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Enhancing combustion efficiency: utilizing graphene oxide nanofluids as fuel additives with tomato oil methyl ester in CI engines

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Abstract

The research aims to conduct a thorough examination of the combustion, injection, performance, and emission characteristics of a diesel engine below different engine loads, as well as the synthesis of graphene oxide (GO) nano fuels and their utilization in combination with Tomato Oil methyl ester (TOME) and diesel fuel blend. The graphene oxide, plays a vital role in the pre-mixed combustion phase of diesel engines. Addition of graphene oxide nano fuels enhances the high-pressure combustion stage, resulting in increased maximum pressure and heat release rate. TOME (B20GO75) and TOME (B20GO100) exhibit comparable heat release rate to diesel due to improved fuel characteristics and quicker ignition delay duration. While TOME (B20) shows a slight decrease in (BTE) compared to diesel, the addition of graphene oxide improves BTE, with TOME (B20GO50) displaying the highest BTE at full load, indicating enhanced combustion efficiency. Moreover, graphene oxide addition leads to a reduction in carbon monoxide (CO) and hydrocarbon (HC) emissions, with emissions decreasing as the concentration of graphene oxide increases. However, NoX emissions initially decrease with TOME (B20) compared to diesel but increase with higher graphene oxide concentration. Smoke emissions increase with TOME (B20) but decrease with higher graphene oxide dosages. Overall, the incorporation of graphene oxide nano fuels into Tomato Oil methyl ester blends demonstrates potential for improving engine performance and reducing emissions.

1. Introduction

Renewable energy sources have recently received a lot of attention due to the fast depletion of fossil fuels [1]. One kind of renewable energy that has found widespread adoption and broad use is biodiesel. It doesn't necessitate any changes to diesel engines and may be made using a variety of oils [2, 3]. Biodiesel feedstocks are often categorized as either edible or non-edible oils, as well as animal fat and (WCOs). The primary ingredients in biodiesel are canola and sunflower oils, but it can also be made from rapeseed, palm, and soybeans. On the other hand, there have been heated discussions on the use of edible oils and the potential conflict between food and fuel [4, 5]. About seventy to eighty percent of the total cost to produce gasoline is attributable to the use of feedstocks made from edible sources [6]. However, using non-consumable feedstock for biodiesel production can cut expenses [7]. Because of its large forest regions and undeveloped peripheral and waste lands, the Indian subcontinent could provide a plentiful supply of non-edible feedstocks [8]. Due to its abundant availability of non-food feedstocks, India's economy has great growth potential [9].

The work investigates into using graphene oxide nano fuels in customized CRDI systems to reduce diesel emissions, improve performance, and improve symmetrical features [10]. Using symmetrical graphene oxide and N-butanol nano fuels, four permanent and symmetrical nano fuel blends were created; these blends are BTE and BSFC. Biodiesel made from Nigella sativa, which is chemically identical to diesel, contains 90% n-butanol and 10% graphene oxide nanoparticles [11]. Additionally, CI engines that run on biodiesel made from dairy scum oil had their performance and emissions evaluated with GO nano fuels [12]. Using fuels containing nanoparticles improved performance while decreasing emissions, according to the data. BTE was enhanced by 7.90% and BSFC was reduced by 9.72% with the help of GO nanoparticles. Because of their enhanced thermal properties and higher surface-to-volume area ratio, they also decreased NoX by 15.17%. Incorporating GO nanoparticles into a binary mixture of biodiesel and diesel improved the performance of CI engines, according to the study [13]. Using biodiesel made from Oenothera lamarckiana, the study also looked at how diesel engine performance and emissions were affected by GO nano fuels. (GO) nanoparticles and injection pressures are the primary areas of interest in this investigation into the performance and emissions of biodiesel engines driven by Sapota seeds [14]. The findings point to the possibility of cleaner, more efficient engines made possible by pressure injection. Two types of biodiesels, B10 and B20, are 90% and 80% diesel, with 10% and 20% sapota seed oil, respectively. At different fuel injection pressures, B10GO50 and B20GO50 blends with 50 ppm GO Nanoparticles were tested. Because of its high conductivity, reactivity, and surface area, the study discovered that decreasing graphene oxide lowers engine performance and emissions [15]. Cylinder pressures and heat release were both enhanced by fuels containing nanoparticles. A one-cylinder, four-stroke diesel engine that is air-cooled and direct-injected was tested using graphene oxide nanoparticles in Jatropha Methyl Ester (JME). Diesel engines that use JME-GO nanofuels have a 17% better thermal efficiency compared to those that use clean JME. The use of JME-GO blends in gasoline reduces emissions of CO by 60% and UHC by 50% when compared to pure JME gasoline. When compared to pure Jatropha biodiesel, JME-GO blends reduce NoX emissions from the fuel by 15% under heavy engine load [16]. The remarkable physical properties and wide range of engineering uses for graphene make it stand out. We evaluate turbocharged diesel engines that use graphene oxide (GO) or graphene nanoplatelets (GNP) as an additive. At 40 and 60 parts per million, respectively, GO and GNP decrease nitric oxide by 26.4% and smoke by 29.2%. In terms of lowering NO, CO, and HC, GNP outperforms GO [17].

The potential of nano additives to improve internal combustion engines and bioenergy generation has been the subject of recent investigations [18]. Examine how diesel-biodiesel fuel mixes are affected by nano additions, paying particular attention to emissions, engine performance, and spray characteristics [19]. For more information on the possible advantages of nanoparticle-based fuel additives, compare how they affect internal combustion engine combustion and emission characteristics [20-22]. Investigates the effects on engine performance and combustion characteristics of diesel-biodiesel fuel mixes treated with zinc oxide nanoparticles [23-25]. In the background, suggest adding carbon nanotubes to petroleum-based diesel fuel to enhance diesel engines' environmental performance. Explain the potential of nanotechnologies for producing bioenergy and the availability of biomass, highlighting the significance of incorporating nanotechnology into sustainable energy solutions [26].

The present study focuses on the production of Tomato seed oil methyl ester (TOME), a biodiesel feedstock that has received limited attention. The aim is to further improve the fuel properties of TOME by blending it with graphene oxide nano fuel additives. The use of these additives recovers the pre-mixed combustion, leading to developed temperatures in the combustion chamber. Additionally, the higher surface area of symmetrical GO nano fuels increases thermal conductivity. This article aims to analyze and investigate these effects of their respective names: B0, which is 100% pure diesel fuel, B20, which is 80% diesel and 20% TOME, B20 + 25 ppm GO, B20 + 50 ppm GO, B20 + 75 ppm GO, and B20 with 100 ppm GO. Please note that the concentrations of these additives are subject to change. The performance characteristics and the emission of CI engines are enhanced when nano fuels are added to advanced diesel fuel and/or biodiesel mixes, according to prior research. Specifically, this research set out to synthesize graphene oxide micro fuels. Afterwards, graphene oxide nano fuels were introduced to the biodiesel-diesel test fuel in increments of 25, 50, 75, and 100 ppm. The engine was run on pure diesel fuel (B0) and a binary mixture of diesel and tomato methyl ester (B20) in order to collect reference data. Nanoparticles of graphene oxide (GO) added to TOME blends boost combustion efficiency, which in turn increases emissions of (CO), (HC), and smoke when contrasted with conventional diesel.

2. Materials and methodology

2.1. Tomato methyl ester formation

Tomato seeds, typically considered waste from sauce factories, are used to extract oil through methods like solvent extraction or mechanical pressing. The extracted oil undergoes transesterification, converting triglycerides into biodiesel and glycerol, resulting in the formation of Tomato Oil methyl ester (TOME). TOME is a biodiesel feedstock with properties that can be further enhanced by blending it with graphene oxide nano fuel additives. Fig. 1 depicts the process of extracting oil from tomato seeds: Make oil by pressing tomato seeds. The two most common methods for this process are solvent extraction and mechanical pressing. When compared to specialized oilseed crops, tomato seeds have a relatively low oil concentration, which could restrict production. If needed, purify the resulting oil during oil refining. Degumming, neutralizing or the bleaching process, and the deodorization are some of the refining processes that can improve oil quality. The method of transesterification can be used to transform the refined oil into biodiesel. Chemical reaction involving vegetable or animal fat and a spirit (usually alcohol) with the help of a catalyst (usually sodium or KOH) [27]. Biodiesel and glycerol, two esters formed from the oil's triglycerides, are the end products of this process. Washing and Separation: After the process of transesterification, the biodiesel needs to be cleaned by washing it away from the glycerol and any other impurities. Dehydration: the extraction of biodiesel by a method of dry.

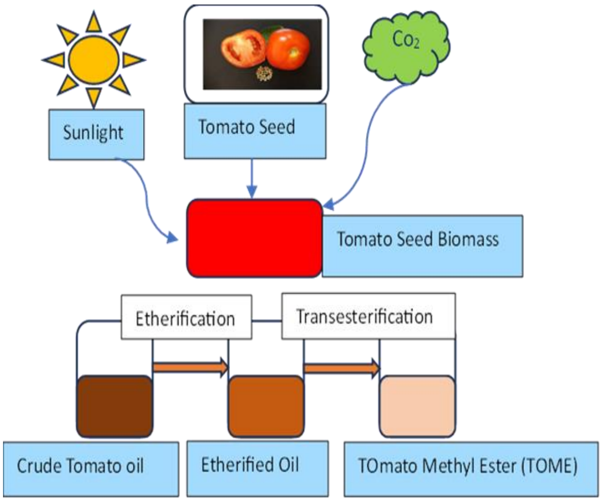

Figure 1. Preparation of Tomato Methyl Ester.

The simplified chemical reaction is as follows: Triglyceride + Alcohol → Biodiesel + Glycerol

2.2. Graphene oxide

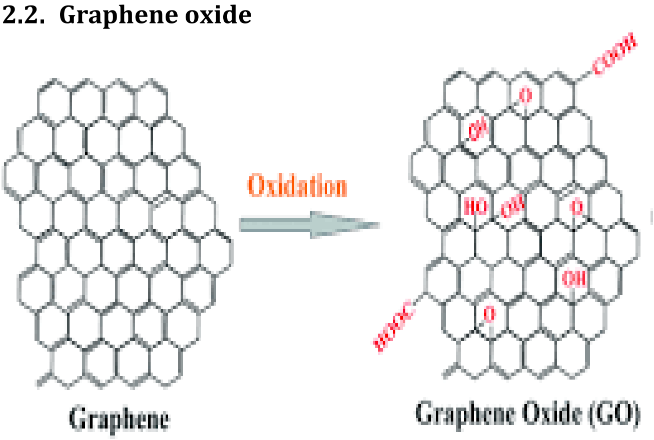

Figure 2. Graphene/graphene oxide.

Figure 2 illustrates the structure of Graphene/graphene oxide, the initial step in producing graphene oxide (GO) nanofluids involves measuring the amount of GO powder based on the desired concentration of the end product. Next, combine the GO powder with a solvent, namely deionized water, which is chosen for its compatibility with both the environment and the materials. Surfactants such as Triton X-100 or sodium dodecyl sulphate (SDS) are included to avoid the clumping of particles and enhance their stability. Subsequently, employ an ultrasonic probe to subject the mixture to sonication. Ultrasonication is employed to break down larger GO aggregates into smaller particles, ensuring even distribution in the solvent. The ultrasonication process is determined by two criteria: the concentration of GO and the intensity of the ultrasonic equipment [28]. To ensure the equal distribution of GO nanoparticles and enhance stability, it is necessary to continuously stir the nanofluid using a magnetic stirrer. Centrifugation can be optionally employed to remove any large aggregates or impurities, resulting in a final nanofluid product. After the preparation phase, the nanofluid needs to be characterized by examining its optical properties, structure, zeta potential, distribution of particle sizes, and using (TEM) and (DLS) techniques, as well as measuring zeta potential and performing ultraviolet-visible spectroscopy. To prevent the degradation or clumping of nanoparticles, store the graphene oxide nanofluid in a sealed container, protected from direct sunlight. The synthesized graphene oxide is then dispersed in a solvent, often water or ethanol, using ultrasonication to achieve a stable nanofluid. Concurrently, TOME is produced by extracting oil from tomato seeds via solvent extraction or mechanical pressing, followed by transesterification to convert triglycerides into biodiesel. The prepared graphene oxide nanofluid is then blended with TOME in varying concentrations using magnetic stirring.

2.3. Diesel, biodiesel and GO blend

Table 1 shows the belongings of diesel, TOME and their GO nano fuel blends.

The test fuels and their respective names: B0, which is 100% pure diesel fuel, B20, which is 80% diesel and 20% TOME, B20 + 25 ppm GO, B20 + 50 ppm GO, B20 + 75 ppm GO, and B20 with 100 ppm GO. Sample shown in figure 3.

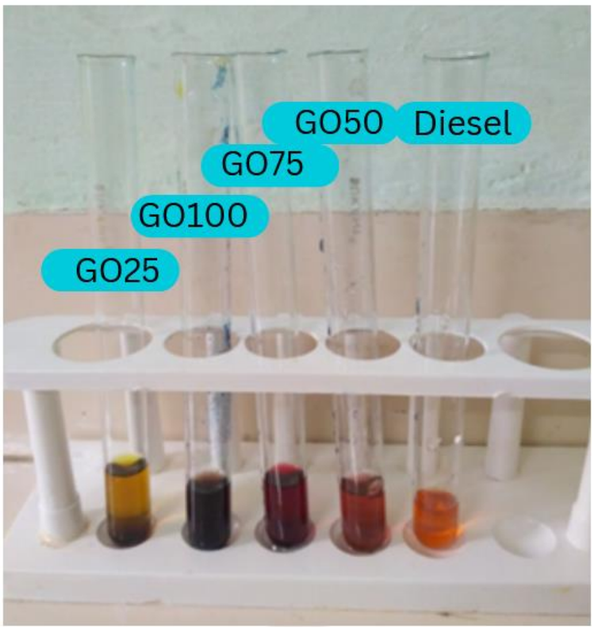

Figure 3. TOME blends containing different levels of nanofluids concentration.

Table 1. Properties of diesel, TOME and their GO nano fuel blends.

Properties	Unit	Diesel	TOME (B20)	TOME (B20GO25)	TOME (B20GO50)	TOME (B20GO75)	TOME (B20GO100)
Viscosity	(cSt)	2.62	2.8	3.8	3.65	3.2	3.3
Flashpoint	(°C)	68	189	132.3	132.8	133	134
Pour point	(°C)	-3	4.52	4.62	4.7	4.76	4.79
Calorific value	(MJ/kg)	42.7	35.9	40.6	40.8	41.08	41.9
Density	(kg/m3)	855	915.1	836	834	832	830

3. Experimental setup

Figure 4 depicts the schematic for a kirloskar engine, which involves of a single chamber, four strokes, and an engine linked to the control panel. The detailed perspective of the investigational engine is shown in Figure 5. Depending on the setup, the load can be anywhere from zero to five and a half kilowatts. The engine produces 5.3 kilowatts of power at 0% load, 25% load, 50% load, and 100% full load, for the benefit of clarity in the instructions. Diesel and biodiesel can be mixed with air in the fuel container, and the amount of the mixture can be adjusted using the fuel analyzer on the control screen. The accessible digital control screen allows for the programming of various configurations, including the smoke meter and inlet manifold. (ECUs) and analytical devices keep tabs on sensors including the fuel, level, and load sensors [29].

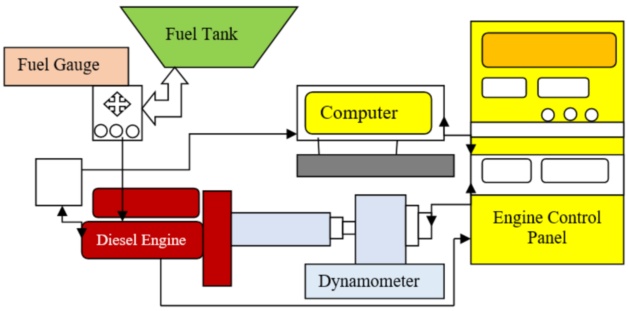

Figure 4. Experimental Setup.

Figure 5. Experimental Setup of VCR Diesel Engine (Photographic View).

4. Result and discussion

4.1. Combustion analysis

4.1.1. Cylinder pressure vs CA

In the initial phase of combustion, referred to as the pre-mixed stage, the maximum pressure exclusive the cylinder of a diesel engine is accurately calculated founded on the proportion of gasoline that has undergone combustion. The GO, or gas opening, is determined by the angular position of the crankshaft at the transition from the compression stroke to the engine's power stroke. The resulting angle is obtained from the point at which the GO is calculated. There's an immediate connection between the fuel consumption during uncontrolled combustion and the pressure generated by the engine's cylinders.

The figure 6 illustrates the difference in the crank angle of the cylinder pressure when the load is at its maximum. Integrating GO into TOME leads to the production of a larger quantity of oxygen and enhances the cetane concentration. Moreover, the significant ratio between the volume and the uneven exterior zone results in an elevation in cylinder pressure.

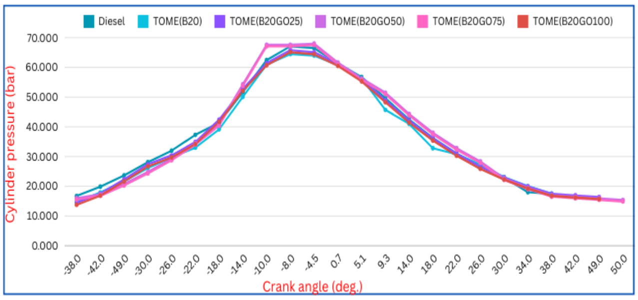

Figure 6. CP vs CA.

4.1.2. Heat helease rate vs CA

The TOME20 blend has a lower HRR than the other fuel mixes because of its lower burning velocity and larger molecular weight. Because of their better-quality surface-to-volume ratio, increased ignition properties, better fuel characteristics, and improved heat transfer, all nano fuel blends have a higher high (HRR). Raising the maximum pressure has the knock-on effect of raising the (HRR). Figure 7 illustrates the difference in (HRR) at the highest loading condition with respect to the crank angle. The TOME (B20) had a decreased (HRR) when compared to diesel. Nevertheless, the inclusion of GO resulted in a noticeable augmentation in the HRR. The higher dosage level of TOME(B20GO75) resulted in a comparable (HRR) to diesel because to improvements in the fuel's coefficient of variation (CV), a quicker ignition delay duration, and a more effective catalytic effect [30]. Variations in the heat release rate (HRR) of different fuel oils are primarily due to differences in their chemical composition, molecular structure, and physical properties, which influence combustion efficiency.

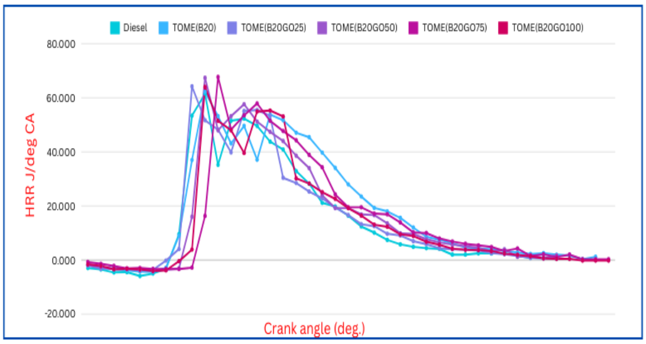

Figure 7. HRR vs CA.

4.2. Performance analysis

4.2.1. BTE vs BP

Figure 8 displays the fuel consumption data for diesel, TOME (B20), TOME(B20GO25), TOME(B20GO50), TOME(B20GO75), and TOME(B20GO100) blends at different BP values, as well as the change of BTE with % load. In comparison to the biodiesel fuel blends discussed earlier, the oxides of nano fuels made of carbon make it easier for the fuel charge to be completely burned. The BTE is increased as a result of graphene oxide's function as an oxygen buffer. As a result, the maximum load condition, the BTE for TOME (B20) decreased by 7.5% compared to diesel (i.e.) for Diesel at full load condition the value is 15.8% but blending of TOME (B20) at while full load condition the value is 11.9%.

As the dosage of GO was increased with all conditions at full load for TOME(B20GO25), TOME(B20GO50), TOME(B20GO75) and TOME(B20GO100) the value is 13.1%, 14.9%, 12.6%, 13.7%. Graphene oxide improves the BTE performance of fuel by lowering the (ID), speeding up the heat conversation process, and encouraging faster, better, and more full combustion of fuel mixes [31].

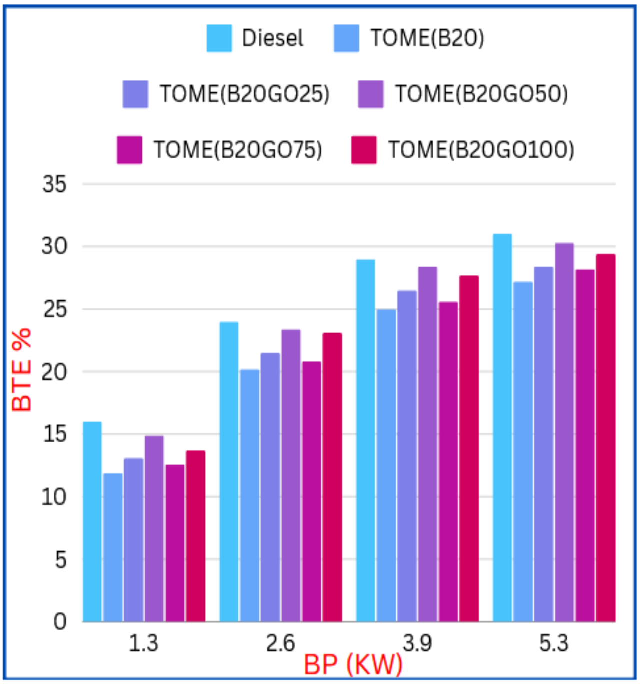

Figure 8. BTE vs BP.

4.2.2. BSFC vs BP

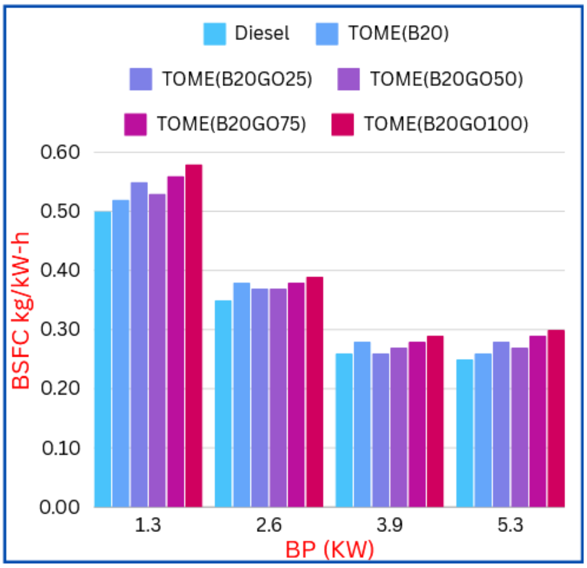

Figure 9. BSFC vs BP.

One of the most important factors in ignition delay is the fuel-to-power ratio, which is affected by the cetane number within the gasoline mixture. The biodiesel blend is greatly affected by cetane, since it is a crucial component of diesel fuel.

Figure 9 shows the BSFC difference with % load and the fuel usage for diesel, TOME (B20), TOME(B20GO25), TOME(B20GO50), TOME(B20GO75), and TOME(B20GO100) blends at different BPs. An increase in the load causes the BSFC to rise. Consequently, under maximum load conditions, the BSFC for TOME (B20) increased by 9.1% when compared to diesel. Specifically, whereas diesel has a value of 0.52 Kg/Kw-h at full load, the BSFC for TOME (B20) blended with diesel is 0.57 Kg/Kw-h. With increasing doses of graphene oxide with all conditions at full load for TOME(B20GO25), TOME(B20GO50), TOME(B20GO75) and TOME(B20GO100) the value is 0.55 Kg/Kw-h, 0.53 Kg/Kw-h, 0.56 Kg/Kw-h and 0.58 Kg/Kw-h respectively. The reason behind this is qualified to the increased density and reduced energy level of TOME mixes in comparison to pure diesel value. Moreover, the elevated viscosity of TOME mixes results in inadequate atomization of fuel dewdrops. This, in turn, contributes to increased fuel consumption throughout the diffusion stage, ultimately diminishing efficiency of combustion.

4.3. Emission analysis

4.3.1. CO vs BP

The main root cause of CO emissions is a absence of oxygen in the combustion chamber, which prevents the fuel from undergoing complete combustion. The extent of this issue is influenced by factors such as temperature and injection timings as per study [18].

The fuel usage for diesel, TOME (B20), TOME(B20GO25), TOME(B20GO50), TOME(B20GO75) and TOME(B20GO100) mixtures at changing BP and the difference of CO emission with full load are shown in Fig. 10.

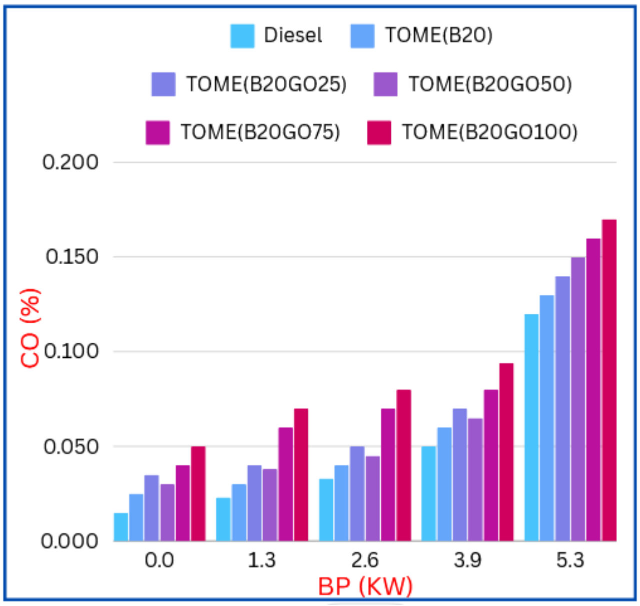

Figure 10. CO vs BP.

By adding GO, an oxygenated additive, to the ignition chamber, additional oxygen atoms are delivered. Graphene oxide nano fuels boost the calorific value of the fuel, which in turn makes it burn faster. Thus, at maximum load conditions, the CO emissions from TOME (B20) were 9.2% higher than those from diesel (i.e., whereas the figure for diesel is 0.12% at full load, the value for TOME (B20) blended with diesel is 0.13%). With increasing doses of graphene oxide with all conditions at full load for TOME(B20GO25), TOME(B20GO50), TOME(B20GO75) and TOME(B20GO100) the value is 0.14%, 0.15%, 0.16% & 0.17% respectively.

4.3.2. HC vs BP

When carbon fragments are combusted inside the combustion zone at the operating temperature of the inner wall of the cylinder, the energy that initiates combustion contained in GO nano fuels in fuel blends increase the amount of hydrocarbon emissions for all nanofuel mixes [18]. The fuel consumption for diesel, TOME (B20), TOME(B20GO25), TOME(B20GO50), TOME(B20GO75) and TOME(B20GO100) blends at changing BP and the difference of HC emission with full load are shown in Fig. 11

Increasing amount quantity of GO included in TOME fuel blends resulted in a significantly reduced amount of hydrocarbon emissions, on the other hand, it increased the HC emission for all other condition. As a result, the maximum load condition, the HC emission for TOME (B20) increased by 8.5% compared to diesel (i.e.) for Diesel at full load condition the value is 36ppm but blending of TOME (B20) at while full load condition the value is 42 ppm. As the dosage of GO was increased with all conditions at full load for TOME(B20GO25), TOME(B20GO50), TOME(B20GO75) and TOME(B20GO100) the value is 44ppm, 46ppm, 49ppm and 53ppm respectively.

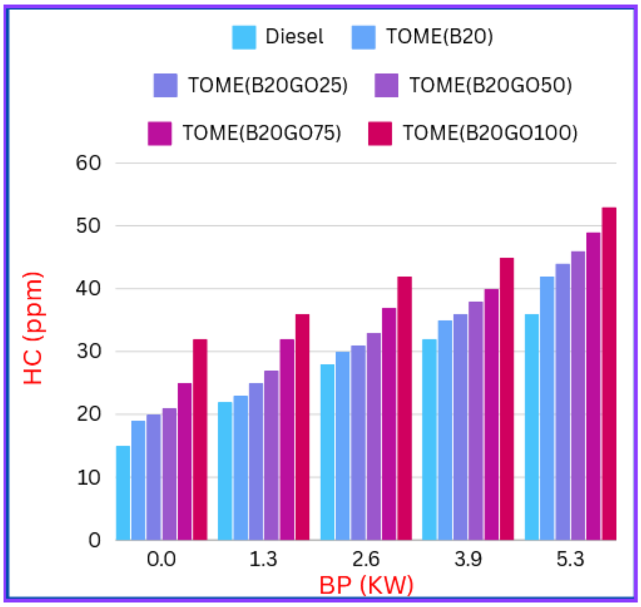

Figure 11. HC vs BP.

4.3.3. NoX vs BP

A lack of oxygen is used to determine the amount of nitrogen oxide that is emitted, according to investigation that was conducted previous to this on the incorporation of nano fuel mixes [18]. They are essentially two ways for reducing down on NoX emissions: lowering the temperature of the DEE additive and the DME additive. The fuel consumption for diesel, TOME (B20), TOME(B20GO25), TOME(B20GO50), TOME(B20GO75) and TOME(B20GO100) blends at changeable BP and the difference of NoX emission with full load are shown in Fig. 12.

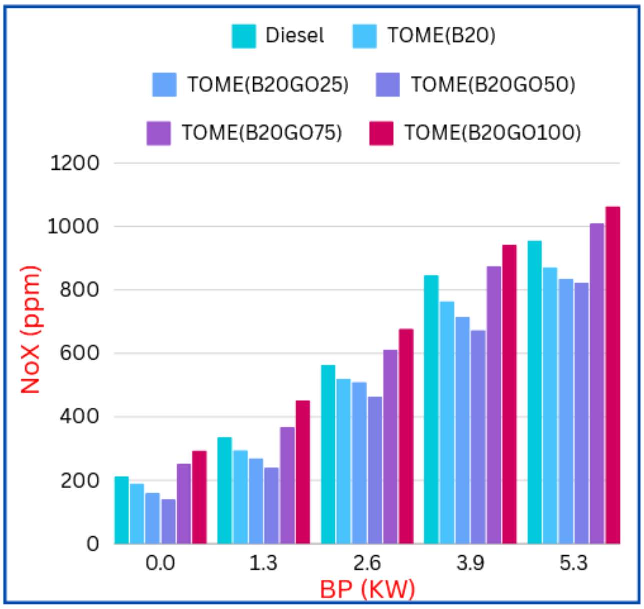

Figure 12. NoX vs BP.

As a result, the maximum load condition, the NoX emission for TOME (B20) decreased by 11.1 % compared to diesel (i.e.) for Diesel at full load state the value is 212 ppm but blending of TOME (B20) at while full load condition the value is 190 ppm. As the dosage of graphene oxide was decreased with all conditions at full load for TOME(B20GO25) and TOME(B20GO50) the value is 160ppm and 140ppm, but simultaneously the NoX emission is increased when the GO as increase at GO75 and GO100 (i.e.) TOME(B20GO75) and TOME(B20GO100) the value is 252ppm, and 294 ppm. Another possibility is that there was a rise in the peak cylinder pressure, which led to a significant increase in the amount of NoX emissions. Because of the occurrence of butanol and a substantial amount of oxygen-donating GO, the nanofuel blend combination of GO75 and GO100 is responsible for the greatest levels of NoX emissions.

4.3.4. Smoke vs BP

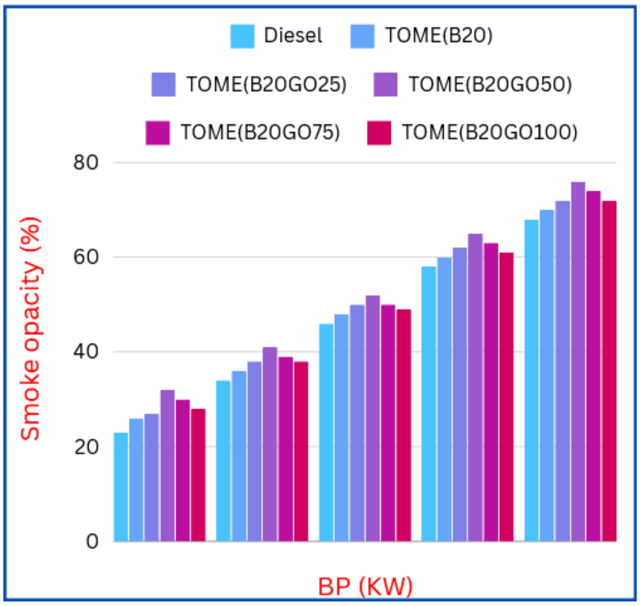

Figure 13. Smoke opacity vs BP.

Smoke usually originates in the fuel-rich region, making it more likely to occur under a complete load [18]. An rise in the oxygen pleased in the TOME blend leads to a decrease in smoke emission. The GO nano fuel function as oxygen-donating ingredients, hence influencing the fuel characteristics. The fuel consumption for diesel, TOME (B20), TOME(B20GO25), TOME(B20GO50), TOME(B20GO75) and TOME(B20GO100) blends at changing BP and the difference of smoke emission with full load are shown in Fig. 13

As a result, the maximum load condition, the smoke emission for TOME (B20) increased by 8.8% compared to diesel (i.e.) for Diesel at full load state the value is 23% but blending of TOME (B20) at while full load condition the value is 26% ppm. As the dosage of GO was increased with all conditions at full load for TOME(B20GO25), TOME(B20GO50) the value is 27% and 32%, but TOME(B20GO75) and TOME(B20GO100) the emission is decreased to 30% and 28% respectively, because the results of which reveal that the fuel is not completely burned under any circumstances of loading. Additionally, the higher viscosity and density of GO75 and Go100 biodiesel nano fuels are responsible for the rise in smoke emission that was seen in use of these nano fuels.

The table 2 compares the performance metrics of diesel, TOME(B20), and TOME(B20GO) blends across various engine parameters including (BTE), (BSFC), (CO) (HC), (NoX) and smoke emissions.

Table 1. Result Comparison.

Blend Ratio	BTE	BSFC	CO	HC	NoX	Smoke
TOME (B20)	↓	↑	↑	↑	↓	↑
TOME (B20GO25)	↑	↑	↑	↑	↓	↑
TOME (B20GO50)	↑	↑	↑	↑	↓	↑
TOME (B20GO75)	↑	↑	↑	↑	↓	↑
TOME (B20GO100)	↓	↑	↑	↑	↑	↓

5. Conclusion

The combination of (GO) nano fuels into TOME biodiesel fuel blends has various effects on engine combustion, performance and emissions were concluded

The addition of graphene oxide (GO) nanoparticles enhances the high-pressure combustion stage, resulting in higher maximum pressure and heat release rate (HRR). Blends of Tomato Oil Methyl Ester (TOME) with 20% biodiesel and varying concentrations of GO (B20GO75 and B20GO100) exhibit comparable HRR to diesel due to improved fuel characteristics and quicker ignition delay duration. While TOME (B20) demonstrates a slight decrease in Brake Thermal Efficiency (BTE) compared to diesel (11.9% vs. 15.8% at full load), the addition of GO improves BTE. Notably, TOME (B20GO50) shows the highest BTE at full load (14.9%), indicating enhanced combustion efficiency. However, the addition of GO increases carbon monoxide (CO) and hydrocarbon (HC) emissions. At full load, TOME (B20) exhibits CO emissions of 0.13%, while TOME (B20GO100) shows 0.17%. HC emissions initially increase for TOME (B20) but decrease with GO addition, with TOME (B20GO100) displaying 53 ppm at full load. NoX emissions decrease with TOME (B20) compared to diesel (190 ppm vs. 212 ppm at full load); however, they increase with higher GO dosages, with TOME (B20GO100) showing 294 ppm at full load. Smoke emissions increase with TOME (B20) compared to diesel (26% vs. 23% at full load); nonetheless, they decrease with higher GO dosages, with TOME (B20GO100) exhibiting 28% at full load.

Overall, the addition of GO nano fuels to TOME biodiesel blends improves combustion efficiency, enhances fuel economy, and reduces emissions. However, careful consideration of GO dosage is necessary to balance emissions reduction with potential increases in NoX emissions.

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Author contributions

P. Kumaran: Conceptualization, experimentation and writing
S. Natarajan: Validation
S.Prakash: Grammar checking
Vasanthraj R & Saranraj P: sample preparation

Conflicts of interest

Conflicts of interest are not acknowledged by the Authors.

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