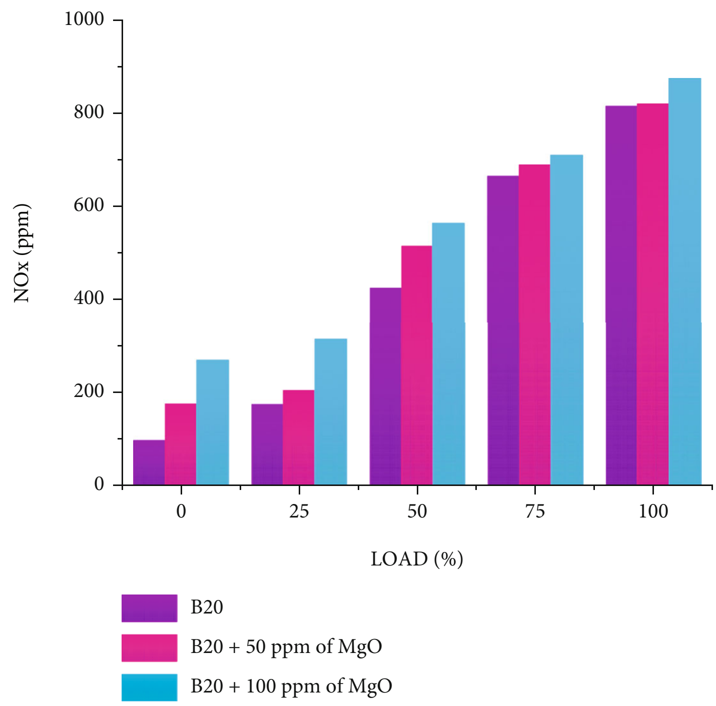

Figure 13: Nitrogen oxide emission vs. load.

4. Conclusion

The performance and emission characteristics of MgO nanoparticle incorporated C. vulgaris fuel were investigated using a single-cylinder diesel engine under different load conditions. The properties were determined following ASTM D6751 standards. Because of its enhanced combustion properties, the MgO nanoparticle impregnated C. vulgaris fuel improved engine performance. In addition, the MgO mixed fuel resulted in lower levels of HC, CO, and smoke emissions. The following conclusions were drawn based on the experimental results. Due to its higher density, viscosity, and lower calorific value, the B20 test fuel had a 15.8% increase in BSFC compared to B20 + 100 ppm of MgO. Compared with B20, brake thermal efficiency increases of 1.9% and 2.4% are obtained for B20 + 50 ppm MgO and B20 + 100 ppm MgO. Carbon monoxide emissions for B20 + 50 ppm MgO and B20 + 100 ppm MgO are reduced by 13.5% and 19.04%, respectively, compared to B20. CO emissions were reduced when the nanoparticle concentration was increased. Hydrocarbon emissions are reduced by 12.81% and 27.9% for B20 + 50 ppm MgO and B20 + 100 ppm MgO, respectively, compared to B20. The MgO nanoadditives added to biodiesel-diesel blends resulted in better combustion. The MgO nanoparticle blended fuel has lower HC emissions when compared with B20. Compared to B20, smoke emissions for B20 + 50 ppm MgO and B20 + 100 ppm MgO are reduced by 1.9% and 3.7%, respectively. When the concentration of nanoparticles was raised, smoke emissions were lowered. The higher oxygen content in B20 + 100 ppm of MgO fuel blend leads to higher combustion temperature, resulting in higher NO_x emission.

Data Availability

The data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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