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Research Article

Performance and Emission Analysis of Waste Cooking Oil Biodiesel Mixed with Titanium Oxide Nano-Additives

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People are using biodiesel in compression ignition engines because it is more environmentally friendly and can be used as a good alternative to diesel. There is a new technology called nanoparticles that can change the way a fuel works. Because waste cooking has a lot of oil in it, it can make biodiesel. To make biodiesel, transesterification was used to turn nonedible oil from waste cooking oil into biodiesel that could be used. Nanoparticles made of titanium oxide were studied by using scanning electron microscopy, transmission electron microscopy, as well as energy dispersive X-ray analysis, among other things. TiO2 nanoparticles are spread out in different amounts in the biodiesel blend. The dosage levels range from 25, 50, 75, and 100 ppm. Tests on how titanium nanoparticles in a waste cooking oil biodiesel blend affect a diesel engine's performance and how it emits were conducted in this study too. At a steady speed, the engine was used when there was a lot of work to do. Tests show that the WCOME 20 TiO2 100 ppm blend worked well. With the increase in the concentration of nanoparticles, there is an increase in brake thermal efficiency and at the same time, there is a decrease in BSFC. It is also less harmful to the environment than other blends, except for NOx, which does no't change.

1. Introduction

Nowadays, population explosion and rapid industrialization have drastically increased energy demands. Increasing demand for fossil fuels from customers has resulted in fossil fuel depletion. Fossil fuels are getting scarce, and their combustion is associated with environmental damage, resulting in an exponential growth in greenhouse gas emissions into the atmosphere, and a rise in fuel cost and initiating a search for alternative fuel [1]. Primary energy sources are conventional fuels like oil, nuclear, natural gas, coal, and renewable energy, such as wind, solar, and hydro. Various biomass-derived alternative fuels are called biofuel, including vegetable oils, bio-hydrogen, biodiesel, bio-alcohol, and natural gas. The most useful in the combustion ignition engine and transport applications is biodiesel. Biodiesel can replace fossil fuel in vehicle engines either directly or in the blended form [2, 3]. A recent study has demonstrated that microalgae feedstocks may be utilized as a viable replacement to fossil fuels that are rapidly decreasing in the environment. Algae can develop in both freshwater and wastewater treatment ponds. Fatty acid methyl esters are derived from the transesterification of oil feedstocks (waste cooking oil, animal fats, vegetable oils, and microalgal lipids) using acid and alcohol as a catalyst. The oxides present in the nano-additives of TiO2 aid complete combustion of the fuel, which improves the calorific value of fuel blends. However, biodiesel has low volatility and high viscosity, causing problems in mixture formation, spray penetration, and atomization when used in diesel engines [4, 5]. These results increase fuel consumption, smoke, and engine deposits. Blending, transesterification, heating the oil, air preheating, micro-emulsification, and nano-additives are all strategies for minimizing issues while utilizing biodiesel in diesel engines. Nano-additives have recently become a viable alternative among all the strategies. Numerous researchers selected metal-based nano-additives to minimize biodiesel drawbacks [6]. In most investigations, nanoparticles have considerable advantages over micron-sized particles, including a larger reactive surface area, which leads to full combustion due to shorter ignition delays. Metal oxide nano-additives improved performance, emission, and combustion properties and minimized emissions. The thermal and physical characteristics of nanoparticle-blended biofuels are enhanced, and oxidation processes are accelerated.

Nanoparticles in biodiesel have been used in a number of studies to improve engine performance and emissions. Using TiO2 nanoparticles, they studied the features of palm biodiesel and corresponding engine performance parameters. Biodiesel blended with TiO2 generated 2.43 percentage points more thermal efficiency than pure diesel in brakes. The use of nanoparticles as an oxidation catalyst ensured that the whole process of combustion occurred. It was also possible to reduce emissions of CO, HC, NOx, and smoke [7]. To evaluate the performance and emissions of jatropha biodiesel, cerium oxide nanoparticles are injected into a diesel engine and operated at high temperatures. The quantities of cerium oxide nanoparticles ranged from 20 to 80 parts per million (ppm). According to the results of the research, adding nano-additions to biodiesel improved brake thermal efficiency while simultaneously lowering specific fuel consumption. Exhaust gas emissions [8] of CO, HC, NOx, and smoke were all found to have been decreased. They looked at the impact of cerium oxide nanoparticles on the performance and emissions of a neem oil biodiesel CI engine powered by neem oil. In comparison to diesel, adding 50 ppm cerium oxide nanoparticles to biodiesel-mixed fuels lowered BTE emissions by 2.8%, CO emissions by 3.4%, HHC emissions by 2.7%, and NOx emissions by 8.4% [9, 10]. The engine's performance and emissions were studied after copper oxide, a metal-based addition, was added to the linseed oil biodiesel. BTE increased by 3 to 4 percentage points as a result of the B20 and 80 ppm of CuO combination. There were significant reductions in all four of these pollutants when compared to diesel fuel [11]. There were no adjustments made to the CI engine when the canola biodiesel, canola biodiesel emulsion, and canola biodiesel nanoparticles were tested. Brake thermal efficiency was increased by 1.2 percent and peak pressure was decreased by 3.4 bar when canola biodiesel with 30 ppm alumina nanoparticles was added to the fuel. The ignition delay time was shown to be shortened by the nanoparticles. In comparison to plain biodiesel, alumina nanoparticles dramatically decreased CO, HC, and NOx but also smoke opacity emissions [12]. Only a few studies on nano-added waste cooking oil biodiesel were found in the review of the literature. In this work, a constant-speed single-cylinder diesel engine was used to test the performance as well as emission characteristics of biofuel blends generated from waste cooking oil and titanium oxide nano material.

2. Experimental Materials and Methods

2.1. Production of Biodiesel. Transesterification, alcoholysis, or supercritical methanol transesterification may all be used to make biodiesel from edible or nonedible oils, animal fats, or waste cooking oil. To produce industrial biodiesel from waste oil, transesterification is the most frequent method of using strong acids or alkalis as a catalyst. A strong alkali catalyst is a common option for transesterification in biodiesel production, since it requires less catalyst and reacts faster than a strong acid catalyst.

2.2. Transesterification Process of Waste Cooking Oil Biodiesel. The technology, known as transesterification, is used to produce biodiesel from a variety of sources, including vegetable oils, animal fats, and even waste cooking oils. When glycerides and alcohols react (typically with in presence of a catalyst), they form fatty acid alkyl esters, which are then converted into fatty acid alkyl esters. Transesterification is shown in Figure 1.

2.3. Biodiesel Preparation Process. Using a 500 ml or bigger beaker, we need to pour the mixture into it and stir it well. A magnetic stirrer heated up 400 milliliters of oil in only a few minutes. We use the magnetic pellet at a speed of less than 500 rpm. We use a thermometer to monitor the oil's temperature on a regular basis. We then pour in the methanol after the oil reaches 40°C. The solution should be heated. We use 125 ml of methanol to dissolve 12 sodium hydroxide pellets (NaOH) or 3.5 grammes of sodium hydroxide. When the oil temperature hits 56°–58°C, we lower the heat. We allow an hour for the dust to settle. The glycerol and methyl ester layers that need to be separated may be seen. We add the accumulated oil to the separator funnel. Glycerine should be poured into a separator and let to evaporate on its own. Now, we separate the glycerin and oil. Finally, we put the oil back in and refill the funnel. To get rid of soap smells, we mix oil and hot water in a separate funnel. For best results, we repeat this procedure two or three times. Later, we remove the oil from the beaker and discard it. Heating the oil to 90°C may remove the residual water. The waste oil is used for biodiesel production.

2.4. Synthesis of Tio_2 Nanoparticles. Purchase of titanium tetra isopropoxide (TTIP, Sigma-Aldrich, AR grade, purity >99 percent) was necessary for the production of TiO2 nanoparticles. Figure 2 depicts the flow chart for the

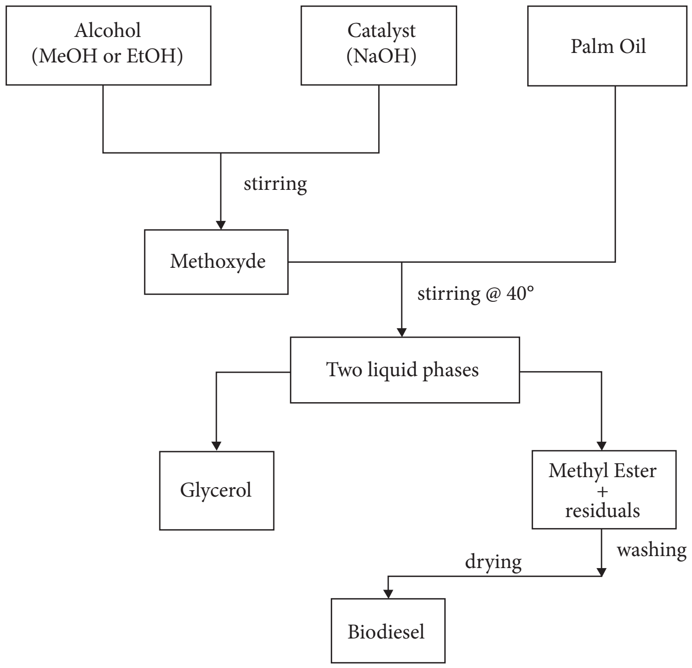


Figure 1: Schematic diagram of the transesterification process.

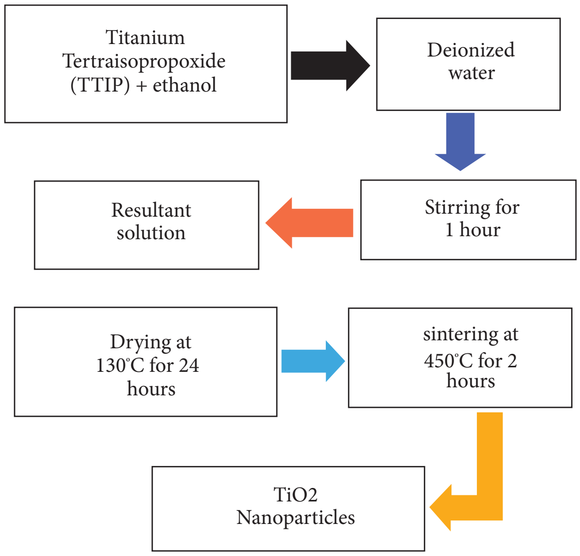


Figure 2: Preparation flowchart of TiO_2 nanoparticles.

synthesis of TiO2 nanoparticles, whereas Figure 3 depicts the TiO2 nanopowder.

2.5. Characterization. The study of the characteristics of nanoaprticles is carried out. Temperatures ranging from 10° to 80°C were used to explore the structural features of TiO2 nanoparticles. A UV-Visible spectrophotometer, the Shimadzu 2700 UV-Visible spectrophotometer, was used to assess the absorption of titanium dioxide nanoparticles in this study. SEM and energy-dispersive X-ray spectroscopy were used to examine the structure of the synthesised TiO2 nanoparticles before they were subjected to chemical analysis using Perkin Elmer FT-IR spectroscopy 400–4000 cm^{-1} and Perkin Elmer FT-IR spectroscopy 400–4000 cm^{-1} to determine the composition of TiO2 nanoparticles (EDXS). The surface form and texture of a nanoparticle were investigated using a transmission electron microscope (TEM) (Titan). The properties of different blends are taken into consideration as per ASTM D6751 [13].

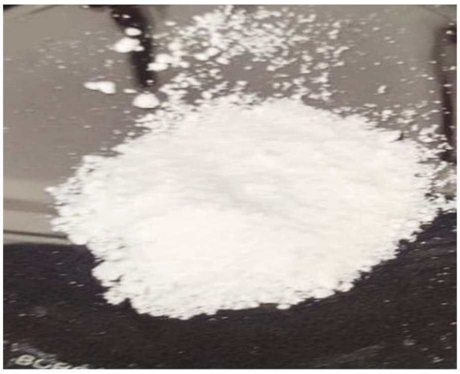


Figure 3: TiO_2 nanopowder.

2.6. Properties of Prepared Biodiesel Blends. Testing on waste cooking oil methyl ester with or without nanoparticles was carried out in accordance with ASTM standards, which measured density, kinematic viscosity, flash point, cetane number, and calorific value. Table 1 displays the biodiesel mixes'attributes. Figure 4 shows graphical representation of the physical and chemical characteristics of mixed biodiesel fuels, both with and without nano-additives.

2.7. Experimental Setup. Compression-ignition, water-cooled, single-cylinder engine was employed in the experiments. The engine output at full load was 5.2 kW at

Table 1: The physical and chemical characteristics of mixed biodiesel fuels, both with and without nano-additives.

Properties	WCOME 20	WCOME 20 TiO$_2$25	WCOME 20 TiO$_2$ 50	WCOME 20 TiO$_2$ 75	WCOME 20 TiO$_2$ 100
Density kg/m^3	889	892	894	897	891.5
Kinematic Viscosity Cst	4.81	4.80	4.82	4.84	4.825
Flash Point °C	190	192	195	194	195
Cetane Number CN	43	45	46	48	50
Calorific value MJ/kg	39.18	37.06	37.21	37.49	37.62

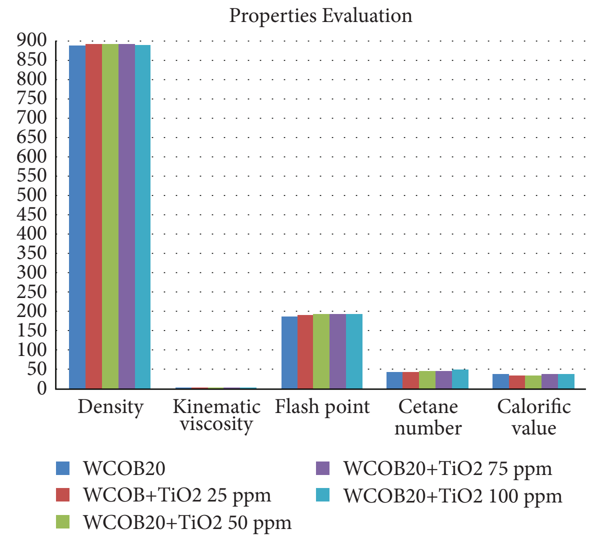


Figure 4: Graphical representation of the physical and chemical characteristics of mixed biodiesel fuels, both with and without nano-additives.

1500 rpm. There are pushrod-controlled overhead valves in the engine, which is a TV1 model from Kirloskar. Fuel injection timing and pressure were maintained at 23° before TDC and 200 bar. Cylinder water jackets circulated the engine coolant and maintained a temperature of 80°C. Using a transducer mounted to the cylinder head, it was possible to measure the cylinder pressure. The engine was put through its paces on an eddy current dynamometer. WCOME20, WCOME20 TiO225, WCOME20 TiO250, WCOME20 TiO275, and WCOME20 TiO2100 ppm were all tested in this study. Four different loads were tested: 25, 50, 75, and 100 percent. It was determined how well the engine performed and what kind of emissions it produced under a variety of operating conditions. As depicted in Figure 5, the experimental setup is depicted in a schematic form.

3. Results and Discussion

3.1. SEM and TEM Analysis of TiO$_2$ Nanoparticles. Scanning electron microscopy (SEM) is a technique in which an electron beam scans a material to produce a magnified image that can be studied. SEM analysis and SEM microscopy are both terms used to describe the process of examining solid inorganic materials using a scanning electron microscope. They are used for microanalysis and failure analysis. Scanning electron microscope, which uses kinetic energy as its operating principle, may provide signals about the interaction of electrons in a sample. To observe crystalline components and photons, we need secondary electrons which are comprised of backscattered electrons and diffracted backscattered electrons among other types of electrons. The morphology of TiO2 nanoparticles was investigated using scanning electron microscopy (SEM). As shown in Figure 6(a), the average diameter of TiO2 particles formed in this method seemed to be 27 nm. It was noticed that powder particles were a bit clumped together. TiO2 nanoparticles were subjected to EDX analysis in order to determine their chemical composition. Only titanium (Ti) and oxygen (O) were found to have peak values in Figure 6(b), with no other metals or elements having further peak values. As a result, the existence of TiO2 particles has been established. Images of TiO2 nanoparticles are shown in Figure 6(c), and images of the EDX spectra of TiO2 nanoparticles are shown in Figure 6(d).

3.2. Brake Specific Fuel Consumption. BSFC is a critical metric for gauging an engine's fuel efficiency. BSFC is a term used to describe the occurrence of fuel combustion that is both efficient and clean. Figure 7 shows the BSFC of waste cooking oil biodiesel blends with and without nano-additions under various loads. Recent studies show that waste cooking oil biodiesel with nano-additions has a lower bulk specific fuel capacity (BSFC) as loading increases. In this mix, there is more waste cooking oil biodiesel, which is thicker and has a lower calorific value than regular biodiesel. Since titanium oxide nanoparticles are dosed from 25 ppm to one hundred ppm, they help oxidise the carbon in the engine combustion chamber, leading to more efficient operation and therefore less fuel use. Its BSFC is lower than those of other biodiesel blends, including WCOME20 TiO2 100 ppm. In addition, the nanoparticles' enhanced surface area-to-volume ratio encourages greater burning, making them more efficient. As the size of nanoparticles rises, the possibility of accumulation increases, and as a result, BSFC decreases, and as a result, the catalytic activity of nano-additives is reduced at greater doping levels [14].

3.3. Brake thermal Efficiency. The valuable work gained from the chemical energy of the fuel is referred to as brake thermal efficiency, and it illustrates how energy conversion occurs. As a consequence, the thermal efficiency of brakes is greatly increased. Figure 8 depicts the effect of TiO2 nanoparticles in

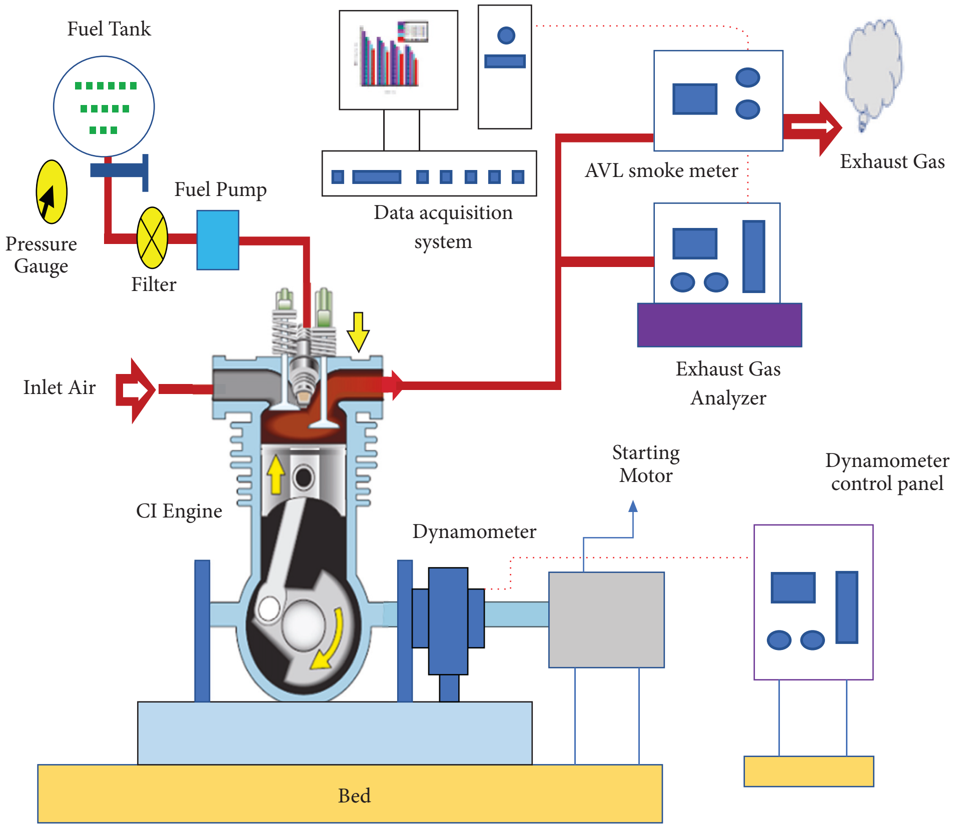


Figure 5: Schematic representation of the experimental setup.

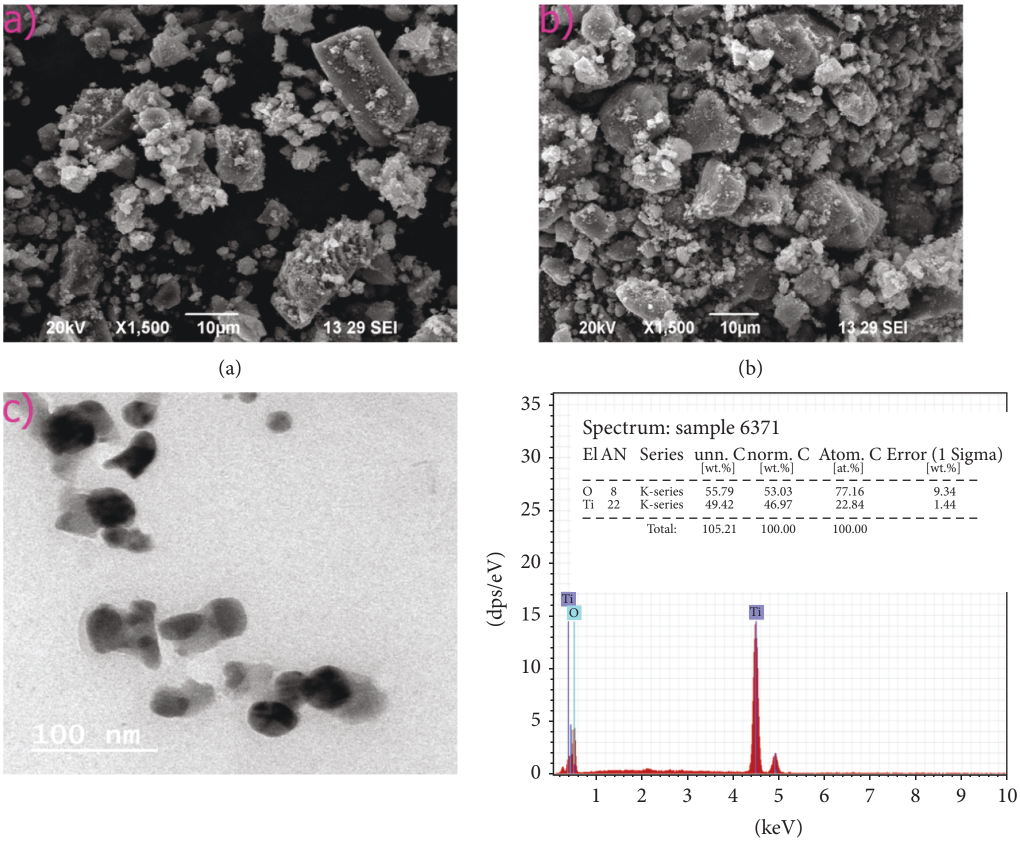
BTE with regard to the load of the test engine. At the highest loading circumstances WCOME 20, WCOME20TiO225, WCOME20TiO2 50, WCOME20 TiO275, and WCOME 20 TiO2100 ppm, brake thermal efficiency values were 24.6 percent, 25.4 percent, 26.2 percent, 27.5 percent, and 30.7 percent, respectively. The findings show that introducing TiO2 nanoparticles into B20 blends increased the diesel engine's BTE. The increase in BTE for nanoparticles distributed in test fuels from 25 ppm to 100 ppm is attributed to improved fuel atomization and combustion. Furthermore, the data show that the BTE of the B20 + 100 ppm mix is more efficient than that of other biodiesel blends. The increased surface area-to-volume ratio, accelerated fuel evaporation, and improved catalytic combustion of titanium oxide nanoparticles improved brake thermal efficiency. According to a recent study, a diesel engine driven by nanoparticle mixtures exhibited a higher BTE than a diesel engine fueled by conventional diesel [15].

3.4. *Carbon Monoxide Emission.*

Figure 9 depicts the engine's CO exhaust flow under load and highly harmful exhaust emissions emerged. CO was released as a result of the partial oxidation of carbon in the fuel. Due to the lack of oxygen in the diesel's chemical structure, the release of carbon dioxide may occur. A lack of oxygen in the combustion process causes CO levels to rise as a result of low flame temperature. When compared to WCOME 20, CO emissions from WCOME 20TiO2 100 were reduced by 25.9%. As a result, the WCOME 20 TiO2100 ppm mix emits less smoke than the other test fuels tested. TiO2 nano-additives have an outstanding surface-to-volume ratio. Because of this, proper atomization and quicker combustion may be achieved. It increases the combustion's oxygen content, resulting in better test fuel ignition and evaporation. Due to nano-additive effects on the cetane index and the heating value of blended fuels at peak load, all fuels with nano-additions have the lowest CO emissions [16].

3.5. *Unburnt Hydrocarbon Emission.*

Figure 10 shows the effect of the TiO2 nano-additive applied to WCOME 20 on HC emission. Compared to WCOME 20, TiO2 nano-addition added waste cooking oil biodiesel fuel blends had lower HC emissions. Exhaust gas concentrations of hydrocarbons peaked at full throttle. More than two-thirds of HC emissions from the WCOME 20 fuel with a 100 ppm TiO2 nanoparticle contained mix are reduced by 21.6 percent. HC emissions from the cylinder and cervix come from volatile hydrocarbons in a lower temperature boundary layer that is immobile. In biodiesel, TiO2 nanoparticles doped at concentrations ranging from 25 parts per million (ppm) to 100 ppm provide oxygen and hence speed up hydrocarbon oxidation. As a result, the combustion chamber is more likely to achieve full combustion. Nanoparticles of titanium dioxide (TiO2) reduce emissions of unburned hydrocarbons. The WCOME 20 blend has a slightly greater unburned hydrocarbon emission than the WCOME 20 blend with



Spectrum: sample 6371

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	55.79	53.03	77.16	9.34
Ti	22	K-series	49.42	46.97	22.84	1.44
		Total:	105.21	100.00	100.00	

(a) (b)

(c) (d)

Figure 6: (a, b) SEM images ofTiO$_2$ NPs, (c) TEM micrograph of TiO$_2$ NPs, and (d) EDX spectra of the TiO$_2$ NPs.

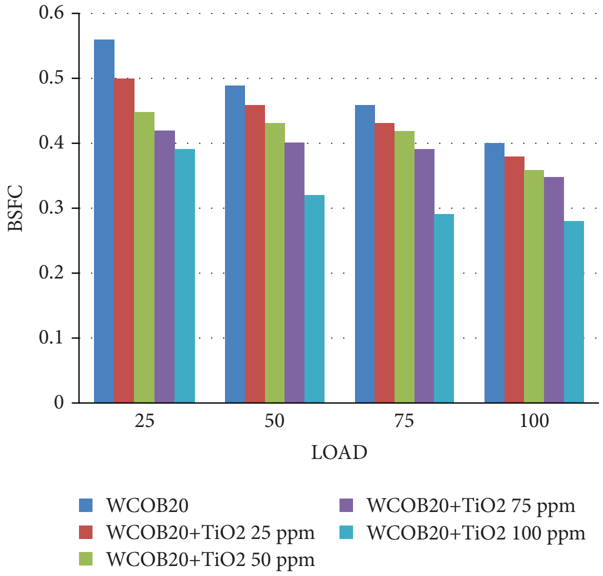


Figure 7: Brake specific fuel consumption with respect to engine load.

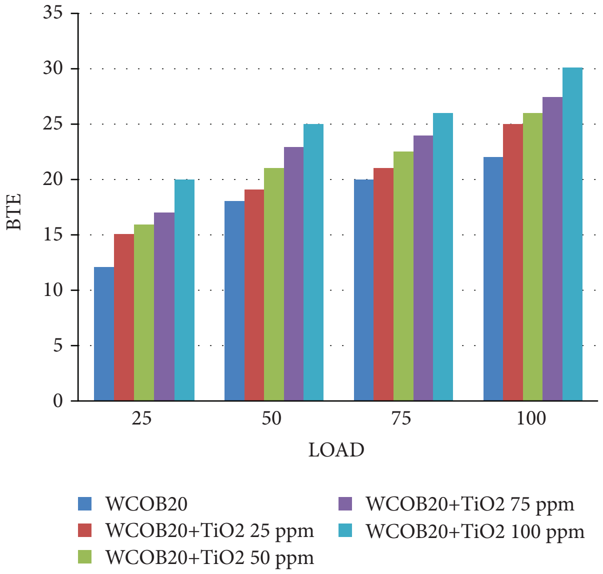


Figure 8: Brake thermal efficiency with respect to load.

additives. The greater the load, the higher the HC emission was for all test fuels. The WCOME 20 TiO2 100 ppm sample showed a significant reduction in HC emissions when compared to the other evaluated fuels [17].

3.6. Smoke Emission. Most of the emissions of smoke are due to the ineffective oxidation of soot in rich fuel zones, which is connected to the efficiency of the combustion of the fuel. Smoke opacity emissions of all investigated fuels are shown in Figure 11. It is clear from the graph that as load grew,

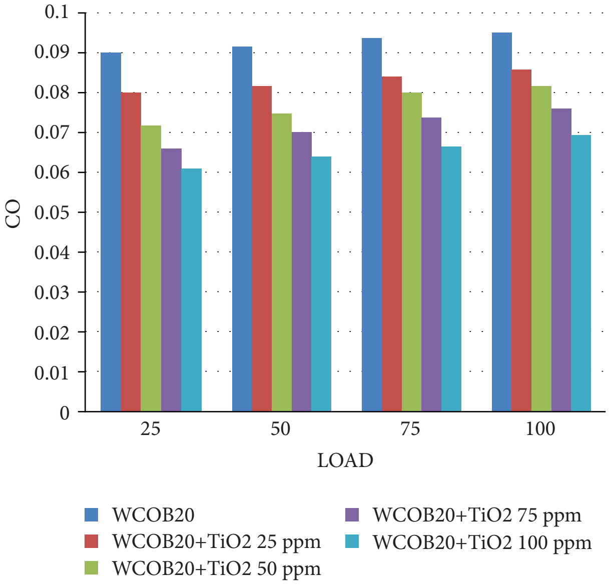


Figure 9: Carbon monoxide with respect to load.

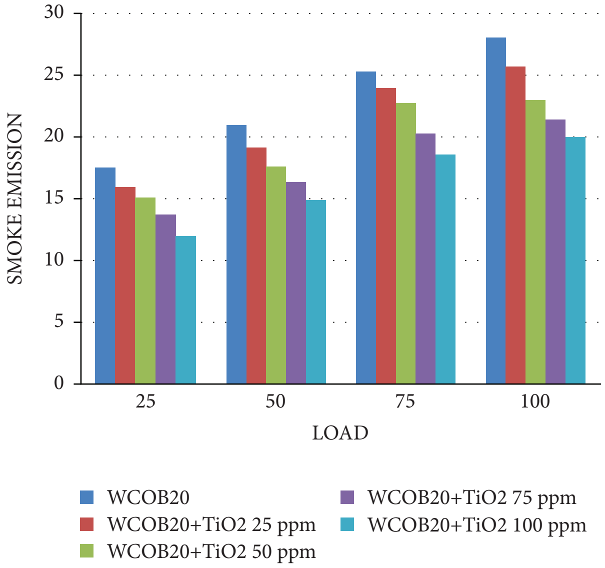


Figure 11: Variation of smoke opacity with respect to load.

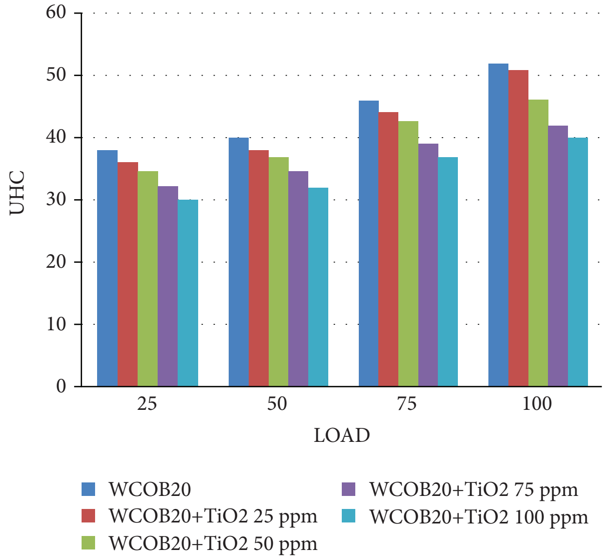


Figure 10: Variation of hydrocarbon with respect to load.

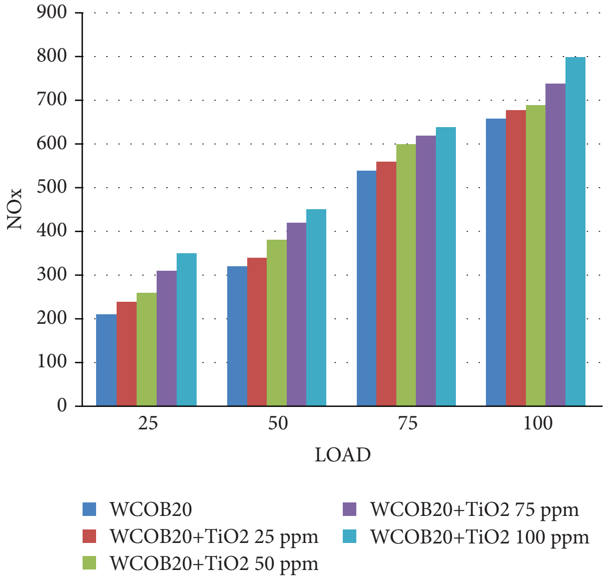


Figure 12: Variation of NO$_x$with respect to load.

smoke opacity increased as well. Using biodiesel resulted in a more efficient oxidation process and full combustion because of the fuel's oxygen concentration. Smoke opacity was reduced as a result of this. There was a 2.1, 3.6%, and 5.4% reduction in smoke emissions at maximum load when the WCOME 20 TiO2 25 TiO2 50 TiO2 75 and WCOME 20 TiO2 75 were employed instead of WCOME 20, respectively. Adding 100 ppm TiO2 nanoparticles to WCOME 20 gasoline decreases smoke emissions by 7.4 percent compared to WCOME 20 at full load. Compared to other fuels, WCOME 20 samples with nanoparticles generate less smoke. It has been shown that a biodiesel mix containing nanoparticle catalysts may reduce smoke emissions more effectively than biodiesel blends without nanoparticles. Chemical reaction time was dramatically impacted by TiO2 nanoparticles in mixed biodiesel fuels, resulting in a brief igniting delay. It was for this reason that soot emissions decreased [18].

3.7. Nitrogen Oxide Emission. NOx emissions are calculated by dividing the applicable fuel consumption rate by the NOx emissions ratio. As the engine's load increases, so does the output of nitrogen oxides. An increase in oxygen concentration and a rise in combustion chamber temperature favor the generation of NOx. The biodiesel sample raised the combustion temperature and caused an interaction between the nitrogen atoms and the additional oxygen in the air during combustion. As a result of the fuel's breakdown into mono-atomic nitrogen, NOx emissions are increased. WCOME 20 biodiesel with or without nano-additions are shown in Figure 12 for various loads. 660, 680, 690, 740, and

800 ppm of NOx were emitted by WCOME 20, WCOME 20 TiO2 25, WCOME 20 TiO2 50, WCOME 20 TiO2 75, and WCOME 20 TiO2 100, respectively, at maximum load. In comparison to other blended fuels, the WCOME 20TiO2100 ppm mix had the highest full-load NOx emission. Because the titanium oxide nano-addition increases the amount of donating O_2 in the fuel mix, the cylinder temperature rises, revealing the source of greater amounts of NOx exhaust emissions [19].

4. Conclusion

The goal of this study is to see how adding TiO2 nanoparticles to waste cooking oil biodiesel affects the performance and emissions of a diesel engine. According to ASTM standards, the fuel qualities of the manufactured waste cooking oil methyl ester with nano-additions met or exceeded expectations. A range of TiO2 doses (25 ppm, 50 ppm, 75 ppm, and 100 ppm) was applied to the gasoline and diesel fuels. Biodiesel and diesel mixes that had nano-additions had improved combustion as a consequence. Nano-additives in biodiesel operate as a catalyst for combustion, guaranteeing full combustion. BTE rises when BSFC declines, owing to an increase in the amount of heat created within the combustion chamber. With the WCOME20 TiO2 100 ppm·mix, CO, HC, and smoke were reduced by 25.9 percent, 21.6 percent, and 7.4 percent, respectively; with the WCOME20 TiO2 0.05% blend, WCOME 20 TiO2 100 ppm blend has a greater oxygen concentration, which results in a higher combustion temperature and a larger NOx output. With the addition of titanium oxide nanoparticles to the WCOME 20 biodiesel mix, the emission of nitrogen oxides was enhanced [20–22].

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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