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Influence of Nano Additives on Performance, Combustion, and Emission Characteristics of Diesel Engine using Tamarind Oil Methyl Ester-Diesel Fuel Blends

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ABSTRACT

Hazardous emissions majorly NOx and the poor performance of alternative fuels (biodiesel/its blends) are global concerns, as fossil fuel depletion and rising energy prices encourage researchers to rely on alternative energy sources with the addition of nano additives in the recent decade. The current experimental study investigates the performance, combustion, and emission characteristics of biodiesel-diesel mixtures dispersed with titanium dioxide (TiO_2) as a fuel additive on a 1-cylinder diesel engine. TiO_2 was dispersed in a Tamarind Oil Methyl Ester (TOME)-diesel blend (B20) in three concentrations of 40, 80, and 120 ppm via ultrasonication in the presence of QPAN80 surfactant to enhance the stability of the prepared fuel sample. A ratio of 1:4 TiO_2:QPAN80 was found to produce the highest stability and homogeneity which is evidenced by the characterization of TiO_2. The engine tests revealed that the greatest decrement in BSFC, CO, HC, and NOx was observed as 15.2%, 15.2%, 11.10%, and 9.06%, and the maximum BTE, HRR,

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and CP were improved by 9.76%, 50.32 J/degree, and 50.32 bar for the B20T80 blend correlated with B20 blend. Thus, the inclusion of TiO_2 nano additives improved overall engine performance and decreased emissions of CI engines significantly.

Keywords: *Titanium Dioxide Nanoparticles; Catalytic Effect; Engine Performance; Engine Emissions; Tamarind Oil Methyl Ester*

Nomenclature

AFD	Aphanizomenon Flos Biodiesel-Diesel blend	CP	Cylinder Pressure
B20	TOME 20%-80% diesel	DI	Direct Injection
B20T40	B20 with 40 mg of TiO_2	FTIR	Fourier Transform Infrared
B20T80	B20 with 80 mg of TiO_2	ID	Ignition Delay
B20T120	B20 with 120 mg of TiO_2	NHRR	Net Heat Release Rate
BP	Brake Power	NOx	Nitrogen oxide
BSFC	Brake-Specific Fuel Consumption	TiO_2	Titanium dioxide
BTE	Brake Thermal Efficiency	TOME	Tamarind Oil Methyl Ester
CI	Compression-Ignition	UHC	Unburnt Hydrocarbons
CO	Carbon monoxide	XRD	X-Ray Diffraction
CO_2	Carbon dioxide		

Introduction

Humankind has relied on a variety of Energy sources for their need and development. In today's world, the energy problem has evolved into a worldwide concern that is threatening the security of civilizations. Fuels are crucial in the generation of large amounts of energy in different sectors like transportation, industrialization, and power generation. Fossil fuels supply 80% of the major contributors to the world's requirements [1]. Fossil fuel depletion, increasing the cost of crude oil products, and the emissions released from the prime movers using fossil fuels are the major concerns today the world is confronting and encouraging researchers to find alternative renewable sources that can perform with similar engine efficiencies less polluting emissions. Alternative source like biodiesel has been well-recognized to replace fossil fuels. Biodiesel is also expressed as mono-alkyl esters prepared from raw feedstock oils/animal fats in the presence of a catalyst and with small-chain alcohols. The direct use of vegetable oils was restricted owing to their higher viscosity, poor atomization, carbon deposits that can clog fuel injection nozzle, and incomplete combustion [2]. Transesterification is the best and most effective method for reducing the viscosity of vegetable oil and can yield a superior quantity. The physicochemical characteristics of biodiesel are closer to the standard diesel and can run with no modifications in the engine, but biodiesel performs with less efficiency than diesel [3]-[5]. On the other side, biodiesel emits hazardous NOx emissions which are attributed to the rich oxygen in biodiesel. Several investigations revealed various techniques like engine modifications, exhaust gas recirculation, and fuel modification techniques to decrease NOx emissions and enhance the performance of diesel engines. The former methods enhance smoke emissions, whereas the fuel reformulation technique uses nanoparticles as a fuel additive in CI engines to address the above issue. The qualities of base fuel have been discovered to be enhanced with the addition of nanoparticles which aid in better atomization, and combustion, as a result, minimize hazardous exhaust emissions like NOx [2], [6].

Dsilva and Bhat [5] investigated the influence of nano additives Titanium dioxide (TiO_2) dispersed in Pongamia Pinnata biodiesel-diesel fuel blends (B10, B20, and B30) on performance, combustion, and emission parameters. The test sample B20 with the inclusion of TiO_2 nano additives enhanced Brake Thermal Efficiency (BTE) by 1.47% and reduced BSFC by 7.29%. Emissions were reduced to a lower value such as Nitrogen Oxide (NOx) (by 4.3%, 3.9%, and 4.2%), Unburnt Hydrocarbons (UHC) (by 20%, 13.6%, and 11.1%), and smoke opacity (by 9.2%, 11.04%, and 7.9%) for the nano additive B10, B20, and B30 blends respectively. Among various fuel blends, the B10T75 results in the highest Cylinder Pressure (CP), and B30T75 improves the highest Heat Release Rate (HRR). In another study, the effect of TiO_2 nanoparticles dispersed in palm oil biodiesel was studied on CI engines. Palm oil biodiesel-diesel samples were prepared in different proportions i.e., B10, B20, B30, B40, B50, and B100, and correlated to the B20 sample which was considered as a reference fuel. The fuel properties such as viscosity, flash point, cetane index, and calorific values were enhanced with the addition of 0.1% wt TiO_2 nano additive. Among all the blends, the fuel properties of the blends B20+0.1%TiO_2 and B10+0.1%TiO_2 meet the ASTM standards. Engine power and torque were improved at low speeds, and Carbon Dioxide (CO_2) and Nitrogen Oxide (NOx) were found to be lowered by the addition of TiO_2 nanoparticles [7]. Jayabalaji and Shanmughasundaram [8] studied the performance and emission characteristics of a diesel engine using Aphanizomenon Flos (AF) biodiesel 20% and diesel 80% (B20) with TiO_2 nano additives at concentrations of 5%, 10%, and 15% which were expressed as AFD-5TiO_2, AFD-10TiO_2, and AFD-15TiO_2. Out of all the blends, the blend AFD-10TiO_2 resulted in reduced BSFC by 5% and increased BTE by 2%. Rameshbabu and Senthilkumar [9] studied the influence of TiO_2 nano additive (with 50 and 100 ppm concentrations) with neat biodiesel (prepared from cottonseed oil) using a diesel engine. The emissions such as NO_x, Hydrocarbons (HC), Carbon Monoxide (CO), and smoke emission were reduced by 11.2%, 6.2%, 8.4%, and 5.8% respectively at full load conditions. BTE was enhanced by 0.8%, and BSFC was decreased by 1.2% with the dosage of 50 ppm TiO_2 nano additive in neat biodiesel. Whereas the addition of TiO_2 in biodiesel results in enhanced BTE by 1.1% and reduced BSFC by 1.5% regarding the neat biodiesel at each load. Karthikeyan and Viswanath [10] studied the emission characteristics of a two-cylinder diesel engine when operated with a punnai seed biodiesel-diesel sample (B30) with the inclusion of TiO_2 nanoparticles at a concentration of 25, 50, 75, and 100 ppm. The pollutants i.e., CO_2, CO, HC, NOx, and smoke opacity were reduced when differentiated from diesel.

The previous literature survey showed that the addition of nanoparticles improves performance, combustion, and emission parameters along with the physiochemical properties. Tamarind oil is found to be the most beneficial feedstock for biodiesel preparation but has not been well recognized, and no research was found to study the performance, combustion, and emission characteristics of a CI engine with nanoparticles dispersed in TOME. Hence, this study is intended to find the overall performance of a diesel engine with the addition of TiO_2 nano additives at several dosages of 40, 80, and 120 ppm in a B20 blend.

Materials and Methodology

Materials

Biodiesel has recently gained popularity as a sustainable, environmentally friendly, and alternative fuel with the potential to significantly reduce exhaust gas emissions and thus provide a far cleaner source of energy. Tamarind trees are abundantly available everywhere in India and tamarind seed is obtained from tamarind fruit which comprises 30% of the oil yield. Along with its importance in the Indian subcontinent culinary techniques. The usage of tamarind fruit is nearly limitless since tamarind oil is unknown as a raw feedstock for biodiesel preparation and its usage in diesel engines is yet to be proposed [11]-[14]. Tamarind seeds were purchased at a low cost from Paderu, Visakhapatnam district, India. The seeds were dried under sunshine and crushed using an expeller and oil is extracted using a solvent extraction technique to find the maximum yield. Merck Laboratories, Mumbai, India, supplied the required solvents and chemicals, which were used immediately without any treatment. Methanol (99.5%), n-hexane (99%), and KOH (85%) pellets were obtained. Tamarind tree fruits and seeds are shown in Figure 1.

Figure 1: Presents tamarind tree fruits and seeds

Extraction of oil

The tamarind oil extraction was followed by a solvent extraction procedure. The pulp was separated, and the seeds were dried in the sunlight. These dried seeds were squeezed into the oil with the aid of a mechanical press. The raw oil was treated with 5% (v/v) n-Hexane at a temperature of 80 °C and then, agitated for half an hour to eliminate gel formation, sediments, and impurities. Since the n-Hexane has a low boiling point, it evaporated during the process. The treated sample was separated from impurities and the pure oil was collected in a separatory funnel after the settling particles were removed. This process was repeated until the required amount of oil was extracted. With 1 kg of seeds, 368 ml of oil was recovered.

Biodiesel synthesis

Biodiesel from tamarind oil is produced in 2 phases acid-catalyzed and base-catalyzed. In the former phase, 2 liters of tamarind oil, 330 ml of methanol, and 2% wt of H_2SO_4 were blended in a round neck bottle at a stirring speed of 600 rpm and a temperature of 50 °C for 90 mins. Following this, the solution was moved to a separating funnel and left for 2 hours [15]-[16]. Finally, the bottom layer was found to be murky and separated from the top layer. The acid content of this segregated top layer is determined to be lower which was subjected to the next phase (base-catalyzed/alkali-catalyzed treatment). 885 g of raw pretreated oil, 1.5% KOH catalyst (on a weight basis), and methanol were placed in a 2 L round-necked flask. The best molar ratio (methanol/oil) for maximum biodiesel conversion was found to be 1:6. This mixture was stirred for 1 hour at a fixed stirring speed of 500 rpm at 60 °C. After 6 hours, the bottom (glycerol) layer was drained by gravity method, and the upper layer was washed many times till the glycerol was removed [17]-[18]. Thereafter, the transesterified ester was brought to 100 °C to remove excess moisture particles. The amount of biodiesel yield was found to be 96% of the given in Equation (1).

$$\text{Biodiesel yield (wt \%)} = \left[\frac{mass\ of\ biodiesel\ (g)}{mass\ of\ oil\ (g)}\right] x\ 100 \qquad (1)$$

Surface modification of TiO_2 nanoparticles

The addition of TiO_2 nano additives should be consistent and safe for stability [18]. Table 1 lists the parameters of the TiO_2 nano additives employed in this investigation. For the uniform and homogeneous dispersion of nanoparticles in base fuel samples, electrostatic and steric processes were preferred. In the initial stage, the nanoparticles were coated with scattering agents, typically known as surfactants (QPAN80). The impact of surfactants on TiO_2 nanoparticles defines the stability of the base fuel. Hence, five trials were made to find the optimum ratio (TiO_2:QPAN80) i.e., 1:1, 1:2, 1:3, 1:4, and 1:5. The dispersed nano additives with QPAN80 were found to be stable, homogeneous, and consistent with a 1:4 ratio. Hence, a 1:4 optimum blend ratio was used to prepare the nano fuel blends at a concentration of 25, 50, and 75 ppm and expressed as B20T40, B20T80, and B20T120.

Table 1: Specifications of the TiO_2 nanoparticles

Manufacturer	Platonic Nanotech Private Limited-Kachwa Chowk, Dist: Godda, Jharkhand
Chemical name:	Titanium Oxide Nanoparticle (TiO_2)
Appearance:	White power
Purity:	>99.9%
Specific Surface area (SSA):	200-230 m^2/g
The average particle size:	30-50 nm
Bulk density (%):	0.15-0.25 g/cm^3
Atomic Weight	79.8658 g/mol
Morphology	Near spherical

Preparation of fuel samples

Nano fuels (Nanoparticles dispersed in B20 blend) were produced through two steps. The first step is to use a mechanical disseminator to disperse nanoparticles in the B20 mix and with the aid of an ultrasonic pulsing frequency approach the nano fuels were blended in the second stage, in which the TiO_2 dispersed fuel blend was placed in an ultrasonicator (Hielscher ultrasonic, 160 W, 40 kHz) for 30 minutes to avoid nanoparticle aggregation and to preserve the stable state [16], [18]. To produce a B20T40 blend, 40 ppm/ 0.040 g of nanoparticles were mixed into a 1 L volume of B20 blend and agitated for 30 minutes in an ultrasonicator to achieve homogeneous blending [19]. Similarly, the additional blends, B20T80 and B20T120, were produced and designated. After 30 days, these mixes were found to be stable. Table 2 shows the physicochemical parameters of diesel, B20, B20T40, B20T80, and B20T120 mixes evaluated according to ASTM standards.

Table 2: Physico-chemical characteristics of fuel blends

Fuel samples	Density at 40 ºC (kg/m^3)	Viscosity (mm^2/s)	Calorific value (MJ/kg)	Flashpoint (ºC)
Diesel	841	2.92	45.6	73
B20	833	3.89	41.2	75
B20T40	835	3.7	42.16	76
B20T80	841	3.74	43.21	78
B20T120	839	3.72	42.68	80
ASTM D975	850	2.0-4.5	42-46	60-80

Experimental setup

Figure 2 depicts the experimental setup. For the current investigation, a Kirloskar-made VCR, 1-cylinder, 4-s, Directe injection, CI engine was considered. The detailed engine configuration is given in Table 3. To assess tailpipe gasses, an AVL 5-Gas analyzer was utilized. Before the trials began, all of the sensors were extensively tested to ensure that experimental test errors were limited to minimal values. For 100 cycles, engine soft software was installed on the computer, and obtained the combustion data. Before the trial of the engine, it was benchmarked with standard diesel by running for 30 minutes. Then the nano-fuel samples were tested. During all the trials, the speed of the engine was maintained constant at 1500 rpm and the engine operated five times to make sure that the data was standardised at each load, and the average findings were presented. The HRR value is determined using the following Equation (2) concerning the crank angle and In-Cylinder Pressure (ICP) of Diesel, B20, B20T40, B20T80, and B20T120:

$$\frac{dQ_{net}}{d\theta} = \frac{\gamma}{\gamma-1}(P)\left(\frac{dV}{d\theta}\right) + \frac{\gamma}{\gamma-1}(V)\left(\frac{dP}{d\theta}\right) \quad (2)$$

where; $\frac{dQ_{net}}{d\theta}$ = Heat Release Rate (HRR) in (kJ/m^3 CA)
V = instantaneous volume in (m^3)
P = instantaneous pressure in (bar)
γ = ratio of specific heat

Figure 2: Representation of engine setup

Table 3: Specifications of engine setup

No.	Engine parameters	Specifications
1	Engine model	Kirloskar
2	No. of cylinders/ no. of strokes	¼
3	Rated power	5.7 Kw
4	Rated speed	1500 rpm
5	Bore diameter/Stroke length	100/105 mm
6	Compression ratio	18:1
7	Injection pressure	220 bar
8	Ignition timing	23° bTDC

Uncertainty analysis

Errors in engine measurements are obtained from a variety of factors. Random uncertainty refers to uncertainty related to measurement repeatability and environmental influences. It also incorporates systematic uncertainty caused by sensor faults. The uncertainties of various devices are given in Table 4. The Kragten spreadsheet technique given in Equation (3) employs to evaluate the uncertainty parameters numerically [20]. The uncertainty in calculating *y* for a single independent variable *x1* is represented as follows:

$$u(y,x_1) = F(x_1 + u(x_1), \ldots x_n) - F(x_1, \ldots x_n) \quad (3)$$

Table 4: Uncertainty about measuring devices

No	Instrument/Device	Uncertainty
1	Torque indicator, Nm	± 1% of reading
2	Fuel burette, cc	± 0.2
3	Speed sensor, rpm	± 5
4	Brake power, kW	± 0.053
5	Brake-specific fuel consumption (BSFC), g/kWh	± 5
6	Brake thermal efficiency (BTE), %	± 0.014
7	CO, ppm	± 10
8	NOx, ppm	± 5
9	Crank angle encoder, degree	± 0.5
10	A pressure transducer, bar	± 1% of reading

Because uncertainty propagation is based on the root sum of squares, the combined standard uncertainty for a dependent variable may be calculated using the individual standard uncertainties of its independent variables, as indicated in Equation (4) [21].

$$Uc\,(y) = \sqrt{\left\{\left(\frac{\partial y}{\partial x_1}\,u_{x1}\right)^2 + \left(\frac{\partial y}{\partial x_2}\,u_{x2}\right)^2 \ldots\ldots + \left(\frac{\partial y}{\partial x_n}\,u_{xn}\right)^2\right\}} \qquad (4)$$

Characterization of TiO_2 nanoparticles

In the current experimental study, titanium dioxide (TiO_2) nanoparticles were combined with B20 in the form of a nanoemulsion, and their effects on CI engines were investigated. TiO_2 nanoparticles were primarily obtained from Platonic Nanotech Private Limited-Kachwa Chowk, Godda District, Jharkhand, India. The specifications of TiO_2 nanoparticles are described in Table 1. Figure 3 depicts the FT-IR (Fourier Transform Infrared) spectra of TiO_2 nanoparticles. A prominent band at 461.23 cm^{-1} was visible in the spectra. The considerable absorption ranges from 3250 cm^{-1} to 3700 cm^{-1} and is accompanied by in-plane deformations at 1395.43 cm^{-1}. The exterior morphology of TiO_2 was investigated using FESEM images, as shown in Figures 4(a) and 4(b). The TiO_2 nanoparticle FESEM study was performed at the Central Analytical Laboratory of BITs- Pilani Hyderabad, India. FESEM pictures of TiO_2 nanoparticles were taken at magnifications of 65,000x and 20,000x. The HRTEM investigation was done utilizing JEOL: JEM 2100F, FEG TEM 200 kV TEM, with an ultra-thin Oxford Instruments EDS window system for a closer look. HRTEM images of TiO_2 nanoparticles are shown in Figures 4(c) and 4(d). TiO2 nanofluid is shown clustered in these images, and the image shows TiO2 nanoparticles to be round with a smooth surface and a mean particle size of 20 nm.

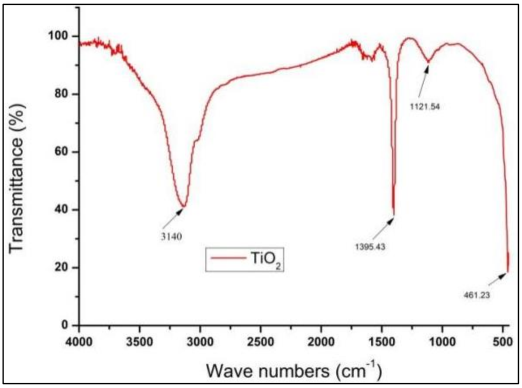
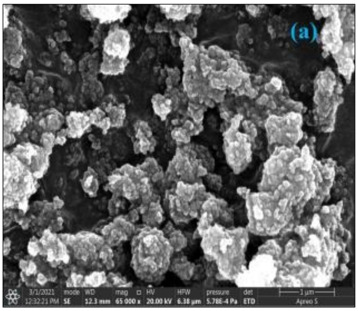
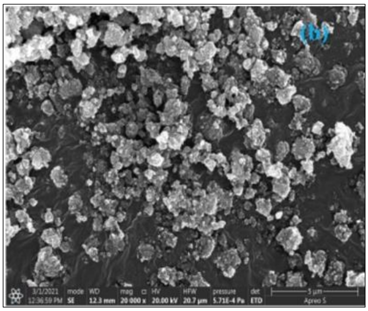


Figure 3: FTIR spectrum of TiO_2 nanoparticles



(a)



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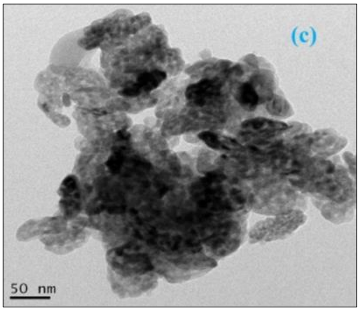
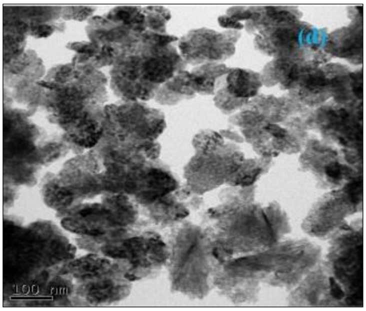


(c)



(d)

Figure 4: (a) FESEM images at; (a) 1µm, and (b) 5µm. HRTEM images at; (c) 50 nm, and (d) 100 nm

Results and Discussions

Combustion parameters

Cylinder pressure

The actual work output derived from the heat energy produced by the combustion fuel is represented in terms of pressure rise during a power stroke in a cycle defined by the engine combustion chamber. The CP of a CI engine is affected by fuel parameters such as viscosity, atomization and evaporation, air-fuel mixture reaction rate, ID duration, and the fuel burned during the premixed combustion stage [22]. Figure 5 displays the variations in cylinder pressure as a function of crank angle for diesel, B20, and B20 nano blends such as B20T40, B20T80, and B20T120 at maximum power output conditions.

As the surface-modified TiO_2 nano additives were scattered in the B20 blend, the CP was found to be improved much more. Because of the enhanced thermal conductivity of TiO_2 nanoparticles and the presence of oxygen in TiO_2, all of the fuel samples dispersed with TiO_2 nanoparticles demonstrated a significant increase in CP [22]-[23]. Furthermore, the TiO_2 nano additive's ability to enhance heat evenly throughout the ignition cycle is responsible for this improvement. Because the addition of nanoparticles in liquid fuels provides an enormous ability for combustion initiation, another key reason for CP improvement was increased heat transfer from TiO_2 nanoparticles to fuel owing to the surface area to volume ratio [23]. Furthermore, dispersion stability improves combustion and mass transportation characteristics, facilitating consistent and controlled combustion in the third phase of the combustion zone. Because of the presence of unburned nanoparticles, the flame lasted longer [22]-[23]. As a result, dispersion plays a vital role in retaining the nanoparticle in the liquid fuel for an extended period, hence improving combustion. The highest CP for B20T80, B20T120, and B20T40 was 50.32 bar, 49.72 bar, and 46.33 bar, respectively. According to Figure 5, B20T80 has a higher peak value of CP than B20. Similar findings were observed in various investigations [24]-[25].

Net heat release rate

Figure 6 displays the heat release rates for several fuel blends at maximum braking power vs. crank angle. Since B20 fuel has a shorter ID period, less quantity of fuel burns in the premixed zone, leading to a reduced HRR. The heat release rate was improved much further when surface-modified TiO_2 nanoparticles were introduced to the B20. The NHRR increased significantly when B20 was blended with surface-modified TiO_2 nano additives. This was attributable to the catalytic reaction activity of TiO_2 nanoparticles and increased convective heat transfer from nanoparticle to liquid fuel [23]. Increased ignition properties contribute to increased heat release [22]. Furthermore, by keeping the nanoparticle stable in the liquid, the dispersant resulted in an increasing rate of combustion [23]. The additive-based B20 produced the most heat energy. B20T80 has the highest heat release rate of 50.32 J/degree compared to all the test fuel blends. Furthermore, the heat release rate of B20T120 and B20T40 was 49.72 J/degree and 46.33 J/degree, respectively, which were greater than diesel and B20. Similar findings were obtained in several papers [24], [26].

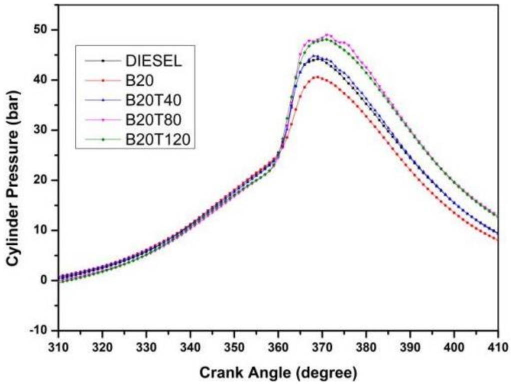


Figure 5: Cylinder pressure vs. crank angle (degree)

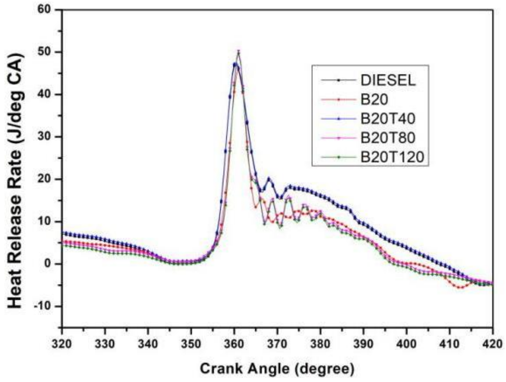


Figure 6: Heat release rate vs. crank angle (degree)

Engine performance

<u>Brake Thermal Efficiency (BTE)</u>

The influence of BTE concerning loads for various fuel samples is depicted in Figure 7. BTE is higher for all dispersed nano additives in B20 samples. The increase in BTE for all nano blends is due to the nanoparticle's high surface energy and catalytic effect [8]. Furthermore, the greater surface-to-volume ratio of nano additives facilitates better evaporation and results in higher BTE [27]-[28]. Reduced BTE was obtained for B20 due to improper A/F ratio, lower calorific value, poor volatility, higher viscosity, and low combustion efficiency [29]-[30]. Maximum BTE produced was 28.45%, 29.57%, and 29.24% for B20T40, B20T80, and B20T120 blends. BTE was improved by 9.76% for the B20T80 sample. The results were correlated with previous findings [26], [31].

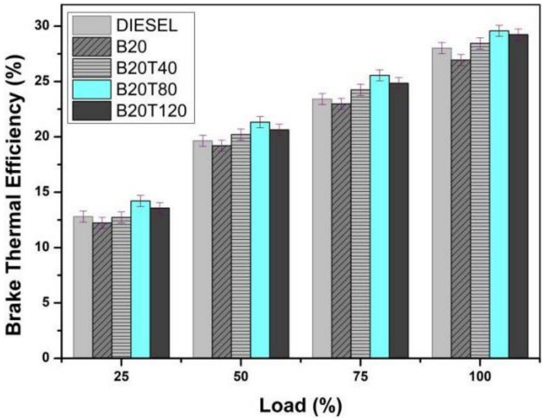


Figure 7: Variation of BTE for various samples concerning various loads

Brake-specific fuel consumption (BSFC)

The effect of BSFC for prepared samples vs. loads is illustrated in Figure 8. BSFC values represent the rate of fuel required as per the load requirements. The figure describes that the BSFC is higher for the B20 blend, which is attributed to the higher viscosity and reduced calorific value [27], [32]-[33]. BSFC was observed to be less for all nano additive blends due to the higher surface-to-volume ratio and catalytic action, thus facilitating an effective combustion process and resulting in less BSFC [30]. The reduction in BSFC was 0.43, 0.39, and 0.42 kg/kWh for B20T40, B20T80, and B20T120 samples, respectively. The maximum reduction in BSFC was 15.2% at full load for the B20T80 sample.

Emission characteristics

Carbon monoxide emissions

The variation of CO pollutants at different loads is illustrated in Figure 9. An incomplete oxidation process tends to form CO pollutants. The Highest CO emission was observed for diesel fuel, and lower values were observed for all nano fuel samples. The reduction in CO emissions for nano additive blends was owing to the increased surface area and improved heat transfer rate with the catalytic activity of TiO_2 nanoparticles that facilitates reduced ignition delay and improved combustion process [34]-[35]. The maximum reduction of CO emissions was 15.2% for the B20T80 fuel blend at full load condition. These findings were found to be similar to the literature [28], [35].

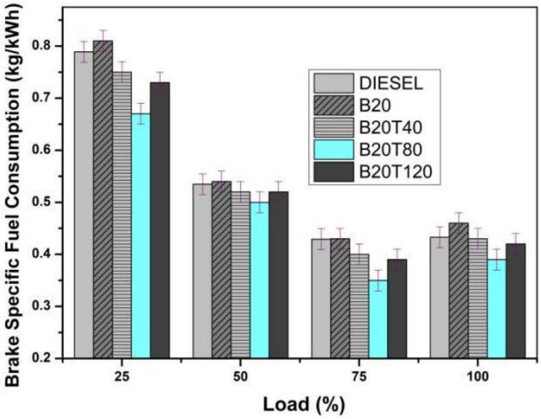


Figure 8: Variation of BTE for various samples for various loads

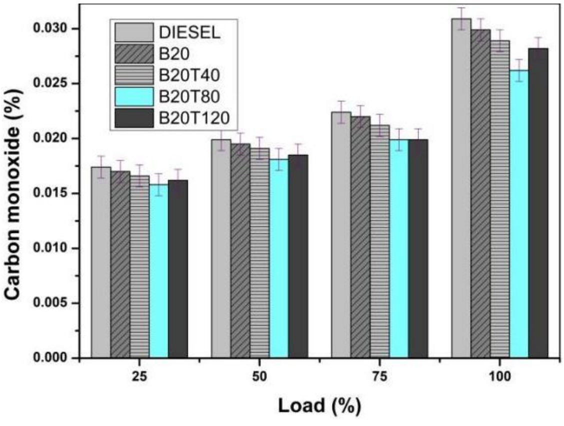


Figure 9: The variation of CO emissions vs. load (%)

Hydrocarbon emissions

The variation of HC emissions for various fuel samples is illustrated in Figure 10. It is found from the figure that sample B20 represents the highest HC emissions, which is attributed to a lower calorific value and greater value of viscosity. HC emissions of nano fuel samples were reduced compared to diesel values. Decreased values were attributed to additional amounts of oxygen in nano additives, and improving physiochemical properties, thus improving the combustion process [36]-[37]. The HC emissions were decreased by 4.06%, 11.10%, and 5.31% for B20T40, B20T80, and B20T120 fuel blends, respectively, at full loads.

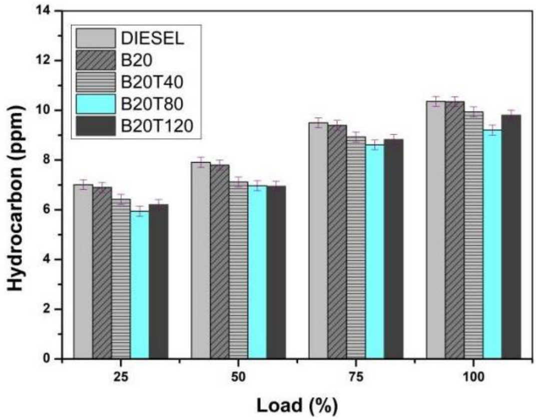


Figure 10: The variation of HC emissions vs. concerning load (%)

Nitrogen oxide emissions

The variation of NOx emissions vs. loads is illustrated in Figure 11. NOx emissions are formed due to the higher temperature of the engine cylinder. The oxides of nitrogen were found to be greater for the B20 blend, while the TiO_2 dispersed fuel blends reduced NOx values at all loads due to the increased surface area to volume ratio and increased heat transfer rate of B20 [9]. The viscosity of B20 is improved by 5.13% compared to nano additive blends. Hence, the fuel blends take less time to form fuel droplets, atomize and combine with the hot surrounding air, which results in better combustion and reduced NOx emissions [38]-[39]. Nevertheless, the addition of TiO_2 additives improves thermal conductivity and decreases the ignition lag period [40]-[41]. The maximum reduction in NOx values were 2.07%, 9.06%, and 5% for B20T40, B20T80, and B20T120 blends, respectively

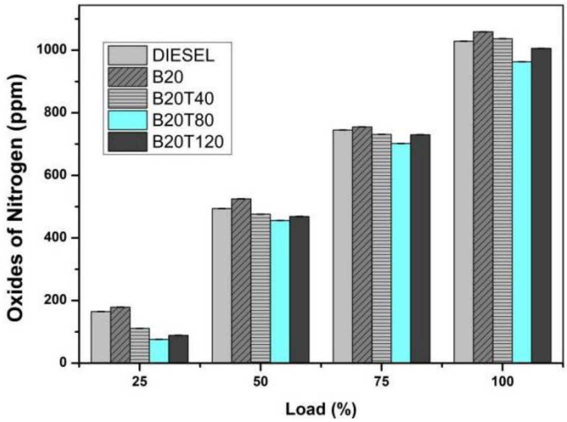


Figure 11: The variation of NOx emissions vs. concerning load (%)

Conclusions

The biodiesel was synthesized from tamarind seed oil in the proposed investigation, and its performance, combustion, and emission characteristics were examined with the inclusion of TiO_2 nano additions at varied concentration levels of 40, 80, and 120 ppm. The dispersion of TiO_2 nanoparticles was found to be well stable at the nano additives to the surfactant ratio of 1:4. The prepared blends were tested for physicochemical properties and found the properties were within ASTM standard limits. Engine operating characteristics were found with the prepared fuel samples at a speed of 1500 rpm and under varying loads. The maximum BTE, HRR, and CP were observed by 9.76%, 50.32 J/degree, and 50.32 bar and the reduction of BSFC, CO, HC, and NOx were observed to be 15.2%, 15.2%, 11.10%, and 9.06%, respectively for the B20T80 sample compared to the B20. According to the results and discussions, it is concluded that the inclusion of TiO_2 nanoparticles in the B20 blend (B20T80) improved overall engine characteristics and suggested use as a substitute for CI engines.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest

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