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Comparative Study of TiO_2 Nanoparticles and Alcoholic Fuel Additives-Biodiesel-Diesel Blend for Combustion, Performance, and Emission Improvements

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ABSTRACT

In the current research, the engine performance, combustion, and emission parameters of biodiesel mixture 20% Tamarind oil methyl ester and 80% Diesel (B20) with the inclusion of titanium dioxide (TiO_2) in different concentrations (25.50 and 75 ppm) and 10% v/v dimethyl carbonate (DMC) as fuel additive investigated using a single-cylinder, 4-stroke, direct injection (DI), compression ignition (CI) engine. The nano fuel blends were prepared through the ultrasonication process. The ratio of 1:4 TiO_2: QPAN80 was produced higher stability and consistency out of five trials. TiO_2 were characterized using FESEM, HR-TEM, and Fourier Transform Infrared (FTIR). Fuel properties were determined as per the ASTM standards. Engine tests were carried out to determine the engine performance under varied loads such as 25, 50, 75, and 100% while keeping a uniform speed of 1500 rpm. The maximum reduction in BSFC, CO, HC, and NOx were found to be 17.64%, 9.49%, 7.81%, and 6.53%, and the increased BTE was observed to be 6.13% for B20T50DMC10 compared to B20 blend at full load. Thus, the combined effect of TiO_2 and DMC served excellent engine performance, combustion, and emission characteristics in CI engine operation.

1. INTRODUCTION

Extensive use of energy sources for transportation, electricity production, industrialization, and other purposes causes rapid depletion of fuel oil supplies, producing a massive demand and hiking fossil fuel prices. Along with this scenario, the significant impact on climate change has driven the research and development cells to investigate renewable fuels to seek alternative fuels to run diesel engines. Biodiesel is anticipated to be promising alternative because of its several advantages, including being renewable, environmentally friendly, outperforming on diesel engines, and producing fewer exhaust pollutants than fossil fuels [1-4]. Nevertheless, biodiesel is ideally suited for diesel engines [5]. But, the successful implementation of biodiesel usage in the various sectors was impaired due to low performance, poor atomization, higher nitrogen oxide (NOx) emissions, poor low-temperature properties, poor oxidation stability, piston ring sticking, and starting problems in cold climates [6, 7]. These shortcomings can be overcome by using different novel technologies, such as the use of oxygenated alcohols and nano additives, which may result in improved engine characteristics [8, 9].

Nanoparticle additions have many advantages such as a high surface area to volume ratio and excellent thermal conductivity, electrical, magnetic, and optical properties. As a result, these nano additives enhance fuel characteristics, stability of blends and serve as a catalyst during the oxidization process. It was also discovered to accelerate the heat transfer rate among the fuel particles and air, leading to a considerable reduction in ignition delay (ID), better combustion properties, and finally, reduced emissions (CO, UHC, CO_2, NOx) [10-12]. Conversely, the oxygenated additives show a better impact on fuel characteristics and emission reduction. The addition of oxygenated additives burns fuel effectively and reduces the ignition temperature of biodiesel which minimizes smoke emission [13].

Many researchers explored the use of nano and alcohol-based additives in biodiesel-diesel blends to enhance fuel characteristics, performance, and emissions parameters. M.A. Mujtaba et al. [5] experimented on the performance and emission parameters of diesel-biodiesel, included with nanoparticles (TiO_2 and CNT) and oxygenated alcohol (Dimethyl carbonate (DMC), and Diethyl ether (DEE)) additives on CI engine. The fuel properties of the prepared blend were found to be within the ASTMD6751 standards. The results showed that the B30+DMC ternary blend reduced maximum brake specific consumption (BSFC) by 4.1%, and the B30+DMC ternary blend improved brake thermal efficiency (BTE) by 9.88% compared to the other blends. Carbon monoxide (CO) and Hydrocarbons (HC) were reduced to 29.9% and 21.4% when correlated to the B30 sample blend. The NOx emission reduction was observed as 3.92% with the B30+CNT blend compared to B30. Razzaq et al. [14] studied the CI engine performance, and emission parameters of biodiesel-diesel (B30) blended with graphene oxide nano additives (at different dosage levels of 40,80 and 120 ppm) and 10%v/v DMC as additives. The maximum BTE was 22.80%, and the maximum BSFC and Nox were reduced to 5.05% and 3.65% for the blend B30GNP40DMC10 than to other blends. The reduction in HC and CO was found to be 25% and 4.41% with the B30DMC10 blend. It was also revealed that the addition of GNP nano additives resulted in a reduced average coefficient of friction by 15.05%, 8.68%, and 3.61% for the dosage levels of 120, 80, and 40 ppm correlated to the B30 blend. Senthilkumar and Rajan [15] experimented on the performance, combustion, and emissions of a single-cylinder CI engine operated using RSME25 with DMC alcohol in the dosage levels of 10%, 20%, and 30% using the fumigation technique. The fumigation of 30% DMC with RSME25 improved overall engine performance and reduced emission parameters Nitric oxide (NOx) 28% and smoke opacity 36%) compared to diesel at higher load. Rangabashiam et al. [16] experimented on a diesel engine using neem biodiesel-diesel blends with 10% volume of DMC and Pentanol. These blends were prepared without surfactant and found to be stable with no phase separation. The addition of DMC and Pentanol blended biodiesel (NBD50D50) improved physicochemical properties, which mainly caused to enhanced the performance of the engine. The performance was improved for NBD50D50 blend DMC and Pentanol (BTE were improved by 0.3 and 0.6%, and BSFC were reduced by 0.4 and 0.5 g/kw). Whereas Peak pressure and heat release rate (HRR) was improved by 2.3 and 3.1 bar, and 3.9 and 2.1 J/CA for 10% DMC and Pentanol in NBD50D50 blend, respectively. The emissions were found to be reduced for CO by 7.4% and 4.9%, for HC 3.1% and 4.7% for 10% DMC and Pentanol in NBD50D50 blend. Parida et al. [17] studied that the performance and emission characteristics were improved when the CI engine was fueled using Karanja oil methyl ester – diesel blend (B10) with TiO_2 nano additives at a dosage level of 80 mg/100 ml of B10 blend. The results were compared with no addition of TiO_2 nanoparticles. The BTE was increased by 1.72%, and BSFC was reduced by 3.57% with respect to the B10 blend as the physiochemical properties were improved. Rameshbabu and Senthilkumar [18] investigated the performance and emission parameters using cottonseed biodiesel (CSBD) with the addition of TiO_2 nanoparticles at concentration levels of 50 and 100 ppm. The BTE and BSFC were observed to be decreased by 0.8% and 1.2% with the inclusion of 50 ppm in biodiesel. In contrast, the BTE and BSFC were noticed to be reduced by 1.1% and 1.5% with the inclusion of 100 ppm in biodiesel. HC and CO emissions were decreased by 6.2% and 8.4% for the CSBD100TiO_2 blend when compared to CSBD. In contrast, CSBD, with the addition of nanoparticles at concentrations of 50 and 100 ppm, reduced NOx emission by 8.8% and 11.2%, respectively.

From the above literature study, many investigations with TiO_2 nano additives and Dimethyl Carbonate alcohol/oxygenated additives found to enhance physiochemical properties, performance and combustion, along with reducing emissions. However, the combination of these additives with Tamarind Oil Methyl Ester (TOME) was not fully investigated. The Characteristics of TiO_2 and Dimethyl Carbonate alcohol would support in the current study in order to enhance performance, combustion characteristics and also to reduce emissions. The major objective of this study is to investigate the performance, combustion, and emission characteristics of a biodiesel-diesel blend (B20) with TiO_2 nano additives and oxygenated dimethyl carbonate additive.

2. MATERIALS AND METHODOLOGY

2.1 Materials

Tamarind seeds were obtained from the byproduct of tamarind fruit which is largely available all over the world. In particular, it is mostly available in Andhra Pradesh, Tamilnadu, Karnataka, Kerala, Madya Pradesh, etc., in India [19, 20]. The use of tamarind fruit is practically infinite due to its key role in Indian subcontinent cooking methods. The oil content in tamarind seed is about 30% [21, 22]. There is a shortage of technical literature on the use of tamarind seed oil as a biodiesel production feedstock, and its use in compression ignition engines has yet to be explored. The tamarind seed used in present study for biodiesel production was obtained at a minimal price from Paderu, Andhra Pradesh. The seeds were sun-dried to obtain the oil by solvent extraction and soxhlet extraction methods. Solvents and chemicals were procured from Merck Laboratories, Mumbai, India. The solvents obtained were methanol (99.5%), n-hexane (99%), DMC Extra Dry (Purity: 99%), and KOH (85%) pellets. Tamarind tree and fruit seeds are shown in Figure 1.

Figure 1. Represents tamarind fruits and seeds

2.2 Extraction of oil

To determine the highest oil yield, two procedures were used: solvent extraction and soxhlet extraction. The seeds were sun-dried for seven days. These dried seeds were manually split with a mallet before being pressed into oil using a mechanical expeller. The splitted seeds were then treated with 5% (v/v) n-Hexane, heated to 80℃ with a heating mantle and stirred for 30 minutes to remove degumming and contaminants. Due to the low boiling temperature of n-Hexane, some of it was vaporized during this reaction. The heated oil was taken into a separating funnel and left a few minutes to settle impurities and sediments. These settled particles were eliminated, and pure oil was collected in a separate beaker. This technique was continued until the desired amount of oil was extracted. The oil extraction procedure in the other approach was continued by a Soxhlet apparatus using an n-Hexane solvent. The seeds were pulverized into fine powder to enhance the surface area of the samples. A 100 g of powder sample was packed on thin tissue paper and kept in a soxhlet extractor. The reaction was then initiated using an n-hexane solvent at 80℃ for 3 hours. After thorough extraction, the solvent was removed with the help of a rotary evaporator, and the oil was collected at the backside of the Soxhlet extractor and recovered via distillation process. This procedure was performed repeatedly until an appropriate volume of oil was collected. The quantity of oil recovered by each technique was compared. For 1 kg of seeds, the quantity of oil extracted using the first technique was 310 ml and 385 ml using the second method. Therefore, Soxhlet extraction was found to be the most effective in terms of yield.

2.3 Preparation of biodiesel

TOME is prepared in two phases such as Acid-catalyzed/pre-treatment and Base-catalyzed/alkali-catalyzed treatment. In the first treatment, the composition of 2 liters of Tamarind oil, 330 ml of methanol, and 2% wt of H_2SO_4 was mixed vigorously in a round neck bottle at a temperature of 50℃ and stirred at a speed of 600 rpm. After stirring for 90 mins, the solution was left undisturbed. Finally, the solution is found to be formed into two layers [23, 24]. The lower layer is removed, and the fatty acid content was found to be lower for the upper layer. This lower acid content solution is subjected to base-catalyzed transesterification. In a 2 L round neck flask, 885 g of raw, pretreated oil, 1.5% of KOH catalyst (on a weight basis), and methanol were mixed. The optimal molar ratio (methanol/oil) for optimizing biodiesel output was discovered to be 6:1. This mixture was swirled for 1 hour with a stirrer at a uniform speed of 500 rpm and a heating mantel temperature of 60℃. After this step, the solution was transferred to a separatory funnel. After 6 hours, this solution was settled. The bottom layer (glycerol) was drained, and the top layer (Biodiesel/methyl ester) was washed multiple times with hot water until the soap and glycerol were removed. Lastly, the methyl ester was heated to 100℃ to eliminate moisture [25, 26]. The maximum biodiesel density was obtained to be 97% using Eq. (1).

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

2.4 Surface modification of TiO2 nanoparticle

The incorporation of TiO_2 nanoparticles should be uniform and safe for stability [27]. The specifications of the TiO_2 nano additives shows in Table 1. Electrostatic and steric processes were preferred for the steady dispersion of nanoparticles in base fluids. In the initial stage, the nanoparticles were coated with scattering agents called surfactants. The interaction of TiO_2 with surfactants determines the stability of the base fuel. In order to find the optimum ratio of nanoparticles to surfactants, five trials were experimented such as 1:1, 1:2, 1:3, 1:4, and 1:5. The dispersion was found to be steady and homogenous in accordance with the 1:4 ratio. This optimal ratio was utilized to make nano fuels with concentrations of 25, 50, and 75 ppm.

2.5 Preparation of fuel samples

Nano fuels were prepared in two stages. The initial step is to disperse nanoparticles in a B20 blend using a mechanical disseminator. In the second phase, an ultrasonic pulsing frequency approach was used, in which the TiO_2 was dispersed fuel blend was placed in an ultrasonicator (Hielscher ultrasonic, 160W, 40kHz) for 30 minutes to inhibit the aggregation of nanoparticles and to maintain stability [27, 28]. To produce the B20T25DMC10 blend, 25 ppm or 0.025 g of nanoparticles and 10% v DMC were mixed into a 1 L volume of B20 blend and agitated in an ultrasonicator for 30 minutes to obtain homogeneous mixing. Similarly, the remaining samples were prepared and labeled as B20T50DMC10 and B20T75DMC10, respectively. These blends were found to be stable after 45 days, and then, the physicochemical properties of Diesel, B20, B20T25DMC10, B20T50DMC10, and B20T75DMC10 were measured according to ASTM standards were given in Table 2.

Table 1. Specification of TiO_2

S. No.	Properties	TiO_2 Nanoparticles
1	Manufacturer	Platonic Nanotech Private Limited-Kachwa Chowk, Godda District, Jharkhand
2	Average size	20 ± 5 nm
3	Molecular weight (g/mol)	82
4	Color	White powder type
5	Appearance	Powder form
6	Appearance	White in color
7	Solubility	Dispersed in B20

Table 2. Physiochemical properties of fuel blends

Fuel blends	Density at 40℃ kg/m^3	Viscosity mm^2/s	Calorific value MJ/kg	Flash point ℃
Diesel	840	2.90	45.34	75
B20	835	3.92	41.42	77
B20T25DMC10	836	3.72	42.27	78
B20T50DMC10	840	3.73	43.24	80
B20T75DMC10	839	3.74	42.82	82
ASTM D975	850	2.0-4.5	42-46	60-80

2.6 Characterization of TiO2 nanoparticle

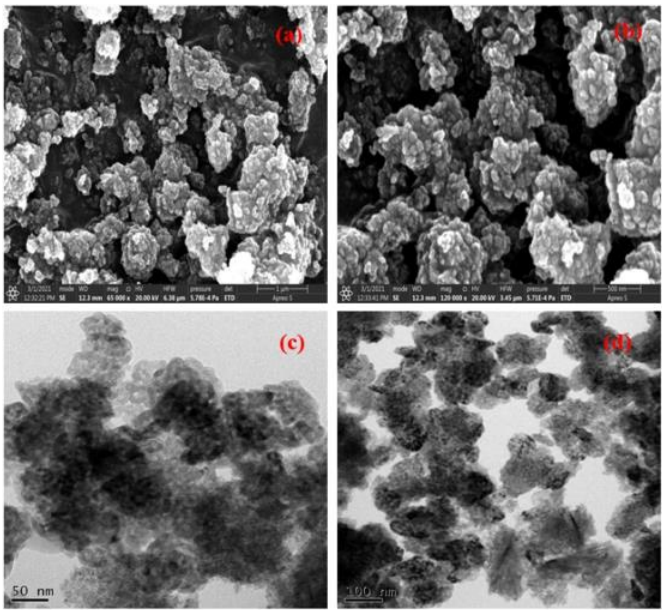

Figure 2. FE-SEM images of TiO_2 at different magnification levels: (a) 65,000 X, (b) 1,20,000 X, (c) HR-TEM image of TiO_2 at 50 nm, (d) HRTEM image of TiO_2 at 100 nm

The FESEM pictures of TiO_2 nanoparticles (Model: FEI-Apreo LoVac) show the dispersion of disordered spherical nanoparticles with minor agglomeration. Figures 2(a) and 2(b) show pictures acquired from the FESEM at two distinct magnification levels. These images show that TiO_2 nano-fluid is clustered, spherical shaped, with a smooth surface with an average particle size of 25 nm. Figure 2(c) and (d) show visible lattice fringes in the HR-TEM (Make: JEOL; JEM 2100F, FEG TEM 200 kV), confirming the nanocrystalline-shaped TiO_2 particles. Figure 3 shows that the chemical structure of TiO_2 was examined using FTIR spectroscopy, with wavenumbers from 400 cm^{-1} to 4,000 cm^{-1}. The extensive absorption at 3,350 cm^{-1} to 3,750 cm^{-1} is related to O-H vibrations and is associated with in-plane deformations at 1,400 cm^{-1}. The spectra showed a small band at 653.82 cm^{-1}.

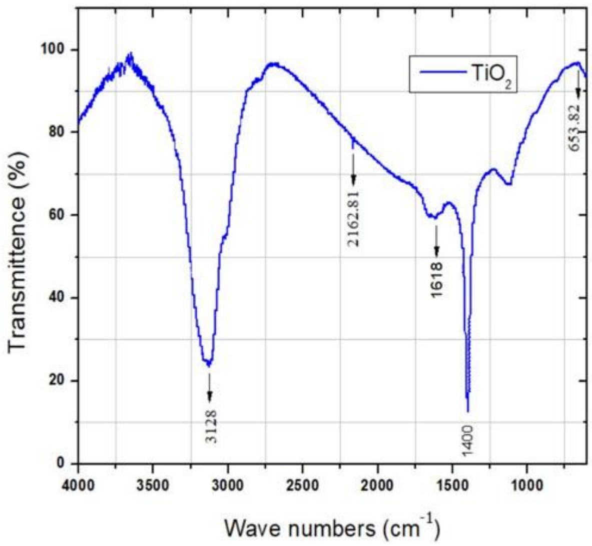

Figure 3. FTIR spectrum of TiO_2

2.7 Experimental setup

Figure 4. Engine set up

Table 3. Specifications of engine setup

S. No.	Engine parameters	Specifications
1	Engine model	Kirlosker
2	No. of cylinders/ No. of strokes	¼
3	Rated power	5.7 kW
4	Rated speed	1500 rpm
5	Bore diameter/Stroke length	100/105mm
6	Compression ratio	18:1
7	Injection pressure	220 bar
8	Ignition timing	23^0 bTDC

The engine setup is depicted in Figure 4. In the present experiment, a Kirloskar, single-cylinder, four-stroke, water-cooled, DI diesel engine was considered. The engine specifications are mentioned in the Table 3. Exhaust emissions were obtained by an AVL 5-Gas analyzer. All sensors for multiple aspects were attached to a digital converter connected to a personal computer and were rigorously tested before the test to ensure that the experimental error was kept to a minimum. A soft engine program that had previously been installed on the PC was used for 100 cycles. Prior to the commencement of the trial run, the engine was stabilized by benchmarking with diesel for 40 minutes. After that, the engine was run with nano-fuel concentrations of 25, 50, and 75ppm TiO_2 and DMC alcohol. Throughout the trial, the engine speed was kept constant at 1500rpm. The experiment was performed in triplicates to confirm that the data was consistent at each load, and the mean results were recorded.

2.8 Uncertainty analysis

Engine measurement errors can be produced by a variety of variables. Uncertainties induced by measurement repeatability and environmental factors are referred to as random uncertainty. It also consists systematic uncertainty, which is the uncertainty caused by sensor errors. The Kragten spreadsheet approach computes the uncertainty components numerically using Eq. (2) [29]. The uncertainty in measuring y in relation to a single independent variable x_1 is referred as given below:

$$u(y,x_1)=F(x_1+u(x_1),\dots,x_n)-F(x_1,\dots,x_n) \quad (2)$$

As a result, using the root sum of squares to determine the uncertainty propagation, the combined standard uncertainty for a dependent variable may be calculated from the individual standard uncertainties of its independent variables, as shown in Eq. (3) [30].

$$Uc(y) = \sqrt{\left\{\left(\frac{\partial y}{\partial x_1}u_{x1}\right)^2+\left(\frac{\partial y}{\partial x_2}u_{x2}\right)^2+\cdots+\left(\frac{\partial y}{\partial x_n}u_{xn}\right)^2\right\}} \quad (3)$$

At maximum torque, the respective uncertainties in measurements are given in Table 4.

Table 4. Uncertainty of measuring devices

S. No	Instrument	Uncertainty
1	Torque indicator, Nm	± 1% of reading
2	Fuel burette, cc	± 0.2
3	Speed sensor, rpm	± 5
4	Brake power (BP), 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	Pressure transducer, bar	± 1% of reading

3. RESULTS AND DISCUSSIONS

3.1 Combustion characteristics

3.1.1 Heat release rate

The HRR value is determined with reference to Crank Angle and In-cylinder Pressure (ICP) for various fuel blends using the following Eq. (4):

$$\frac{dQ_{total}}{d\theta}=\left(\frac{\gamma_{sp.heat}}{\gamma_{sp.heat}-1}\right)(P_{cyl})\left(\frac{dV}{d\theta}\right)+\left(\frac{1}{\gamma_{sp.heat}-1}\right)(V)\left(\frac{dP}{d\theta}\right)+\left(\frac{dQ_w}{d\theta}\right) \quad (4)$$

where,

Q_{total}=HRR_{net};
p-ICP;
γ=Specific heat ratio;
V=Immediate cylinder volume;
θ=Crank-Angle.

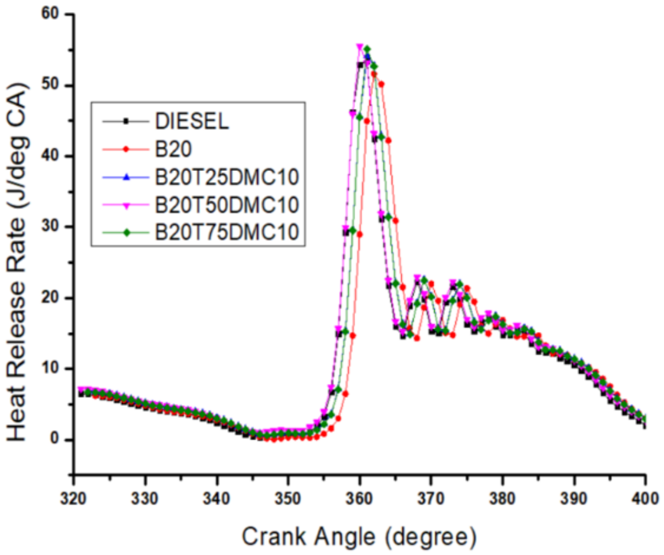

Figure 5. NHRR versus crank angle (At 100% load)

Figure 5 depicts the variation of NHRR with the load. Related to poor spray atomization, low volatility, increased viscosity, and surface tension, and density, the fuel blend B20 had a lower HRR (50.6 J°/CA) than all other fuel blends. When B20 was blended TiO_2 nanoparticles with surface modification and DMC alcohol, the heat release enhanced much more. This combined effect improved physicochemical properties, leading to increased heat transfer rate, thermal conductivity, ignition properties, and heat release rate. All of the test fuels disseminated with surface-modified TiO_2 nano additives showed a significant increase in NHRR. This was attributed to catalytic activity and improved convective heat transfer of nanoparticles in liquid fuel [31]. Improved ignition qualities result in a faster heat release rate [32]. The maximum heat release rate of B20T50DMC10 is 56.01 J/degree, which is more than that of the other test fuel samples. The cooling impact of fuel vaporization and cylinder wall heat loss was ascribed to a negative heat release rate [33]. Nevertheless, As the nanoparticle were found to be stable and homogeneous in the liquid fuel blends, the dispersant impacted and increased the rate of combustion [31, 32].

3.1.2 In-cylinder-pressure

Figure 6 depicts the in-cylinder gas pressure (ICP) to the higher load's crank angle. It is noticed that the in-cylinder gas pressure would rise as engine load increases owing to increased fuel consumption to produce the same power output at a stable engine speed of 1,500 rpm. The engine operated with diesel fuel was found to produce greater peak cylinder pressure than the B20 sample. This behavior explains that diesel fuel has a higher heating/calorific value than B20, resulting in higher peak cylinder gas pressure. At higher load, the maximum cylinder pressure for standard diesel was 50.02 bar and 49.07 bar for B20. When the surface-modified TiO_2 nanoparticles were dispersed in B20 mixed with DMC, the ICP improved much more. Moreover, this enhancement is attributable to the ability of nanoparticles to improve heat evenly around the ignition cycle. Because the dispersion of nano additives in liquid fuels provides a unique potential for combustion initiation. DMC produces more ICP than B20 in biodiesel/diesel with TiO_2 blends. The maximum CP for B20T25DMC10, B20T50DMC10, and B20T75DMC10 were 49.21 bar, 51.21 bar, and 50.13 bar, respectively.

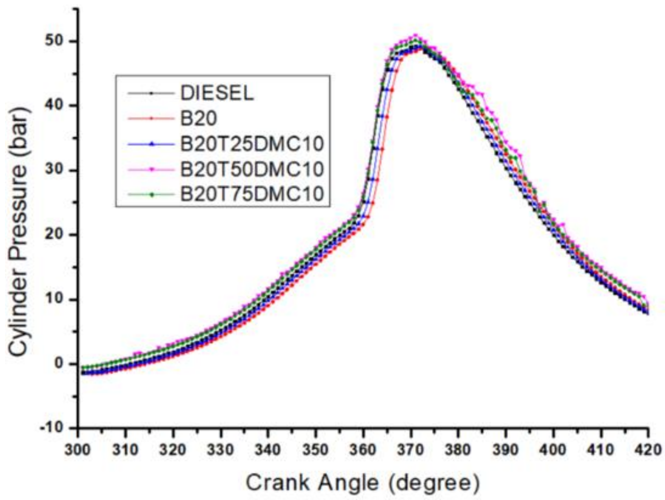

Figure 6. CP versus crank angle (At 100% load)

3.2 Engine performance

3.2.1 Brake thermal efficiency

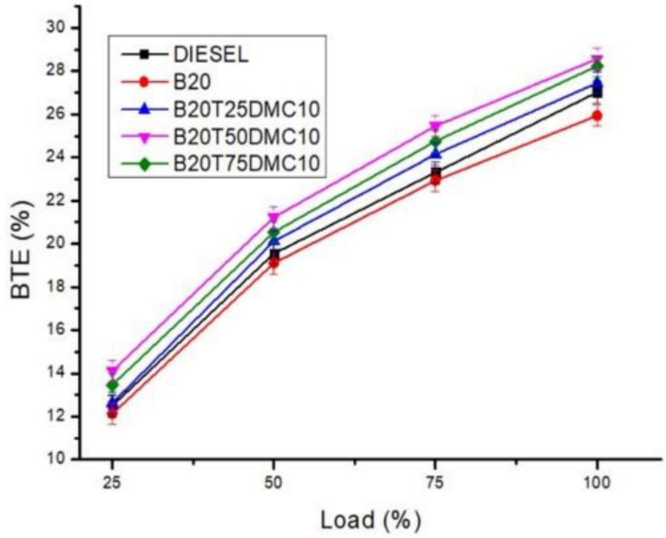

Figure 7. Illustrates brake thermal efficiency vs load

BTE for various fuel blends at several loads is given in Figure 7 Lower BTE was noticed for the B20 blend due to higher viscosity, poor atomization, and results in lower BTE. Whereas, B20 with the addition of nano and DMC additives showed higher values against diesel and B20 blend, which is mainly attributed to micro explosion phenomenon and higher thermal conductivity of nano additives that causes maximum heat transfer during ignition delay. Moreover, the surface-to-volume ratio of nano additives improves BTE [31, 34]. Nevertheless, the addition of DMC oxygenated additives reduced viscosity which 6.13% at maximum load condition for B20T50DMC10 blend compared to B20 blend. Similar trends are noticed in various studies [35, 36].

3.2.2 Brake specific fuel consumption

BSFC at various loads for several blends is presented in Figure 8. It is noticed from the graph that maximum BSFC is seen for B20 blend owing to higher viscosity, lower calorific value, and oxygenated nature of biodiesel blend [31, 37]. In contrast, the dispersed nano additives and oxygenated additives showed reduced BSFC due to modified fuel properties [34]. Maximum reduction in BSFC is observed as 17.64% at full load for B20T50DMC10 blend compared to B20 sample. Oxygenated additives (DMC) helps in reducing viscosity and density, which tends to form a better air-fuel mixture and causes better atomization. Nevertheless, the volatility of DMC alcohol is high, which may also be the reason for superior air-fuel mixing and improved combustion efficiency [38, 39].

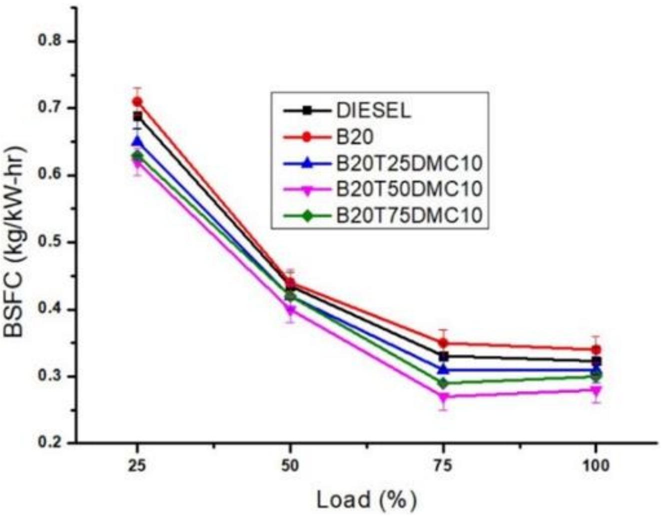

Figure 8. Presents brake specific fuel consumption vs load

4. EMISSION CHARACTERISTICS

4.1 Carbon monoxide

The effect of CO emissions at various loads is given in Figure 9. Partial combustion of fuel leads to producing CO emissions [40]. CO emissions are higher for the diesel. B20 blended with nano and alcohol additives exhibited lower CO emissions due to the catalytic activity of nano additives and the high oxygen content in additives that resulted in a substantial reduction in CO emissions. CO emissions are reduced by 9.49% at full load condition for the B20T50DMC10 blend when compared to the B20 blend. A similar result is found in the study presented by Atmanli [41, 42].

4.2 Unburnt hydrocarbons

UHC emissions trend with respect to various loads is depicted in Figure 10. Incomplete combustion results increase in UHC emissions. Reduction in UHC emissions by 9.07% at maximum load for B20T50DMC10 blend than diesel fuel. The reduction in UHC emissions is owing to the higher surface to volume ratio of nano additives, higher oxygen content in the blend, and shorter ignition delay [31, 34]. Similar results are shown in other studies [43, 44].

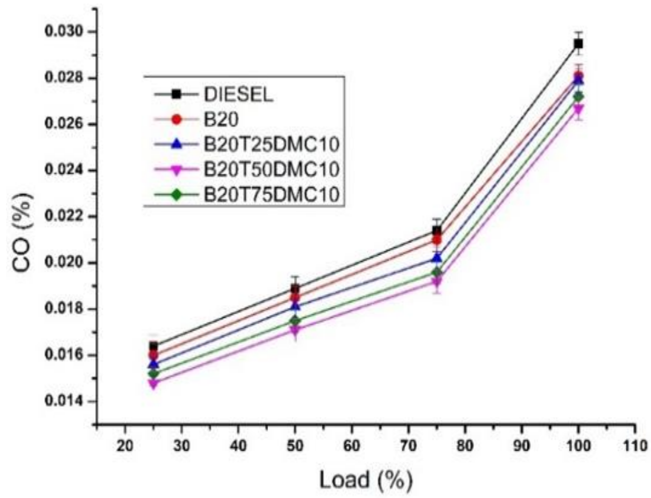

Figure 9. Variation of CO emissions for all tested fuels at different loads

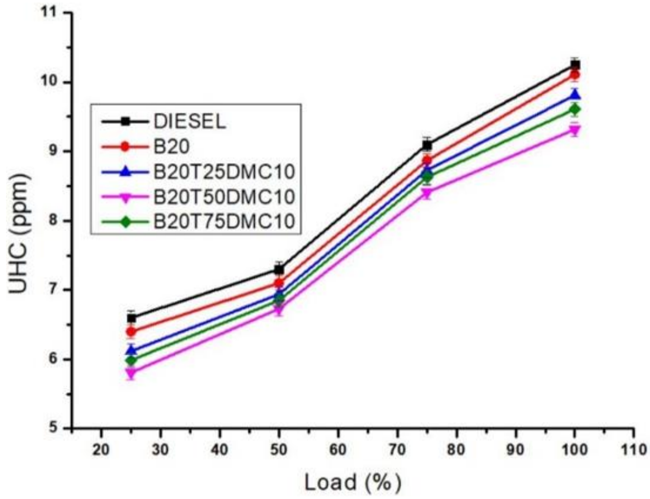

Figure 10. Variation of UHC emissions for all tested fuels at different loads

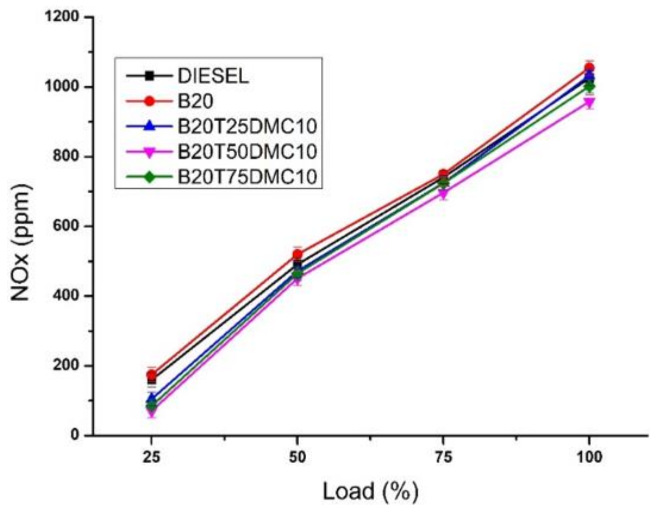

Figure 11. Variation of NOx emissions for all tested fuels at different loads

4.3 Nitrogen oxide

NOx values at different engine loads are illustrated in Figure 11. B20 blend possesses the highest NOx emissions than diesel and other blends due to the combustion temperature, accessibility of oxygen in the combustion zone. NOx emissions can be minimized with the addition of nanoparticles which improves catalytic action and the ability of nano additives to carry away the nitric oxide [31, 34]. Maximum reduction in NOx is observed as 6.53% at full load for B20T50DMC10 than B20 blend.

5. CONCLUSION

The current study is proposed to substitute the diesel fuel by using tamarind oil biodiesel with two different additives (TiO_2 nanoparticles and DMC alcohol). As per the results and discussions, the following are the conclusions were drawn.

►The biodiesel blended with nano and alcohol additives were found to be stable and homogeneous that are shown in the characterization results using FESEM, HR-TEM, and Fourier Transform Infrared Spectroscopy (FTIR).

●FESEM shows the better dispersion of disordered spherical nanoparticles.

●The TEM analysis showed the visible lattice figures which confirms nanocrystalline shaped particles.

●FTIR spectroscopy showed better stability as their extensive absorption at are from 3,350 cm^{-1} to 3,750 cm^{-1} related to O-H vibrations and is also associated with in-plane deformations at 1400 cm^{-1}.

►Physiochemical properties of nano additives and DMC alcohol-based additive improved the BTE By 6.13% and reduced BSFC By 17.64% for the B20T50DMC10 blend which is due to the enhanced physiochemical properties of nano-alcohol based B20 blend.

►Combustion parameters were found to be improved for all B20-nano-alcohol blends.

●The net heat release rate is improved to be 10.6% for the B20T50DMC10 blend compared to B20 blend which is due to the improvement in physiochemical properties, catalytic effect, thermal properties, and ignition properties with the combined effect of nano additives and oxygenated additives.

●Peak pressure and cylinder pressure were observed to be improved for the B20T50DMC10 blend by 4.36% when compared to the B20 blend, which is attributed to improved ignition properties, higher calorific value, thermal conductivity, and heat transfer rate of nano additives when compared to the B20 blend.

►The CO, HC, and NOx pollutions were significantly decreased by 9.49, 9.07, and 6.53% due to the addition of nano and alcohol additives in the B20 blend, respectively.

According to the findings of this study, both TiO_2 and DMC additives improved the combustion properties of tamarind oil biodiesel-diesel blends, resulting in a considerable reduction in greenhouse gas emissions.

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NOMENCLATURE

ASTM	American Society for Testing and Materials
BP	Brake power
CI	Compression ignition
FTIR	Fourier Transform Infrared
ICP	In-cylinder pressure
CO_2	Carbon dioxide
UHC	Unburnt hydrocarbons
TiO_2	Titanium dioxide
TOME	Tamarind oil methyl ester
BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
DEE	Diethyl ether
NHRR	Net heat release rate
ID	Ignition delay
CO	Carbon monoxide
NO_X	Nitrogen oxide
DMC	Dimethyl carbonate
B20	Tamarind Oil Methyl Ester 20%-80% diesel

B20T25DMC10
Tamarind Oil Methyl Ester 20%-80% diesel blend with 25 mg of TiO_2 and 10% v DMC

B20T50DMC10
Tamarind Oil Methyl Ester 20%-80% diesel blend with 50 mg of TiO_2 and 10% v DMC

B20T75DMC10
Tamarind Oil Methyl Ester 20%-80% diesel blend with 75 mg of TiO_2 and 10% v DMC