SSRG International Journal of Mechanical Engineering
ISSN: 2348-8360/ https://doi.org/10.14445/23488360/IJME-V10I11P101

Volume 10 Issue 11, 1-11, November 2023

Original Article

Performance, Combustion and Emission Characteristics of a Diesel Engine with the Effect of TiO_2 Nano Additives in Diesel-Tamarind Oil Blends

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Received: 03 September 2023 Revised: 21 October 2023 Accepted: 12 November 2023 Published: 30 November 2023

Abstract *- This investigation has the purpose of enhancing both the emission and performance behavior of a 25%Tamarind Oil Methyl ester blend with diesel (75% Diesel+ 25% Tamarind Oil Methyl Ester- TME25). Comparative analysis was done to add different dosages of titanium nanoparticle (TiO_2) at various operating conditions. Various ratios of test fuels were prepared with diesel, TME25, TME25 with 50 ppm of TiO_2 (named TME25T50), and TME25 with 100 ppm TiO_2 (named TME25T100) nanoparticle as additives. The findings of the experimental tests showed that, when related to TME25 without TiO_2 additive, the Brake Specific Fuel Consumption (BSFC) decreased by 8.0% and enhanced the brake thermal efficiency (BTE) by 2.6%. At full power, CO, HC, and smoke emissions have been lowered by 40, 16, and 50%, correspondingly, but NO emissions significantly diminished by 13%. Because TiO_2 improves engine efficiency and combustion, adding it to TME25 raises cylinder pressure and Heat Release Rate (HRR). Finally, it is recommended that a TME25 mixture with 100ppm of TiO_2 nano additive be utilized in diesel engines to advance the combustion characteristics, engine performance and exhaust gas emissions.*

Keywords *- Diesel engine, Nanoparticle, Performance, Tamarind Oil Methyl Ester, Titanium dioxide.*

1. Introduction

Globally, the increased demand for petroleum and dependence on oil and gas, as well as the rising cost of increased supply, has prompted research into alternative and renewable energy sources [Misra et al. 1]. The demand for petroleum fuels increased day by day as the number of automobiles on the road increased and industries modernized. Transportation, rail, industrial, and agricultural industries frequently use diesel engines [Rajan et al.]. Diesel engines discharge a wide range of adverse emissions from the combustion of traditional fossil fuels, including particulate matter and nitrogen oxides, which contribute to acid rain, ozone layer thinning, greenhouse gas generation, smog creation, and other unfavourable effects on the environment [Nandi et al. 2]. Due to the rapidly dwindling supply of petroleum sources, rigorous emission laws and regulations, and damage to the planet, researchers are exploring alternate fuels for IC engines [Balan et al. 3]. Biodiesel is a renewable and biodegradable alternative energy source to be manufactured from different original causes such as edible and non-edible related to waste vegetable oils and waste fat from animals [Ramadhas et al. [4], Ando et al., [5].

Most recent biodiesels have been produced from non-edible sources, including rubber seed, Jatropha, Pongamia, rapeseed, Karanja, Mahua, etc. Asokan et al. [6] investigated biodiesel generated from papaya and watermelon seed oil in a diesel engine. Diesel and B20 have fairly similar performance and combustion characteristics. In contrast, because B20 emits less CO, HC, and smoke than diesel, it has better emission properties. Sigar [7] obtained the Karanja oil and tested the CI engine performance behaviours with its diesel blends. Results showed that the BSFC and BTE of neat Karanja oil were higher as well when compared to diesel. Although the smoke density and total hydrocarbon emissions from the K20 blend were higher than those from diesel, CO and NOx emissions substantially decreased.

Nwafor [8] examined how a diesel engine's combustion and exhaust characteristics would change as the input temperature of vegetable oil was enhanced. When heated vegetable oil was employed instead of diesel, the results proved that CO and CO_2 emissions were only slightly higher. Hydrocarbon emissions were greatly decreased by running towards plant oils. The SFC was somewhat greater when using heated vegetable oil than diesel. Monirul et al. [9] investigated three different biodiesel mixes used in diesel engines, specifically Pongamia, Jatropha, and waste vegetable biodiesel mixes.

In comparison to diesel and additional biodiesel blends, they determined that the Jatropha Biodiesel blend (JB10) had the highest BSFC. Additionally, a 20% palm biodiesel mixture delivered minimum levels of smoke and HC emissions compared to all other fuels. However, the fuels utilised in diesel engines, diesel fuel has reduced NOx emissions.

Various works have looked into the use of biodiesel in CI engines, but there are significant drawbacks, including a slight drop in fuel economy because of its higher density and viscosity, increased NOx emission, and problems with cold starting [Ong et al., 10, Shahir et al., 11]. According to other scientists, when using oxygenated additives with biodiesel, its mixtures can be burned in an environmentally friendly manner that produces fewer emissions [Kumar et al. 12]. Rajasekar et al. [13] observed the analysis of a CI engine working on Jatropha biodiesel mixtures and noticed that, except for NOx, the engine produced lower emissions.

Valli et al. [14] examined the engine with algae oil mixtures and observed that straight pine oil lowered CO, HC, and emissions of smoke. Rajendran et al. [15] explored engine performance with biodiesel-coated pistons and observed decreased pollution levels except for Nitrogen Oxides (NOx). Manigandan et al. [16] describe the operation of an engine powered by a corn biodiesel mixture, which generates more NOx while emitting fewer other pollutants than diesel.

Researchers examined how different gaseous fuel additives affected the operation characteristics in diesel engines driven by a tamarind seed methyl ester blend when they were under different loads by Raju and Kishore [17]. They found that adding oxidised chemical additives to the biodiesel mix lowered viscosity, which improved the vaporisation of the air mixture ratio with fuel and contributed the most to the enhancement in BTE. Biodiesel emulsions were the focus of Sadhik Basha’s [18] research. Both are derived from vegetable oil and may contain additives such as DEE and CNT. Seela et al. investigated how using biodiesel blends altered the operation of CI engines. [19] They discovered that biodiesel had the same efficiency as diesel. The early injection of gasoline also increased emissions of nitrogen oxide. It investigated how various oxygenated fuel additives impacted the combustion of diesel engines operating on a mixture of TME and regular petrol.

Using metal oxide nanoparticles like Ceria, Zirconia, Alumina, and Titanium Dioxide is one of the best ways to reformulate diesel to reduce emissions. Metal oxide nanoparticles have the capacity to stimulate combustion responses by offering oxygen atoms for oxidation. Results from tests conducted on diesel engines using a biodiesel-alumina nanoparticle mixture related to an increase in NO emissions and a decrease in CO and HC emissions [Patel et al. 20- Tarun et al. 21]. The effectiveness of plastic pyrolysis oil containing Al_2O_3 nanoparticles at EGR levels was investigated by Tarun John Thomas et al. [22]. Results indicated that the emission of CO decreased, and with Alumina and EGR, a substantial reduction in NOx emission was found. TiO_2 nanoparticle-mixed biodiesel was studied for its result on engine performance, and the outcome revolved that BTE increased alongside a down in CO, HC, and NOx emissions [23–25].

Engine performance was evaluated by Alex et al. [26] using a biodiesel blend containing orange peel oil and cerium oxide nanoparticles. Incorporating cerium oxide nano-fluid into biodiesel led to reduced emissions of s (NOx), (CO), and smoke. Carbon Nanotube (CNT) impact on JME emulsion was studied by Basha and Anand [18]. CNT mixed JME emulsion fuels considerably reduced NOx and smoke emissions due to both micro-explosion and secondary atomizing properties.

Based on the extensive literature analysis discusses the thorough qualities of various nanoparticle-blended Tamarind oils and their effect on diesel engines’ working behaviours that have not previously been investigated. As per the author’s current understanding, there are no expected endeavours to conduct comprehensive assessments pertaining to the analysis characteristics of Tamarind oil combined with titanium dioxide nanoparticles. This study looks at how diesel-TME with TiO_2 nanoparticle blends (50 ppm and 100 ppm) might affect the combustion process, emissions, and performance of a diesel engine in various working conditions. Base fuels are also compared.

2. Materials and Methods

2.1. Production of Tamarind Methyl Ester Using Transesterification

The diesel mixture used in the experiments was found in a nearby commercial petroleum bunk. Tamarind seeds were processed to produce tamarind methyl ester. Transesterification is a chemical method used to prepare tamarind biodiesel in which glycerine is extractable from the oil from tamarind seeds. Figure 1 depicts the transesterification procedure used to produce biodiesel. Higher viscosity, lesser instabilities, and higher density are the main disadvantages of unprocessed tamarind seed oil. The most well-known method for reducing viscosity and improving the excellence of biodiesel is transesterification. Figure 1 demonstrates the transesterification reaction employed in the procedure, which involved 15 L of TME, 3 L of methanol as the mixing solution, and 120 g of (KOH) as a catalyst. Sodium hydroxide is used as the catalyst in the transesterification process, which also calls for a response temperature of 65°C, a response time of 120 minutes, and constant 500 rpm stirring. In a separating funnel, the finished product is allowed to settle for twenty-four hours. Consequently, glycerine and TME were acquired.

The found tamarind biodiesel has a huge density, flash point, and cetane number and less sulphur than diesel. Table 1 compares the properties of TME and diesel fuel.

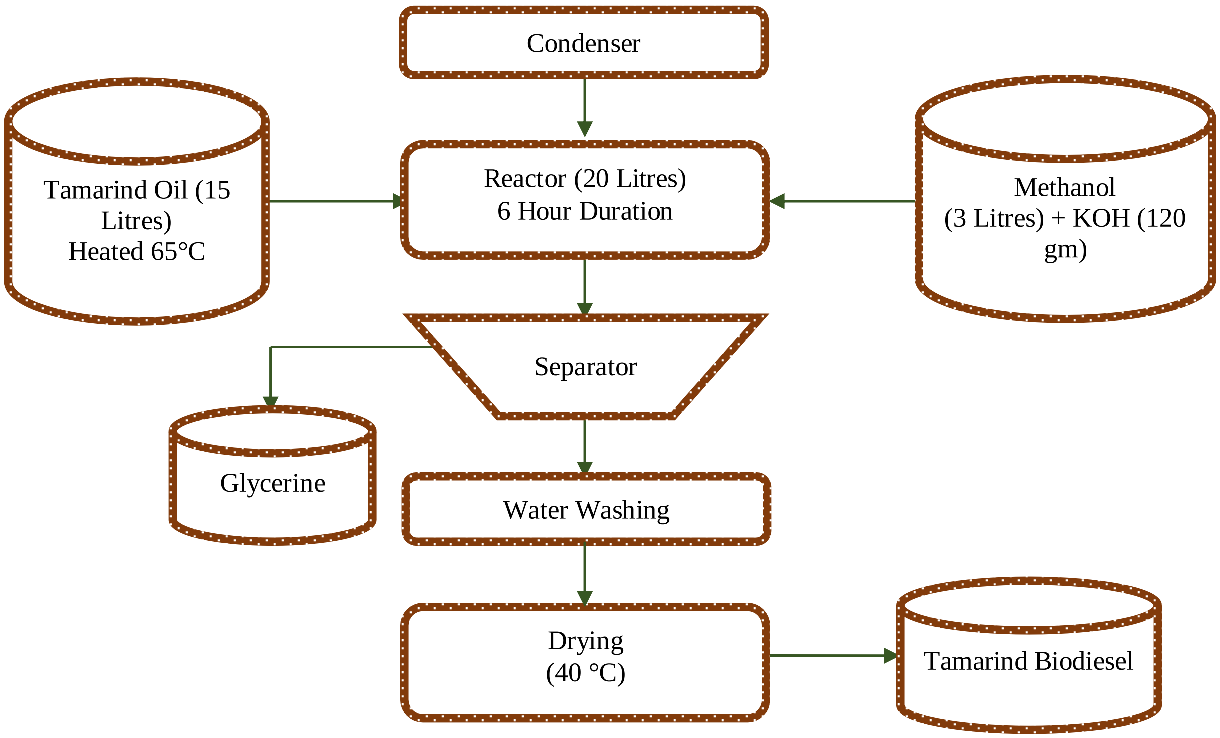

Fig. 1 Tamarind biodiesel production process

Table 1. TME and diesel as per ASTM D 6751

Property	Diesel	TME
Density - 20 °C (kg/m^3)	840	868.4
Kinematic Viscosity - 40 °C (cSt)	2.84	3.85
Calorific Value (J/kg)	42.5	41.81
Flash Point (°C)	54	184
Fire Point (°C)	58	198
Cetane Number	48	52

3. Test Engine

The experiment was performed in a Kirloskar mono-cylinder with a fuel-air mixing cooled constant speed diesel engine generating 4.4 kW and connected to a supply current dynamometer to solve the brake load. Figure 2 depicts a line illustration of the test engine setup. A Chromel-Alumel thermocouple and a numerical temperature indicator remained employed to measure the exhaust gas using a numerical temperature meter. Throughout the test, the pressure pickup was positioned on the cylinder head and used to determine the cylinder pressure. With the help of an AVL-444 analyzer of gas identified and an AVL-437C to identify the smoke value, exhaust emission concentrations remained measured. In the beginning, the engine is powered by diesel, and then it is turned over to MPO mixes with standard pressure for injection (200 bar) and timing (23° bTDC). After that, it is turned over to regular injecting pressure (200 bar) and timings (23° bTDC), and it is kept moving until an engine speed of 1500 revolutions per minute. For each mix and load, measurements and calculations were made regarding fuel consumption, combustion data, and exhaust emissions data. The experiments on each fuel were performed three times, and the averages of the values measured according to steady-state and comparable situations were captured for comparison to diesel.

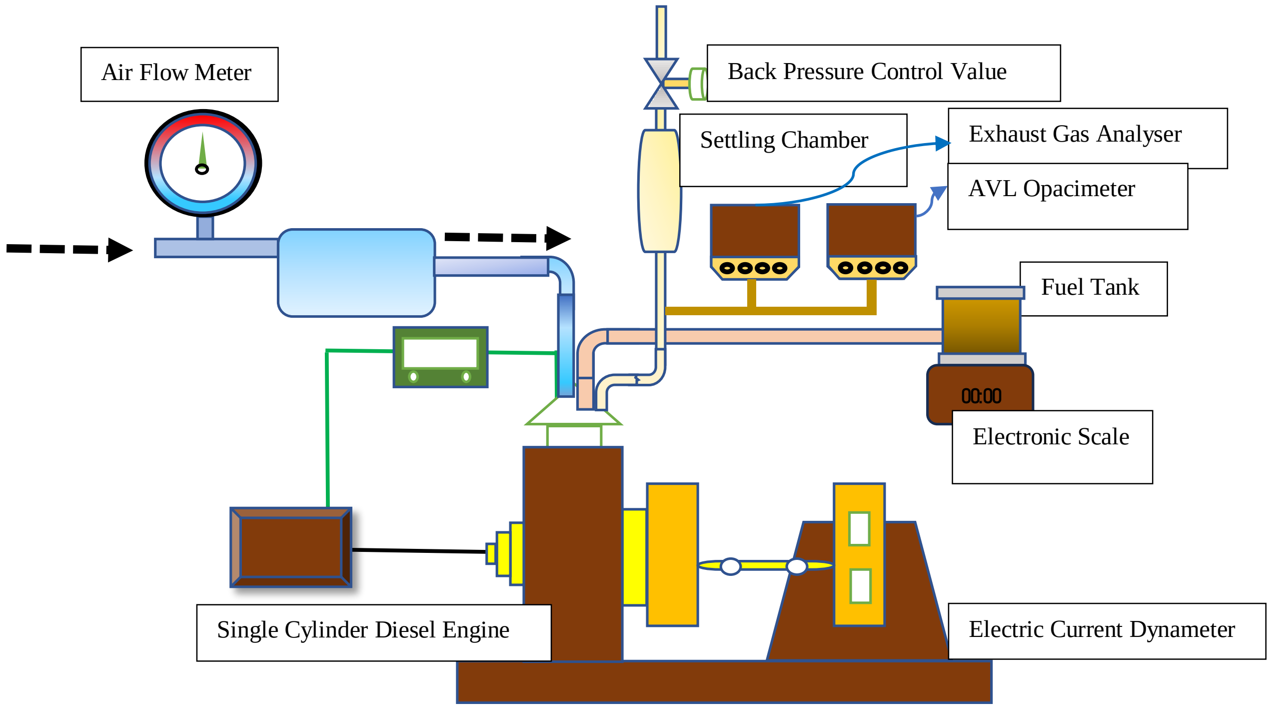

Fig. 2 Test engine setup

4. Result and Discussion

Research on a Kirloskar diesel engine was agreed upon with the objective of estimating the engine performance and emission of the combustion features using diesel and TME25-diesel-TiO_2 nanoparticle mixtures. In this section, all measured and calculated values are discussed and linked to diesel.

4.1. Pressure –Crank Angle Diagram

Figure 3 shows the connection between cylinder pressure and (CA) at the maximum load for the fuels that were tested. In a (CI) engine, the quantity of fuel injected during the rapid combustion stage controls the cylinder pressure advancement. As depicted in the diagram, it is evident that the peak pressure exhibited by diesel surpasses that of TME25 as the calorific value increases. At maximum power, the cylinder pressure for TME25 with 100 ppm TiO_2 nanoparticles exceeds that of TME25 with 50 ppm TiO_2 mix, TME25, and diesel. The peak pressure values were obtained as 74 bar and 72 bar for TME25T100 and TME25T100, respectively. The increase in cylinder pressure for TME25 with 100 ppm of TiO_2 nanoparticles is 2 bar and 6 bar greater than TME25T50 and TME25 mixture.

The cylinder pressure increases could be attributed to the catalytic act of TiO_2, which relates towards their high surface volume ratio and takes a significant role in making the reaction process by adjusting excess oxygen for ignition. Furthermore, the catalytic act of TiO_2 is significantly more active oxidation at maximum power towards the higher temperature private the combustion chamber outcomes in increased cylinder pressure. The peak pressure values attained as diesel and TME25 are 70 bar and 68 bar, respectively. Comparable results were found by Srinivasan Senthilkumar et al. [25] when investigating the impact of nanoparticles with tomato seed oil methyl ester mixture.

4.2. Heat Release

Figure 4 demonstrates how HRR varies with CA for diesel, TME25, and TME25 mixed with various levels of TiO_2 nanoparticles (50ppm and 100ppm) at maximum load. When the ignition delay is longer, more fuel mixes with air to form a combustible mixture. When the self-ignition temperature is attained, the mixture burns rapidly, producing a considerable amount of energy. Nanoparticles such as Alumina and TiO_2 have a catalytic effect, enhancing fuel particle oxidation. Including 50ppm and 100ppm TiO_2 nanoparticles in TME25 fuel resulted in improved particle oxidation during combustion, as evidenced by the changes in HRR shown in the figure. According to the results presented in the statement, the heat generated by TME25 blended with 100 ppm TiO_2 nanoparticles is higher than that produced by TME25 and TME25 with 100 ppm TiO_2 at maximum power conditions. Specifically, the HRR for TME25 blended with 100 ppm TiO_2 is 2 J/°CA and 4 J/°CA greater than TME25 with 50 ppm TiO_2 and TME25 respectively. Moreover, at maximum power conditions, the HRR for TME25 with 100 ppm TiO_2 (66 J/°CA) is slightly higher than that for TME25 with 50 ppm TiO_2 (64 J/°CA). Diesel and TME25 have HRRs of 63 J/°CA and 62 J/°CA, respectively. Comparable findings were conveyed by Nanthagopal et al. [29] when they investigated the effect of nanoparticles–biodiesel mixtures.

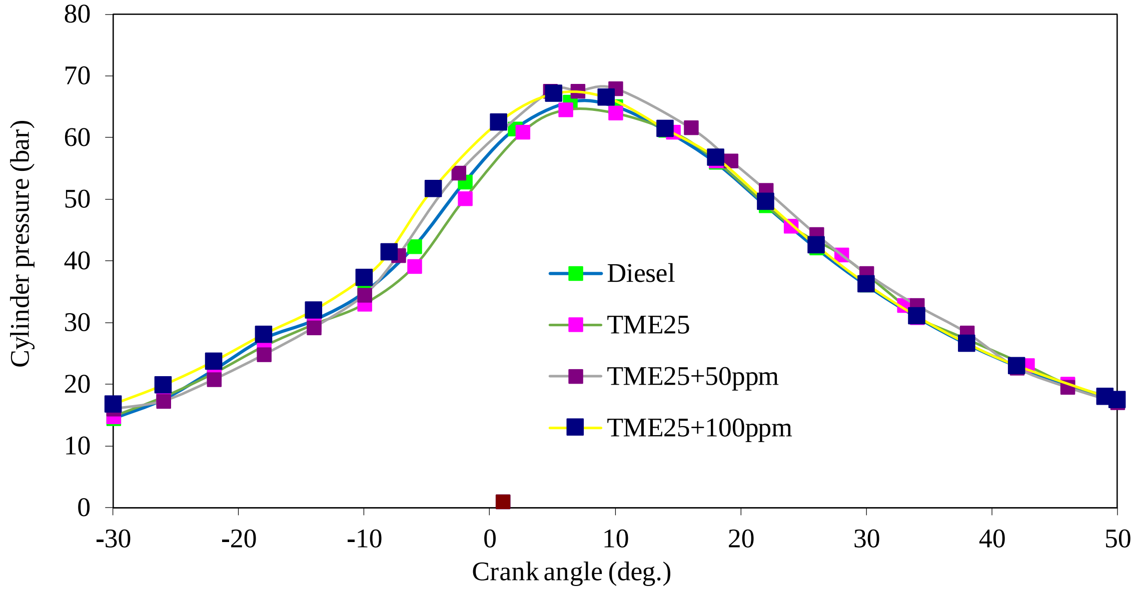

Fig. 3 Cylinder pressure Vs CA

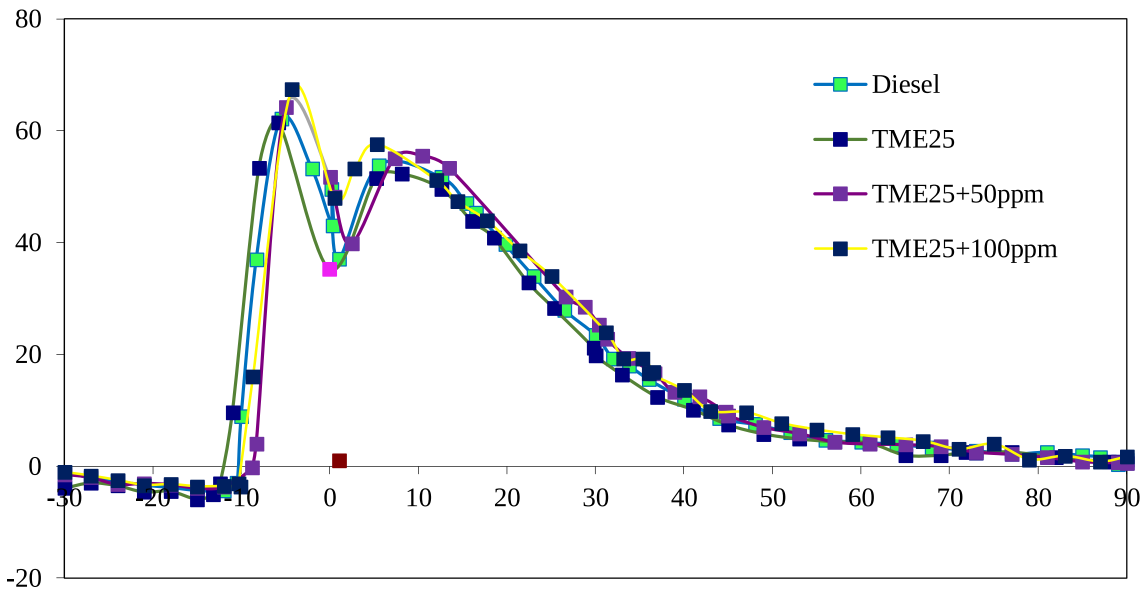

Fig. 4 Change of HRR with CA

4.3. BTE

Figure 5 illustrates the variations in (BTE) in relation to Brake Power (BP) for diesel, TME25, TME25T50, and TME25T100. The engine variable, which characterizes the efficiency of adapting air fuel energy into mechanical output, governs the magnitude of BTE generated. Based on the graphical representation, it can be shown that BTE exhibits enhancement as the load increases, mostly attributed to the reduction in heat dissipation and the consequent elevation in cylinder wall temperature. The BTE of TME25 has been found to be lesser compared to the diesel due to the lower energy satisfied and increased viscosity of the mixture, resulting in suboptimal combustion. Additionally, it has been noted that, when associated with the TME25 mixture, all TME25T100 nanoparticle additives have displayed higher BTE. This might be explained by incorporating nanoparticles into the biodiesel mixture, which goes through a secondary atomization and micro explosion that encourages complete burning. It has been noted that the BTE for diesel and TME25 is 30.8 and 29.2%, respectively, while it is 31.1% and 31.8% for TME25T50 and TME25T100, respectively. At extreme load, the BTE of TME25T100 increased by 2.6% as compared to TME25. A similar pattern of results was reported by [25] when investigating the effect of TiO_2 blended with rubber seed oil biodiesel.

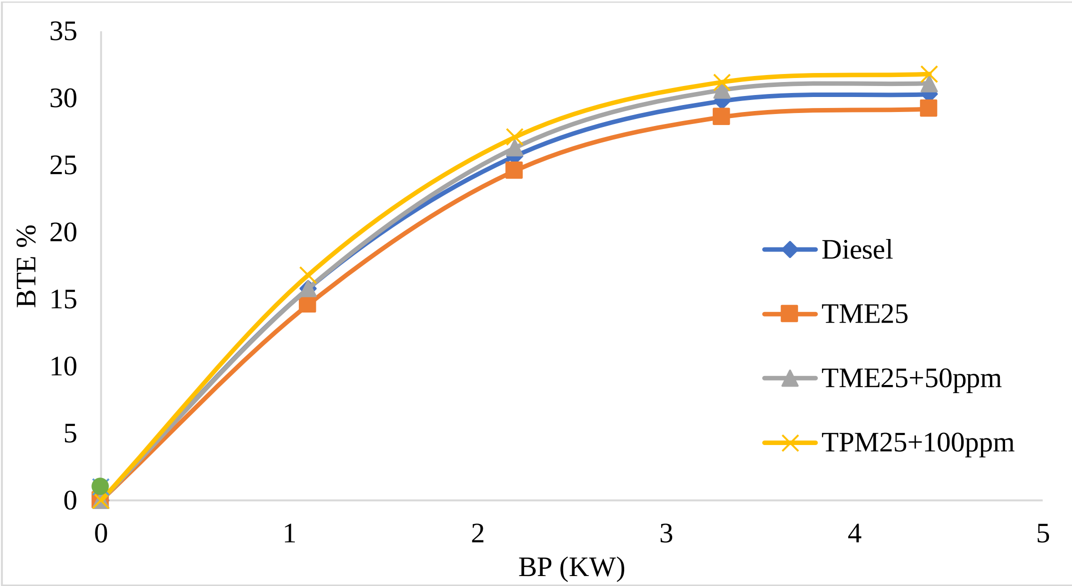

Fig. 5 BTE Vs BP

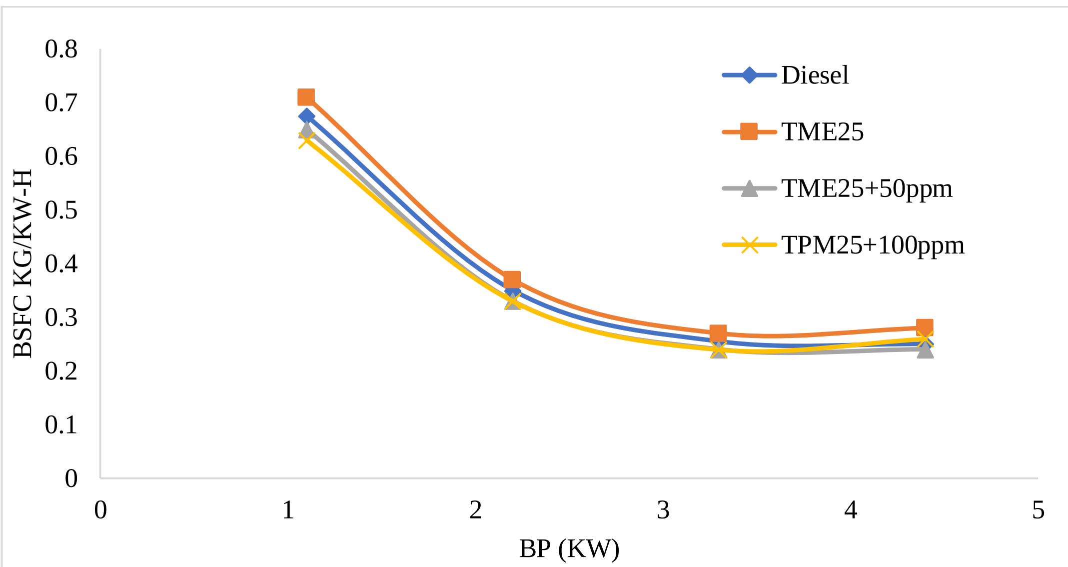

Fig. 6 BSFC Vs BP

4.4. BSFC

Fuel efficiency is an engine's ability to completely transform the energy with the fuel into useful engine output. Diesel has a higher BSFC than neat biodiesel, which has less energy and a higher viscosity. BSFC is used to compare engine performance when different heating values of furls are used. TME25 has a higher BSFC than diesel because it contains less energy and has a higher viscosity. Figure 6 illustrates the changes of BSFC with BP for all tested mixtures.

The graph clearly shows that at all engine loads, biodiesel-nano particle mixtures displayed lower BSFC than biodiesel mixture. The physio-chemical properties of nanoparticles contribute additional oxygen, which promotes the combustion of biodiesel mixtures, resulting in a decrease in BSFC.

In comparison to TME25, which has a BSFC related to 0.286 kg/kWh, and diesel, which has a BSFC of 0.259 kg/kWh, the BSFC observed for the TME25T50 and TME25T100 is 0.259 kg/kWh and 0.249 kg/kWh, respectively.

When related to TME25 fuel, the BSFC for 100ppm of TiO_2 nanoparticle-dispersed biodiesel mixtures decreased by 8% compared to base fuel TME25. This is because nanoparticles have fine atomization properties that lead to better combustion. At maximum load, the BSFC of TME25T100 decreased by 7% when compared to TME25.

4.5. CO Emission

Figure 7 illustrates the relation in CO emission compared to BP for diesel, TME25, TME25T50, and TME25T100. Poor air-fuel mixing, a lack of oxygen during combustion, and affluent local areas are all contributing factors to the formation of CO emissions (Heywood John, [27]). CO emission is down initially as the load increases up to about 3/4 of the full load before suddenly rising at peak load towards a rise in fuel injection rate, leading to insufficient combustion for all test fuels. CO emissions for TME25T50 and TME25T100 are lower than diesel at all loads. Compared to Yuvarajan et al. (2018), the oxygen molecules in biodiesel could be the cause.

TiO_2 nanoparticles added to the TME25 mixture may also be responsible for decreased CO emission. The TME25T50 and TME25T100 have lower CO emissions due to their higher surface volume ratios, which activate the catalytic action and cause a significant decrease in CO emissions (Yuvarajan et al. [28]). At maximum brake power, CO emissions were found to be diminished by 40% by incorporating 100 ppm of TiO_2 nanoparticle into TME25. For diesel, TME25, TME25T50, and TME25T100, the CO emissions at maximum brake power are correspondingly 0.15, 0.13, 0.09, and 0.07%. When subjected to maximum load, the CO emissions of TME25T100 showed a reduction of 47% in comparison to TME25. The study conducted by Senthil Kumar et al. [25] yielded comparable findings when examining the impact of nanoparticles combined with rubber seed oil biodiesel.

4.6. HC Emission

Figure 8 illustrates the relation between HC emission and brake power for diesel, TME25, TME25T50, and TME25T100. Heywood B. John (2018) identifies two main factors contributing to the release of Hydrocarbons (HC): the absence of sufficient oxygen for burning and the non-uniformity of the air-fuel combination. The down in BP outcomes in a corresponding increase in HC emissions for all tested fuels.

An increase in brake power requires a corresponding increase in fuel consumption, given a fixed amount of air, to sustain a consistent power output. As a consequence of the richer air-fuel mixture, all tested fuels have higher HC emissions (Yuvarajan et al. 2017).

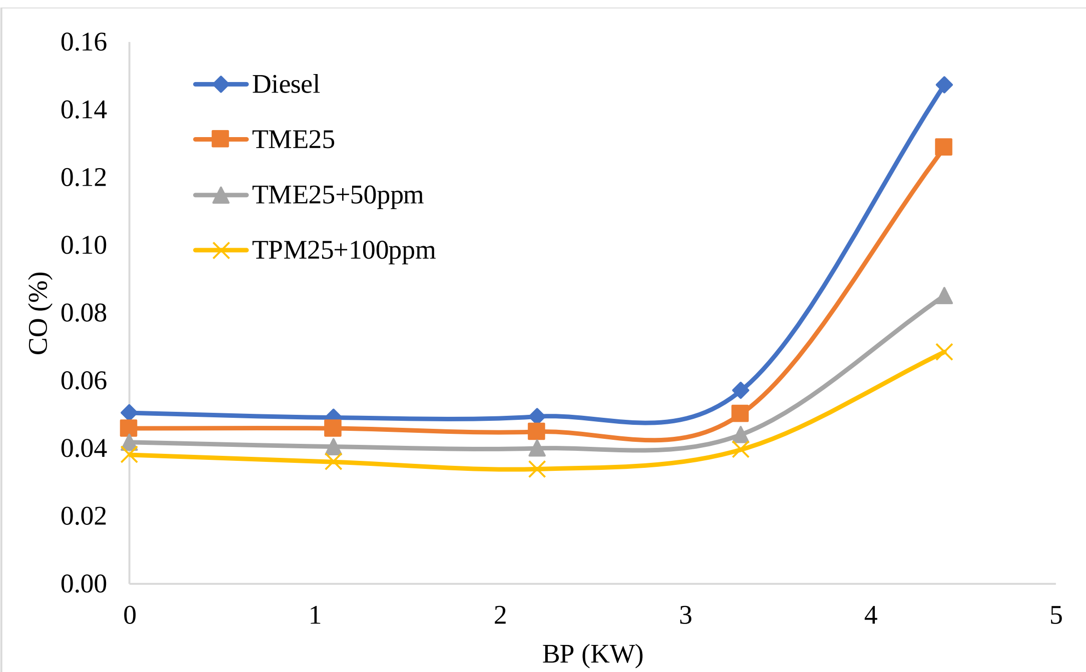

Fig. 7 Change of CO Vs BP

According to the existence of TiO_2 nanoparticles, which speed up the oxidation process and drop the temperature needed to start burning carbon, may be the cause of lower HC emissions. At peak power, HC emissions were found to be diminished by 16% by the dispersion of 100 ppm of powdered TiO_2 nanoparticles into TME25. HC emissions for TME25, TME25T50, and TME25T100, and diesel were 58, 55, and 52 ppm, respectively, at peak brake power, whereas diesel was found to have 60 ppm. At maximum load, the HC of TME25T100 decreased by 27% when compared to TME25. A Comparable pattern of results was reported by [20] when investigating the result of nanoparticles blended with rubber seed oil biodiesel.

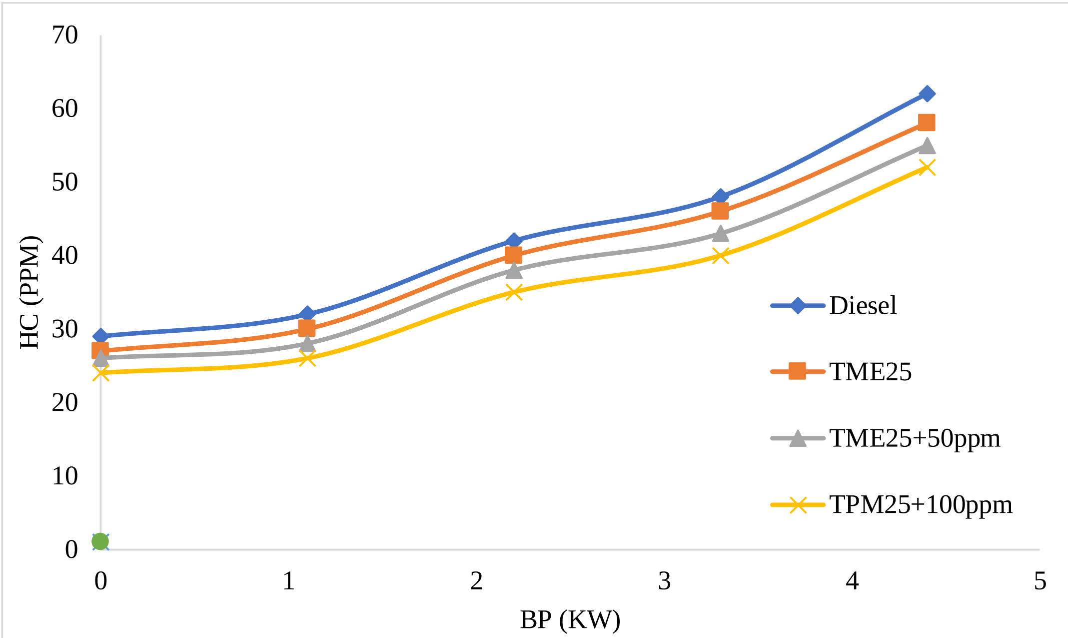

Fig. 8 Change of HC Vs BP

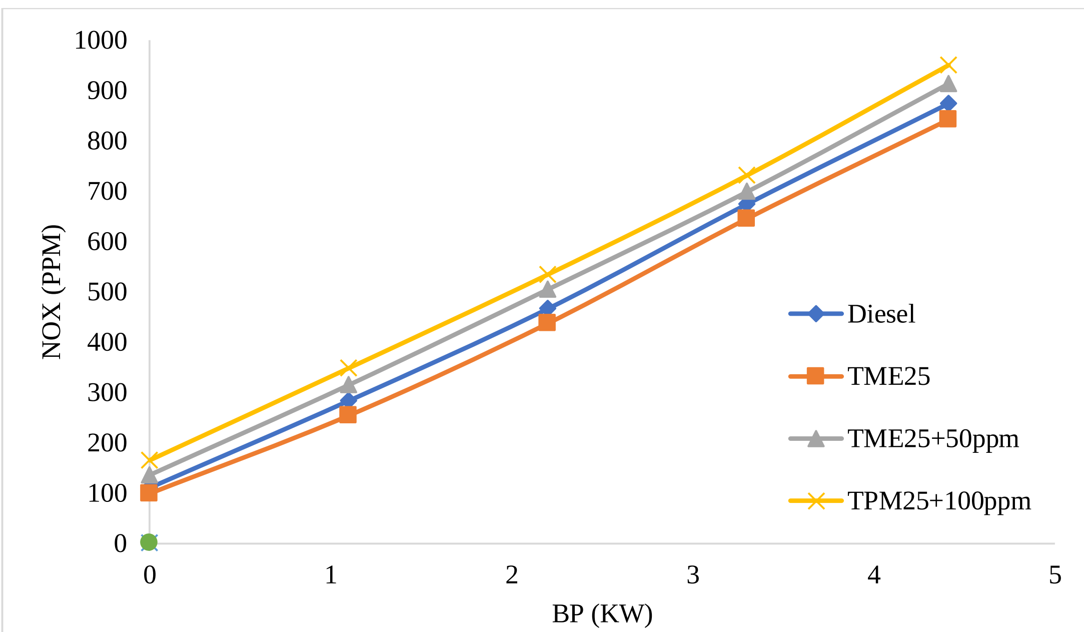

Fig. 9 Change of NOX Vs BP

4.7. NOX Emission

Figure 9 illustrates the variations in NOX emissions in relation to brake power for four different fuel types: diesel, TME25, TME25T50, and TME25T100. The graph illustrates a positive correlation between the brake power and NOX emissions across all test fuels. The introduction of supplementary fuel injection to enhance power output resulted in elevated NOX emissions. Additionally, the inherent oxygen concentration in biodiesel facilitates the oxidation process, leading to an escalation in peak temperature (Yuvarajan et al. [28]). It has been observed that NOX emissions from TME25 are higher than diesel emissions. TME25T50 and TME25T100 emit significantly more NOX than diesel and TME25 at all loads. According to Yuvarajan et al. [28], the higher oxygen availability in Tamarind oil against diesel promotes combustion and raises combustion temperature and NOX emissions. However, after dispersing TiO_2 nanoparticles in TME25, there is a noticeable increase in NOX emissions at all loads. The presence of TiO_2 nanoparticles, which increases the total surface area of fuel and promotes complete combustion of the biodiesel mixture, is responsible for the rise in NOX emissions for TME25T50 and TME25T100, as stated by Yuvarajan et al. [28]. By incorporating 100 ppm of TiO_2 nanoparticle into TME25, NOX emissions were elevated by 13% at maximum brake power. For TME25, TME25T50, TME25T100, and diesel, peak NOx emissions seemed to be 842, 914, 950, and 874 ppm, respectively. A similar pattern of results was obtained by [25] when investigating the effect of nanoparticles blended with rubber seed oil biodiesel.

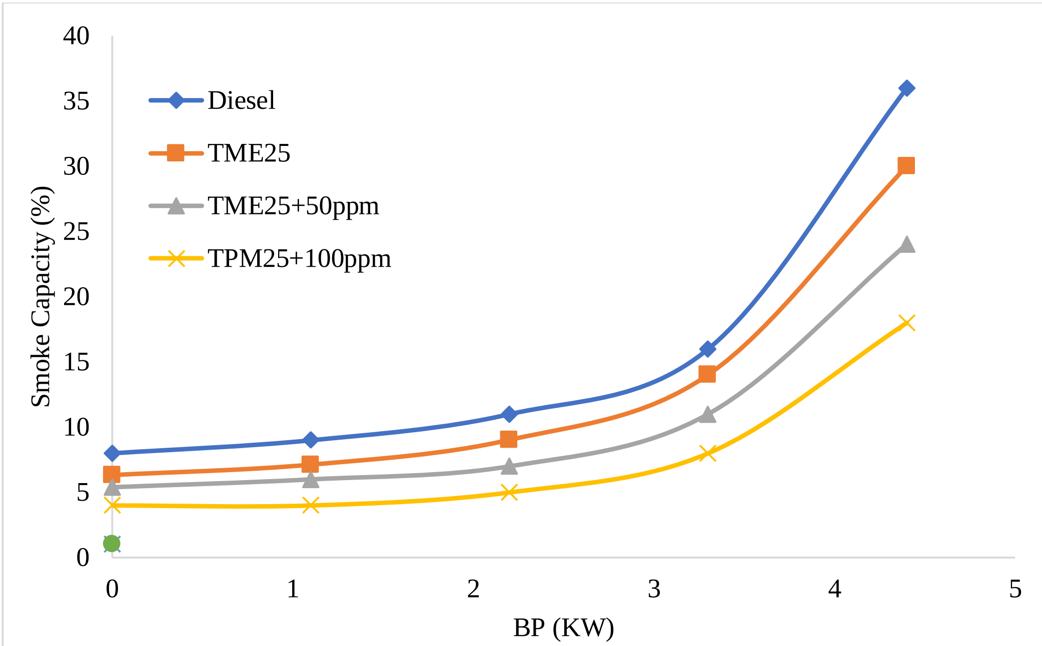

Fig. 10 Change of smoke opacity Vs BP

4.8. Smoke Opacity

Figure 10 illustrates the variations in smoke opacity among diesel, TME25, TME25T50, and TME25T100. The study revealed a positive correlation between brake power and smoke opacity across all evaluated fuels. As brake power increases, a greater quantity of fuel is introduced into the combustion chamber relative to the amount of air present. This imbalance leads to reduced efficiency in the oxidation process and consequently results in elevated levels of smoke emissions. At all brake powers, smoke emissions from TME25, TME25T50, and TME25T100 are less than those of diesel. Due to Tamarind biodiesel already contains oxygen, which encourages oxidation reactions and reduces smoke emissions (Nandagopal et al. [29]. Incorporating TiO_2 nanoparticles significantly lessens the smoke's appearance at various concentrations.

TiO_2 nanoparticles, in varying amounts, significantly reduce the smoke's opacity. TiO_2 nanoparticles accelerate TME25's oxidation process and rate of evaporation [25]. TiO_2 nanoparticles related to oxidation catalyst, enhancing carbon oxidation and minimizing smoke emissions at all loads Yuvarajan et al. [28]. When 100 ppm TiO_2 nanoparticles were dispersed in TME25, smoke emissions diminished by 50% when compared to base fuel. For TME25, TME25T50, and TME25T100, the smoke emissions at maximum power were 30, 24, and 18, respectively, whereas for diesel, it was 36% at maximum power. A similar pattern of results was obtained by Senthil Kumar et al. [25] when investigating the result of nanoparticles blended with rubber seed oil biodiesel.

5. Conclusion

In the present work, research was accepted using TME25 blends and varied with TiO_2 nanoparticles at various quantity levels to examine the effects of TiO_2 engine combustion and emission behaviors of diesel engines. The findings from the experiment bring about the following conclusions:

- Adding TiO_2 to biodiesel improves the engine's working characteristics, resulting in better cylinder pressure and HRR at maximum load due to maximum cylinder temperature and promoting the oxidation of fuel and air, subsequently enhancing combustion.
- The engine's performance is better when nanoparticles are integrated into biodiesel, which boosts the BTE, and a drop in BSFC is noticed. TiO_2 oxide nanoparticles improve combustion as a whole, leading to raised BTE and minimize the BSEC. A maximum 2.7% increase in

BTE and a 7% decrease in BSFC for TME25T100 at full load.

- The addition of 100 ppm TiO_2 nanoparticles-bio-oil mixtures (MTO25T50) reduced all the emissions except NOX for bio-oil due to built-in oxygen in the biodiesel. Furthermore, adding TiO_2 nanoparticles to TME25 reduced HC, CO, and smoke emissions by 27, 47, and 40%, respectively.
- Resulting with the 100 ppm TiO_2 nanoparticle to biodiesel mixture increased NO emissions by 12.8% due to enhanced thermal conductivity and catalytic effect of TiO_2.
- Finally, it is suggested that the engine can be operated with TME25 + 100 ppm of TiO_2 nanoparticle as additives with an increase in performance, lowering the emissions and having a positive impact on the environment.

Future Work

In conclusion, the research presents promising results in terms of efficiency improvement and emission reduction through the addition of TiO_2 nanoparticles to TME25. The future scope involves further optimization, assessing long-term effects, evaluating economic viability, ensuring compatibility, and conducting a comprehensive environmental impact assessment for practical implementation and widespread adoption.

Acknowledgments

The researchers thank the management of AVIT and the Vinayaka Mission Research Foundation for providing the laboratory resources.

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