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Research Article

Assessment of combustion, performance, and emissions in a direct injection compression ignition engine using blends of jatropha, karanja, waste cooking, sunflower, and palm oil methyl esters with diesel

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ABSTRACT

As prospective alternative fuels for diesel engines, the current study examines two edible oils, namely sunflower and palm oil, and three non-edible oils namely jatropha, karanja, and waste cooking oil. The transesterification process was used to produce methyl esters from Karanja oil, Jatropha oil, Sunflower oil, Palm oil, and Waste cooking oil. The physical properties of these methyl esters met the specifications of IS biodiesel standards and were found to be similar to those of conventional diesel. An experimental setup used a single-cylinder, air-cooled, four-stroke direct injection diesel engine with a power output of 4.4 kW to assess the fuels performance, emission and combustion characteristics with varying blends of the methyl esters (20%, 40%, 60%, 80%, and 100%). Peak pressure, ignition delay and heat release rate were assessed in the combustion analysis. The performance metrics assessed included brake thermal efficiency, while the exhaust emissions analyzed were nitrogen oxides, hydrocarbons, smoke, and carbon monoxide. The experimental outcomes were compared to baseline data from diesel fuel. The findings indicated that the low blends of 20% biodiesel of Jatropha oil methyl esters (JTME), Karanja oil methyl esters (KME), Palm oil methyl esters (POME), Sunflower oil methyl esters (SFOME) and Waste cooking oil methyl esters (WCOME) served as the effective alternative fuel for performance and emissions under full load conditions among all fuels tested.

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INTRODUCTION

The growing industrialization and motorization across the globe have significantly increased the demand for petroleum products. Fuels from petroleum come from limited reserves that are predominantly found in specific areas of the world. As a result, countries without these resources are facing an exchange crisis, largely because of their dependence on crude oil imports. Therefore, it is

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crucial to investigate alternative fuels that can be produced from locally available materials. The rapid rise in fuel prices and the depletion of global hydrocarbon resources have compelled us to seek alternatives that can meet the surging energy demand while also safeguarding the environment by reducing harmful pollutants.

The current study focuses on non-edible vegetable oils. Karanja oil, which is native to India, has been for this investigation. Additionally, Jatropha oil is recognized globally as an ideal option for biodiesel production. The Indian government encourages the cultivation of these seeds by making use of plentiful wastelands found throughout the country. Sunflower and palm oils are used as cooking oils in some regions. However, WCO offers substantial benefits in terms of both availability and cost when compared to these oils. The amount of used cooking oil, which is often discarded after use, is considerable and remains largely untapped. This oil has significant potential for biodiesel production, especially in major urban areas of the country. Taking all these factors into consideration, Jatropha oil, Karanja oil, sunflower oil, palm oil, and waste cooking oil have been identified as viable sources for biodiesel production.

Phan et al. [1] carried out an experiment to study the transesterification of waste cooking oil at reaction temperature is up to 60° C. The methanol to WCO molar ratio ranged from 5:1 to 12:1, with KOH catalyst concentrations varying between 0.5 wt% and 1.5 wt% of the waste cooking oil. The results showed that the optimal biodiesel yield, ranging from 88% to 90%, was obtained with methanol to WCO ratio of 7:1 to 8:1, at temperatures between 30°C and 500°C, for a duration of 80 to 90 minutes, using a 0.75 wt% KOH concentration. The physical properties of the biodiesel and its blends were evaluated and found to meet the EN14214 standard. Nurun Nabi et al. [2] examined a single-cylinder, water-cooled, naturally aspirated, direct-injection diesel engine and discovered that diesel-NOME blends led to lower levels of CO and smoke emissions, although NOx emissions increased. The ester from this oil offers an eco-friendly alternative fuel for diesel engines, helping to address the food versus fuel issue. Brake thermal efficiency (BTE) improved steadily with increasing engine speed up to 1000 rpm, after which it began to decline as brake mean effective pressure (BMEP) rose. Carbon monoxide levels remained nearly constant and were 25 ppm lower than those of diesel. As BMEP increased, NOx emissions initially rose, then stabilized temporarily, and eventually exceeded the levels of neat diesel by approximately 5%.

In a four-stroke CI engine, Razzaq et al. [3] examined the performance and emissions properties of biodiesel blends containing dimethyl carbonate additions and graphene oxide nanoplatelets. According to the study, adding these compounds reduced pollutants while also enhancing engine performance. At a blend ratio of 20% biodiesel, 10% dimethyl carbonate, and 0.1% graphene oxide nanoplatelets, the largest reduction in emissions was noted. According to the study, using these compounds may prove to be a viable strategy in the future for lowering emissions and enhancing engine performance.

Alruqi et al. [4] mixed diesel, diethyl ether, and algae biodiesel in varying amounts and tested the mixture on a diesel engine to examine the engine's performance and emission characteristics. The results show that the additions raised the net heat release rate, peak pressures, and BTE. On the other hand, NOx increased as a result. A contemporary supervised machine learning technique called Gaussian process regression was applied to create a model for the engine's performance and exhaust pollutants. After the model and experimental findings were compared, it was discovered that the primary absolute error, which ranged from 0.001 to 2.591, was extremely small.

Sharma [5] investigated the impact of the additive di-tert butyl peroxide (DTBP) on engine performance and emissions. The effects of DTBP-biodiesel blends on engine performance and emissions are predicted and optimized in this study using the multi-objective response surface methodology. The study sheds light on the ideal blend ratio for enhancing engine performance and lowering emissions, and the results demonstrate that DTBP significantly affects combustion and emission parameters.

In trials on diesel engines, Joseph Shobana Bai et al. [6] used wheat germ oil as fuel and added hydrogen in various compositions, such as 5%, 10%, and 15% energy share. Compared to pure wheat germ oil, the addition of 15% energy sharing via hydrogen produced 33% more NOx emissions. But the 15% energy contribution of hydrogen led to a 15% decrease in smoke emissions.

Karpanai Selvan et al. [7] conducted extensive experiments with a diesel engine using various biodiesel blends that included ethanol, cottonseed oil, eucalyptus oil, and micro- and macroalgae oils. The experiments were performed on a single-cylinder diesel engine operating at 1500 RPM, with a compression ratio of 18:1 and a load of 3.75 kW. At 50% load, the emissions of CO2, CO, NOx, and smoke were reduced by 2.3%, 22%, 0.97%, and 6.54%, respectively. The A010D blend, in particular, demonstrated potential as a viable option for use in diesel engines at half load.

Puhan S. et al. [8] conducted a study on a high linolenic linseed oil methyl ester in a diesel engine operating at a constant speed with three different fuel injection pressures (200 bar, 220 bar, and 240 bar). The primary objective of the research was to investigate how varying injection pressures affect engine performance, emissions, and combustion characteristics. At 240 bar, thermal efficiency was found to be comparable to diesel, with reduced CO, HC, and smoke emissions, but an increase in nitrogen oxides compared to diesel.

In a study by S. Mahla et al. [9] the performance and exhaust emissions of a dual fuel engine using various blends of diethyl ether, biogas, and diesel were evaluated as a new fuel alternative. The research explored different proportions of diethyl ether (10%, 15%, and 20%) and biogas flow rates

(10, 20, and 30 LPM) combined with conventional diesel fuel at varying engine loads (20%, 60%, and 100%). The study predicted a brake thermal efficiency of 22%, hydrocarbon (HC) emissions at 56 ppm, carbon monoxide (CO) emissions at 0.09%, nitrogen oxides (NOx) emissions at 102 ppm, and smoke at 24%. The high desirability value of 0.74 from the derived models demonstrated that the response surface methodology could effectively optimize and model the performance of a three-fuel diesel engine. Suresh Vellaiyan [10] investigated the combustion and emission characteristics of a diesel engine operating on soybean biodiesel. The study explored the effects of incorporating carbon nanotube (CNT) nanoparticles and water emulsion into the fuel. The results showed that these additives improved engine performance, reduced emissions, and enhanced combustion efficiency. Additionally, the research found that diesel-soybean biodiesel blends with zinc oxide nanoparticles coated with cerium resulted in lower engine performance and emissions. The study suggests that using water emulsion and nanoparticle additives in biodiesel engines could be an effective strategy to increase efficiency and reduce emissions.

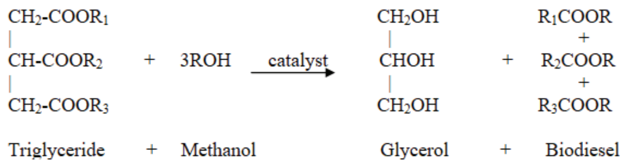
Nalgundwar et al. [11] investigated the performance and emission tests on a single-cylinder engine using a dual biodiesel blend a mixer of two distinct types of biodiesel, namely palm and jatropha. The results for a lesser blend of biodiesel revealed a little loss in BSFC, while a larger blend of biodiesel indicated an average gain in brake thermal efficiency (BTE) of up to 15% and a decrease in exhaust gas temperatures. The CO reduction ranged from 7.1% to 14.5% depending on the blend of biodiesel used. On the other hand, NOx emissions rose by 9.2% with higher biodiesel ratios.

Saini Mahesh Chand et al. [12] investigated on impact of biodiesel blends on performance, emissions and waste heat recovery of diesel engine driven cogeneration system. Diesel fuel has the highest brake thermal efficiency and the lowest brake specific fuel consumption (BSFC). B20 has the highest brake thermal efficiency and the lowest BSFC among all blends of biodiesel. Also, B20 has better emission characteristics than all other blends of biodiesel. The exhaust gas temperature and waste heat recovery increase with the percentage of biodiesel in the blends.

M. P. Joshi et al.[13] investigated on Combustion Analysis of CI Engine Fuelled with Algae Biofuel Blends. The brake thermal efficiency showed decreasing trend (upto 5%) whereas specific fuel consumption (upto 7%) and exhaust gas temperature (upto 3%) showed increasing trend for algae biofuel blends compared to diesel. Reduction in hydrocarbon (upto 28%) and carbon monoxide (upto 22%) emission was noted for algae biofuel blends along with a marginal increase in NOx (upto 13%) emissions.

Transesterification

Methanol, NaOH, and raw oil are needed for the transesterification of vegetable oil to produce methyl esters. For every 1000 ml of raw oil, dissolve 100 ml of methanol and 3.75 grams of sodium hydroxide. Transesterification, on the other hand, is an equilibrium reaction that needs sufficient alcohol to propel it extremely nearly to completion. Methyl esters were produced via a chemical reaction between vegetable oil and alcohol in the presence of a catalyst. A byproduct of the transesterification reaction was glycerol.

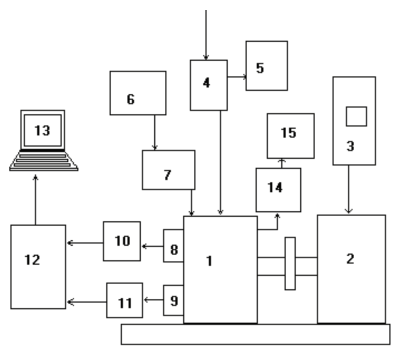


Where R1, R2, & R3 are long chain hydrocarbons. After continuously stirring the mixture, it was let to settle in a separating funnel due to gravity. After a whole day of gravity settling, two separate strata emerge. Glycerol formed the lower layer, while the ester formed the upper layer. The lowest layer was carefully separated.

In order to eliminate the catalyst contained in the separated ester, it was combined with warm water and let to settle under gravity for a further 24 hours. Water was used to dissolve the catalyst, separate it, and extract the moisture. Then, different concentrations of mineral diesel (20%, 40%, 60%, 80%, and 100%) were combined with methyl ester to create biodiesel blends that could be utilized in CI engines to perform different engine tests.

Test Procedure

The engine was fueled with biodiesel, conventional petroleum diesel, and blends containing 20%, 40%, 60%, and 80% biodiesel. When switching fuels each time, the fuel lines were cleaned, and the engine was allowed to stabilize in order to ascertain optimal temperature for at least thirty



1. Diesel engine
2. Swinging field electrical dynamometer
3. Dynamometer controls
4. Air box
5. U-tube manometer
6. Fuel tank
7. Fuel measurement flask
8. Pressure pick up
9. TDC position sensor
10. Charge amplifier
11. TDC amplifier circuit
12. A/D card
13. Personal computer
14. Exhaust gas analyzer
15. AVL smoke meter

Figure1a. Layout of Engine Test Rig.

Figure 1b. Experimental setup.

minutes under the new conditions. The experiments were conducted at various load levels (0%, 25%, 50%, 75%, and 100% of the rated load of 4.4 kW).

RESULTS AND DISCUSSION

Cylinder Pressure Variation

For diesel and blends of 20B, 40B, 60B, 80B, and 100% of KME, JTME, SFOME, POME, and WCOME are shown in figures 2 to 6. The pressure variation follows same trend with all the methyl esters of 20B under all the loads at different crank angles.

Three separate zones exists:

Zone I: Compared to diesel, the cylinder pressure for biodiesel and its blends is higher from the beginning of combustion until 40 bTDC. In this area, the blend's methyl ester proportion rises in tandem with the cylinder pressure.

Zone II (40 bTDC to 100 aTDC): For all methyl ester mixes, the cylinder pressure is reduced in this zone when compared to diesel. This is mostly because methyl esters and their mixes have lower heat releases because of their lower calorific values. Because methyl ester-operated engines' exhaust gas has a higher specific heat capacity than diesel, it absorbs more heat energy, which lowers the gas's high temperature and pressure in the cylinder.

Region III (10 aTDC): Because of the delayed combustion, the biodiesel and its blends have a somewhat lower pressure in the cylinder.

Additionally, a minor shift away from TDC is noted in the crank angle where maximum pressure is reached. For instance, the peak pressure for diesel (74.629 bar), 20B KME (70.215 bar), 40B KME (70.847 bar), 60B KME (70.861 bar), 80B KME (70.991 bar), and KME 70CA aTDC (69.554 bar) all occur at 80CA aTDC at rated power (4.4 kW). Figure 45 displays the following: 20B KME (70.215 bar), 20B WCOME (67.743 bar), 20B JTME (69.166 bar), 20B POME (69.683 bar), and 70CA aTDC 20B SFOME (69.638 bar). This data relates to diesel.

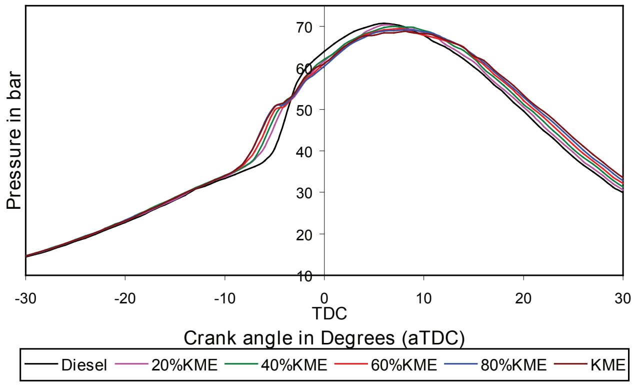


Figure 2. Diagram of pressure and crank angle for KME and its blends.

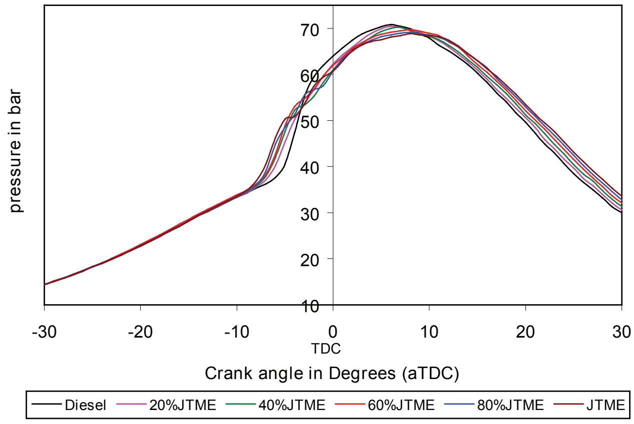


Figure 3. Diagram of pressure and crank angle for JTME and its blends.

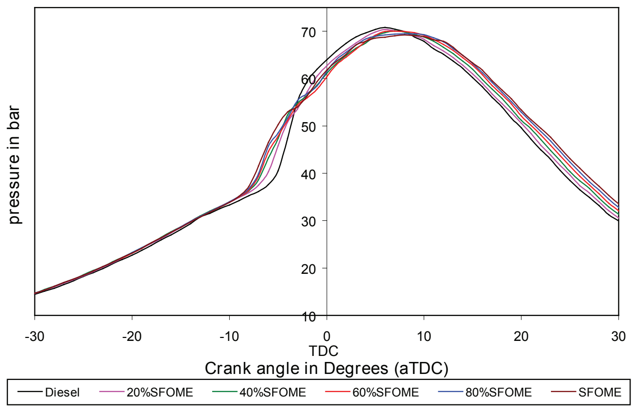


Figure 4. Diagram of pressure and crank angle for SFOME and its blends.

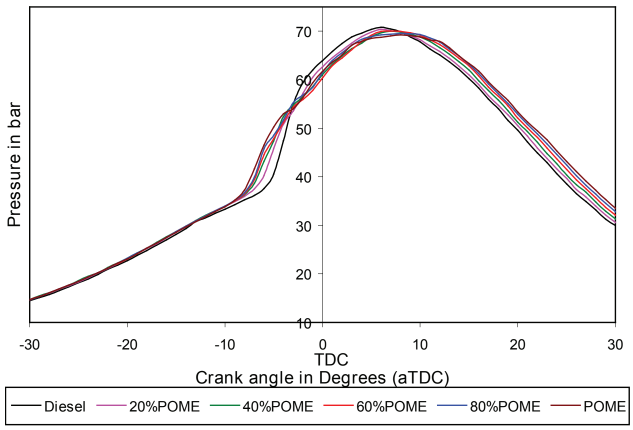


Figure 5. Diagram of pressure and crank angle for POME and its blends.

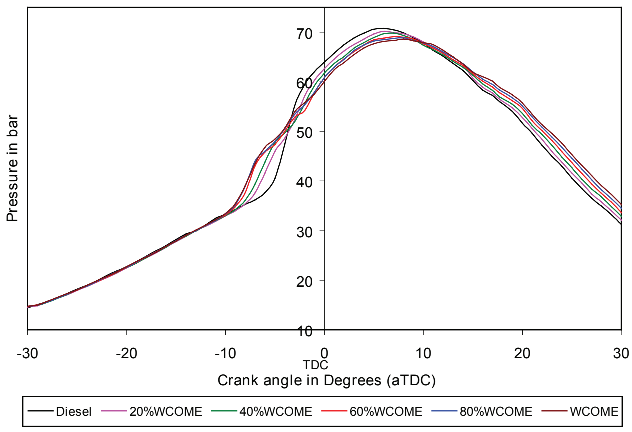


Figure 6. Diagram of pressure and crank angle for WCOME and its blends.

Heat Release Rate (Q)

Figures 7-11 illustrate the variations in heat release rates for methyl esters and their blends in comparison to diesel at rated power. The heat release rate curves of methyl esters, diesel, and their mixtures exhibit comparable trends, as may be observed. Diesel has a higher peak heat release rate than methyl esters and their mixes. According to Figure 8, the ignition delays at rated power for diesel and JTME at 20%, 40%, 60%, 80%, and 100% are, respectively, 14.650, 14.420, 14.20, 13.80, 13.60, and 150 respectively. It is observed that for blends of JTME, the delay period at rated power decreases as their fraction in the mix increases.

Consequently, when the proportion of methyl ester in the blend rises relative to diesel, the peak heat release rate falls and happens sooner for methyl esters and their mixes.

The viscous nature of the larger fatty acid components in methyl esters delays the combustion. This leads to all methyl esters and their blends exhibiting higher heat release rates compared to diesel during the latter part of the combustion process.

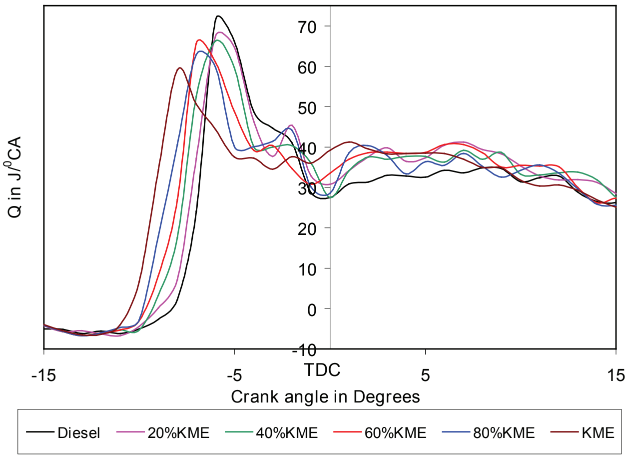


Figure 7. Rate of heat release comparison for diesel and KME mixes at rated load.

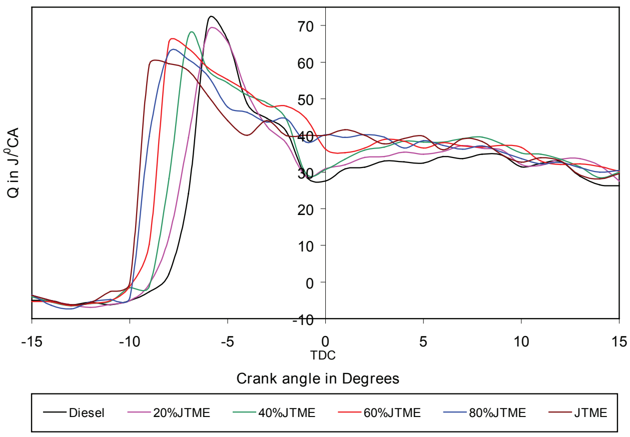


Figure 8. Comparison of heat release rates for diesel and JTME blends at rated load.

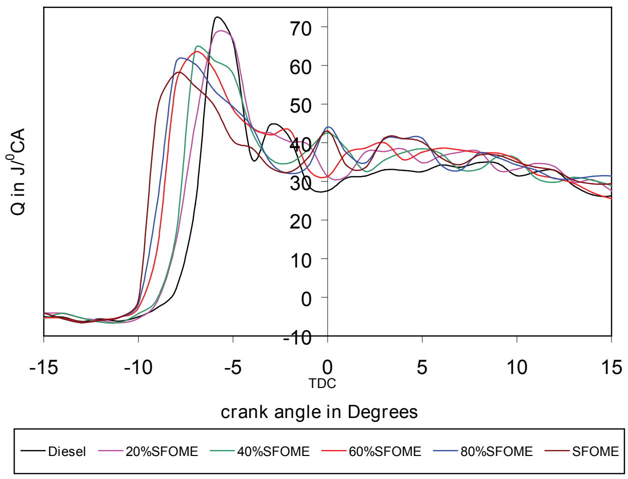


Figure 9. Rate of heat release comparison for diesel and SFOME mixes at rated load.

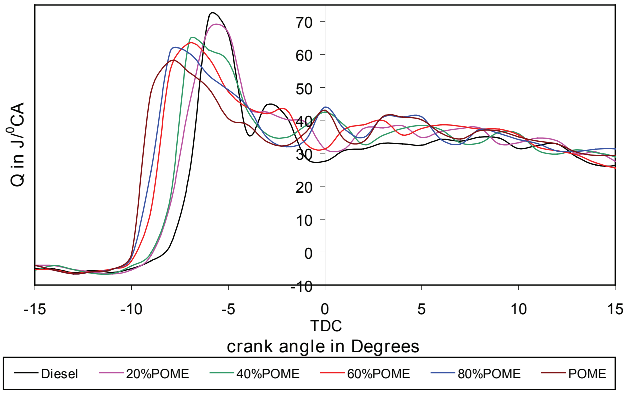


Figure 10. Comparison of heat release rates for diesel and POME blends at rated load.

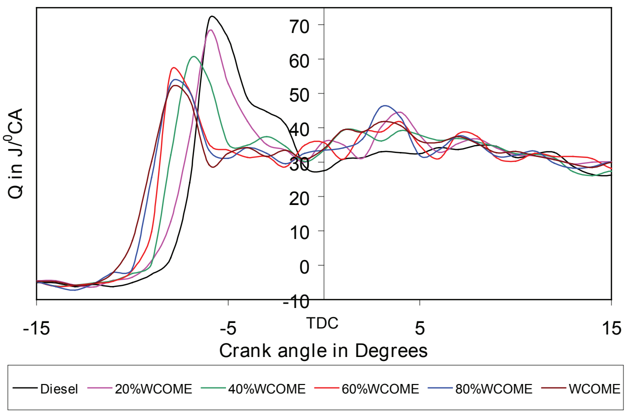


Figure 11. Comparison of heat release rates for diesel and WCOME blends at rated load.

Ignition Delay (ID)

The ignition delay of a fuel plays a pivotal role in determining the knocking behavior of diesel engines. This delay is influenced by multiple factors such as the engine's compression ratio, inlet pressure, injection parameters, and the inherent properties of the fuel itself. Cetane number (CN) signifies the quality of the fuel, as the CN of a fuel increases, the ignition delay tends to decrease, and the opposite holds true. Figures 12-16 illustrate a comparison between the ignition delays of different methyl ester blends under varying load conditions and that of standard diesel.

It is clear that pure esters exhibit the shortest ignition delay compared to their blends and diesel. Additionally, methyl esters and their blends have a significantly shorter ignition delay than diesel, with the delay decreasing as the proportion of methyl ester in the blend increases. For instance, at full load (4.4 kW), the delay decreases by 1.9%, 3.5%, and 5.1%. In comparison to diesel, the percentages for 20%, 40%, 60%, 80%, and JTME, respectively, are 7.5% and 9.2%.

Esters undergo chemical reactions and polymerization during injection because the air temperature in the cylinder is rather high at that moment. This causes the injection characteristics to differ from those of diesel. Esters have higher viscosities, but when their higher fatty acids split, lighter molecules, or volatile matter, are created.Larger dispersion and a shorter ignition delay are thus produced by these lighter combinations. Reduced fuel buildup before ignition leads to a reduced rate of heat release when the ignition delay is lowered.

This shows that because methyl esters ignite more quickly than diesel oil, they have greater cetane numbers in their mixes. Additionally, it is noted that when brake power increases, ignition delay for all test fuels reduces. This is because with greater braking powers, there is less dilution of exhaust gas and a higher temperature on the combustion chamber wall.

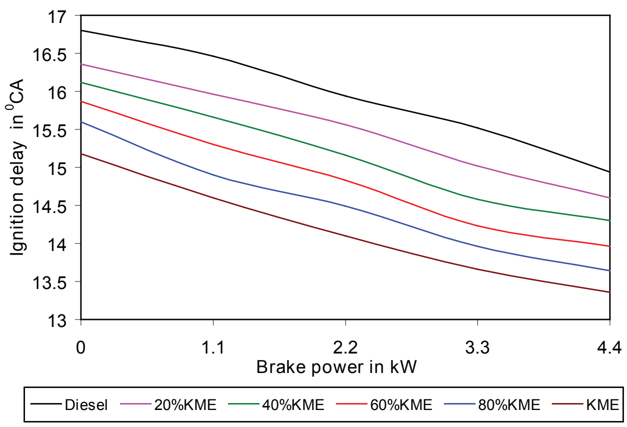


Figure 12. Analysis of KME/diesel blends ignition delays.

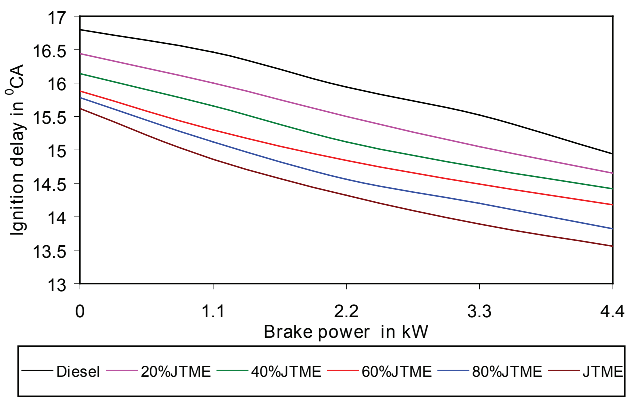


Figure 13. Analysis of JTME/diesel blends ignition delays.

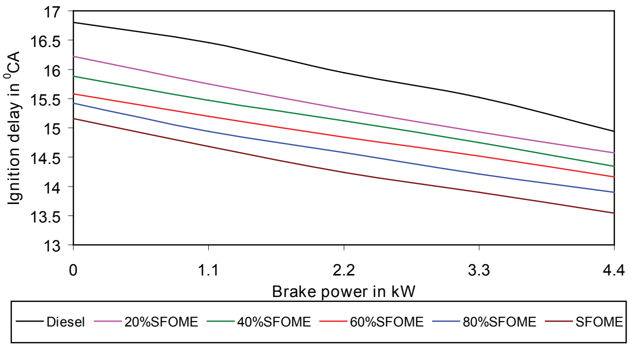


Figure 14. Analysis of SFOME/diesel blends ignition delays.

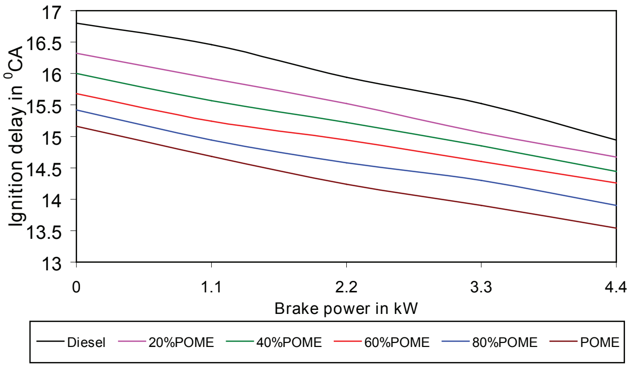


Figure 15. Analysis of POME/diesel blends ignition delays.

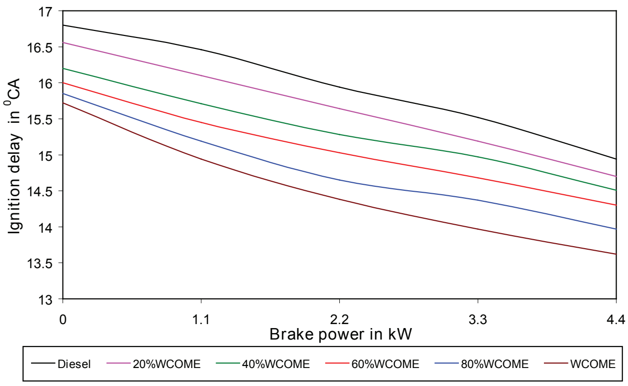


Figure 16. Analysis of WCOME/diesel blends ignition delays.

Brake Thermal Efficiency (BTE)

Figures 17 to 22 display the changes in brake thermal efficiency for the different test fuels. For every test fuel, the brake thermal efficiency rises as the braking power does. Methyl esters and their mixtures have a somewhat worse brake thermal efficiency than diesel at all loads. For instance, the brake thermal efficiencies for diesel, 20% JTME, 40% JTME, 60% JTME, 80% JTME, and pure JTME at rated power (4.4 kW) are 33.36%, 32.8% (a decrease of 0.56%), 31.6% (a decrease of 2%), 31.22% (a decrease of 2.14%), 30.87% (a decrease of 2.49%), and 29.37% (a decrease of 3.99%), respectively. The reduction in braking thermal efficiency of JTME blends in comparison to diesel is indicated in brackets. When compared to diesel, the highest drop for different JTME blends at rated power is only 3.99%.

Because methyl esters and their mixes have a shorter ignition delay when the engine is run continuously with injection advance, combustion starts well before TDC. As a result, the engine's brake thermal efficiency is decreased and compression work is increased. When the majority of the heat is discharged near TDC, the efficiency is at its highest. For methyl esters and their mixes, the onset of heat release happens well in advance of TDC. Lowerthermal efficiency follows from a greater departure from the ideal cycle. The same pattern is seen in blends of different methyl esters.Figure.22 compares the braking thermal efficiency of Jatropha methylester (JTME) tothat of methyl esters of karanja, sunflower, palm, and waste cooking.

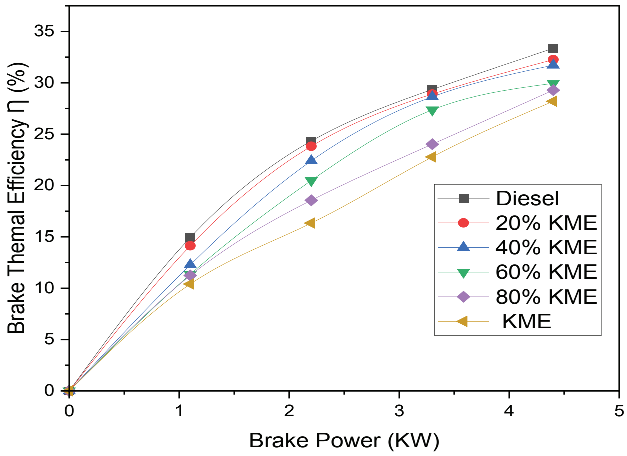


Figure 17. Brake thermal efficiency comparison for blends of KME and diesel.

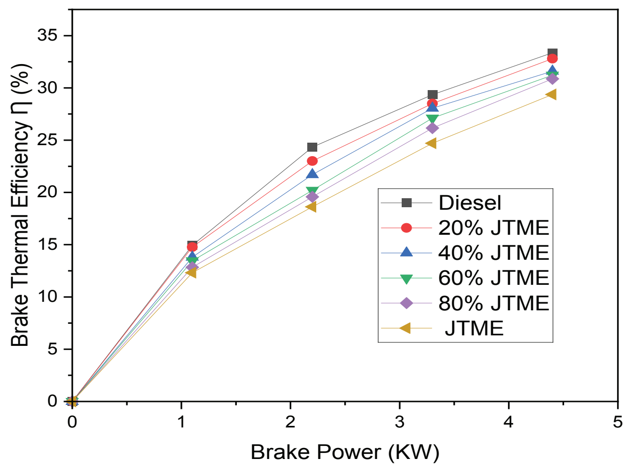


Figure 18. Brake thermal efficiency comparison for blends of JTME and diesel.

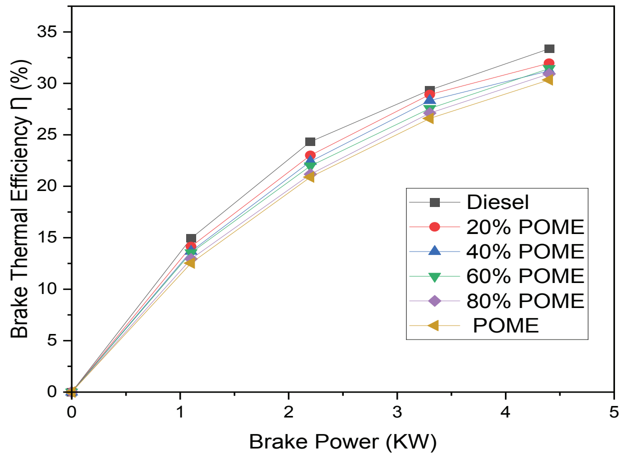


Figure 19. Brake thermal efficiency comparison for blends of POME and diesel.

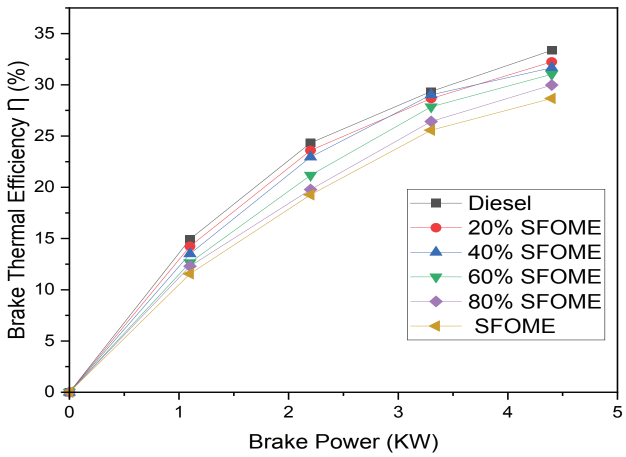


Figure 20. Brake thermal efficiency comparison for blends of SFOME and diesel.

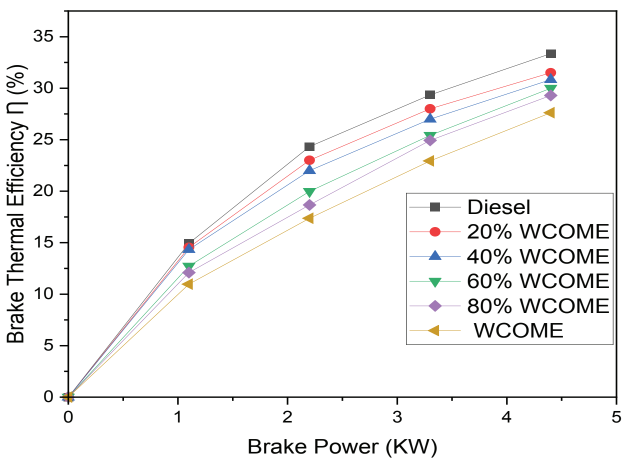


Figure 21. Brake thermal efficiency comparison for blends of WCOME and diesel.

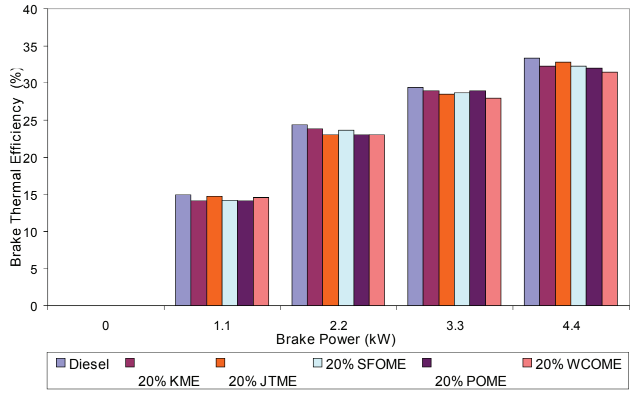


Figure 22. Brake Power Vs Brake Thermal Efficiency for B20 blends of all methyl esters/diesel

Carbon Monoxide (CO) Emissions

Figures 23 to 27 illustrate the variation in CO emissions for different esters and their mixes at varying braking power. Diesel engines typically have minimal CO emissions since they run on lean mixes. It has been noted that at all brake powers, diesel emits more CO than any esters or their mixtures. Esters contain oxygen and hence their blends have higher oxygen availability for CO oxidation than diesel because of the ester's inherent oxygen content, which lowers CO emissions. According to figure 28, the percentage of CO in the exhaust gas is 0.24%, 0.23%, 0.21%, 0.19%, and 0.16% for 20% KME, 40% KME, 60% KME, 80% KME, and Karanja methyl esters (KME) at rated power (4.4 kW), respectively. Consequently, CO emissions, which are already minimal in diesel engines, are further decreased with the use of methyl ester and its blends. As the proportion of methyl ester in the fuel increases, the percentage of CO emissions consistently declines. This pattern is also observed with blends of other methyl esters.

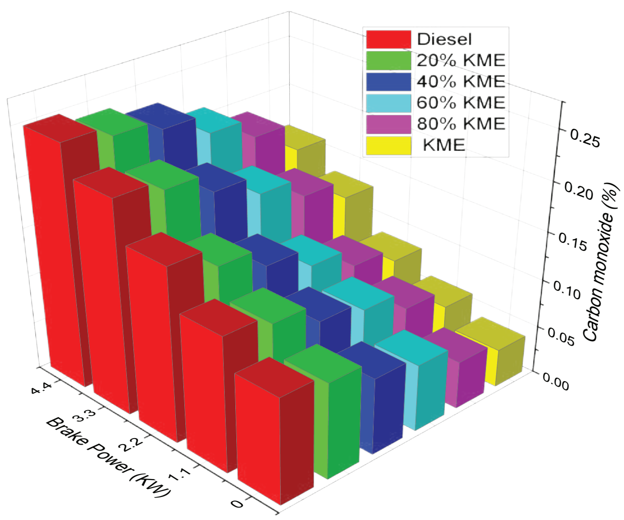


Figure 23. CO comparison for diesel and KME blends.

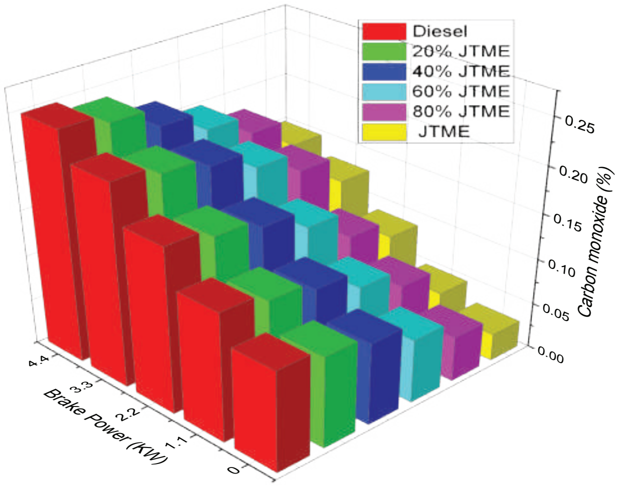


Figure 24. CO comparison for diesel and JTME blends.

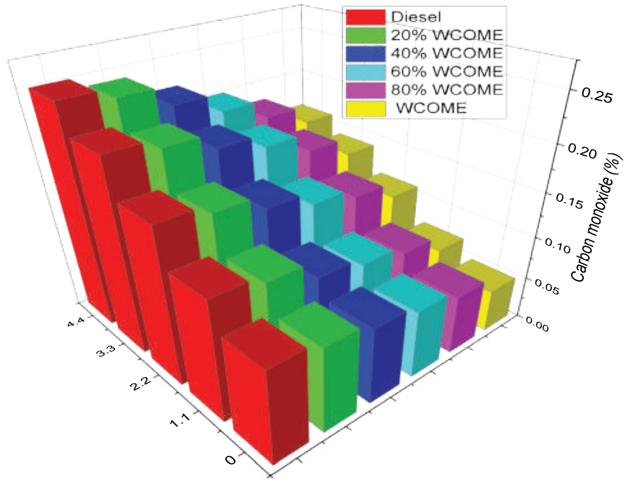


Figure 27. CO comparison for diesel and WCOME blends.

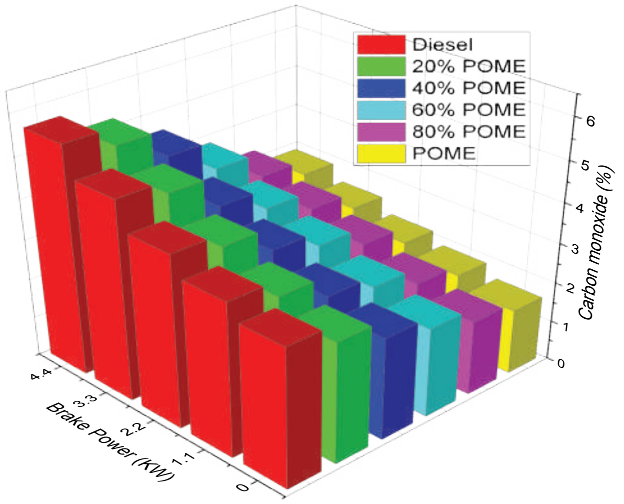


Figure 25. CO comparison for diesel and POME blends.

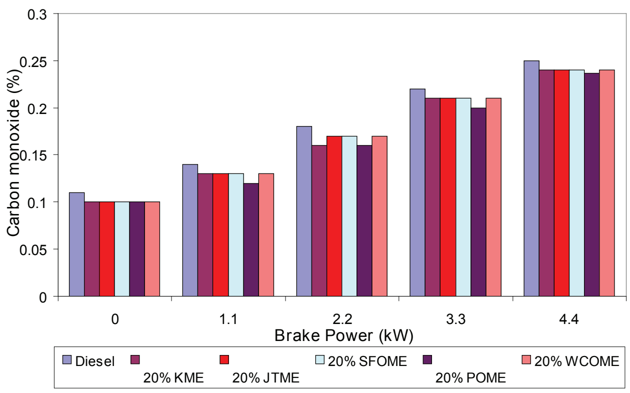


Figure 28. Brake Power Vs Carbon monoxide for B20 blends of all methyl esters/diesel.

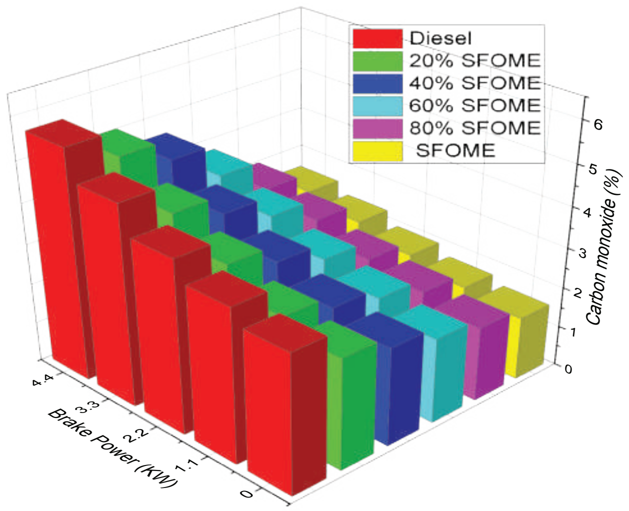


Figure 26. CO comparison for diesel and SFOME blends.

Hydrocarbon (HC) Emissions

Figures 29 to 33 depict the variation in HC emissions with brake power for different methyl ester blends. It is clear that as the load increases, HC emissions rise for all the tested fuels, likely due to a richer fuel mixture at higher brake power. Compared to diesel, methyl esters and their blends produce significantly lower HC emissions across all load conditions. Adding methyl ester to diesel increases the oxygen content thereby enhanced combustion, resulting in reduced HC emissions. As the methyl ester content in the fuel increases, HC emissions decrease substantially.

Figure 34 shows that at rated power (4.4 kW), HC emissions are 45 ppm, 41 ppm, 37 ppm, 34 ppm, and 31 ppm for 20% KME, 40% KME, 60% KME, 80% KME, and pure Karanja methyl ester (KME), respectively, compared to 48 ppm for diesel. A similar trend is observed for blends of other methyl esters.

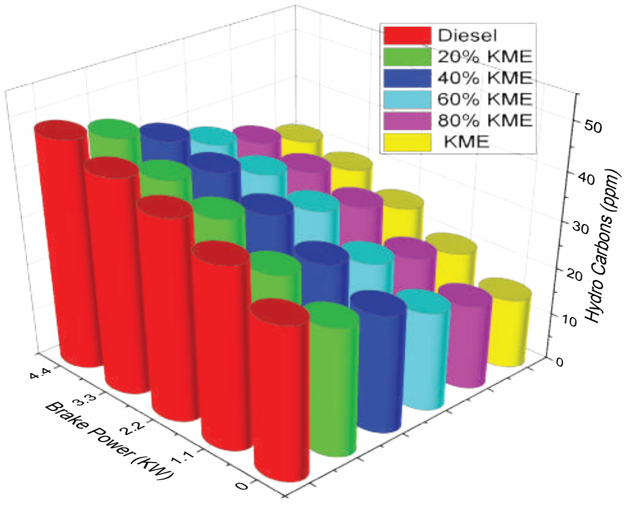


Figure 29. Comparing HC for blends of KME and diesel.

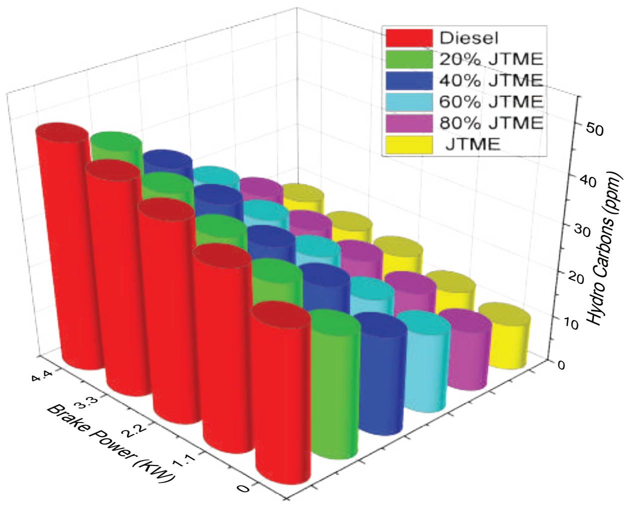


Figure 30. Comparing HC for blends of JTME and diesel.

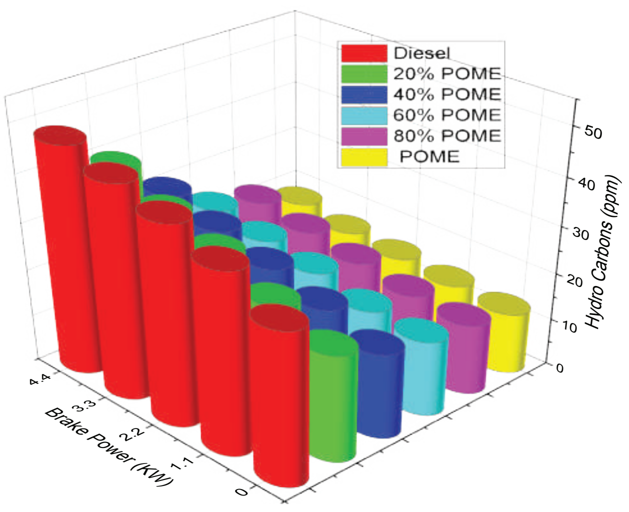


Figure 31. Comparing HC for blends of POME and diesel.

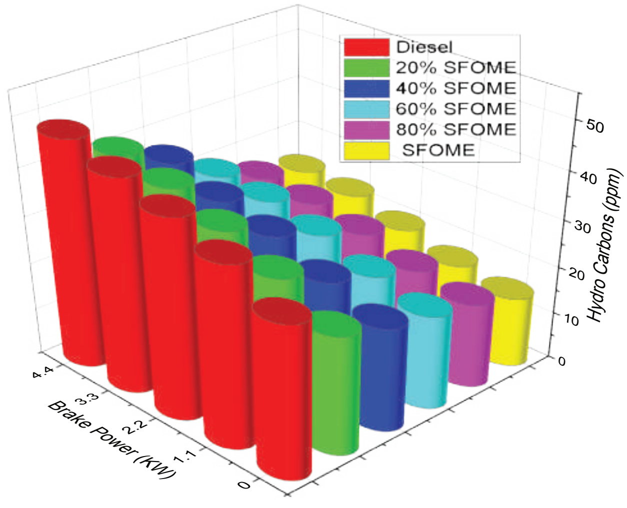


Figure 32. Comparing HC for blends of SFOME and diesel.

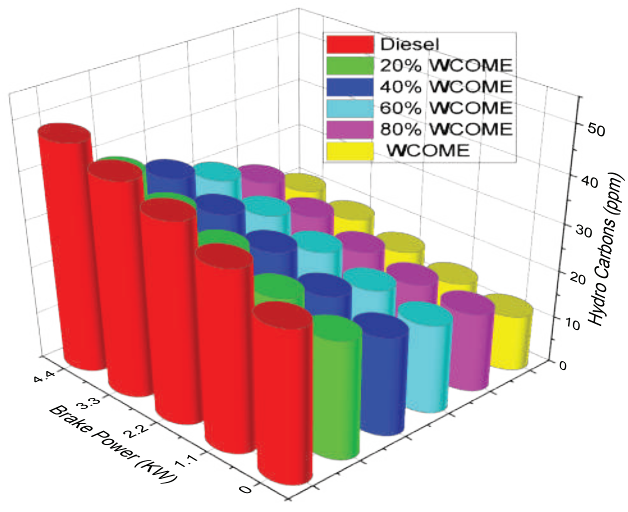


Figure 33. Comparing HC for blends of WCOME and diesel.

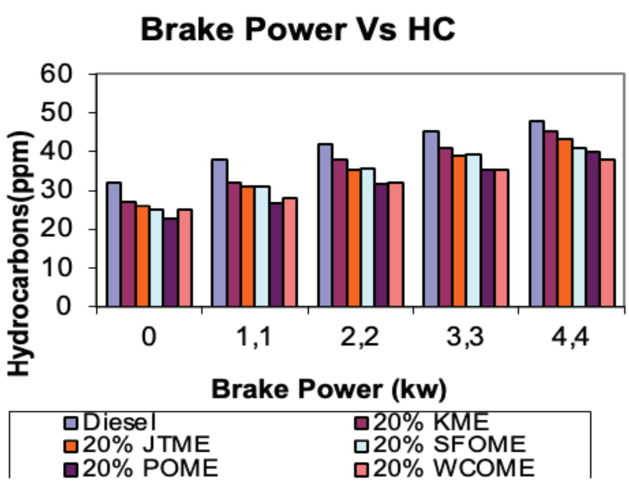


Figure 34. Brake Power Vs HC for B20 Blends of all methyl esters/diesel.

Nitrogen Oxide (NOx) Emissions

Figures 35 to 39 compare the variations in NOx emissions with brake power for different methyl esters and their blends in relation to diesel. For every test fuel, it has been found that NOx emissions rise as power increases. This is because when there is a load, the amount of fuel consumed increases, raising the temperature of combustion. Nitrogen oxide (NO_X) emissions are seen to increase with a rise in the fuel's methyl ester content at any given brake power. Compared to diesel, methyl esters have more oxygen available for the production of NOx. As a result, when the blend's methyl esters proportion rises, so do the NO_X emissions. Figure.35 shows that at rated power (4.4 kW), NOx emissions are 20%, 40%, 60%, 80%, and Karanja methyl esters (KME) at 534 ppm, 570 ppm, 595 ppm, 620 ppm, and 665 ppm, respectively, whilst diesel emissions are 510 ppm.

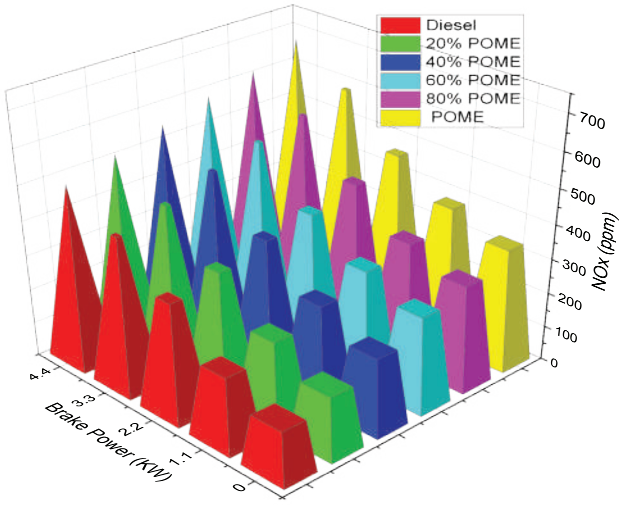


Figure 37. Nitrogen oxide comparison for POME/diesel blends.

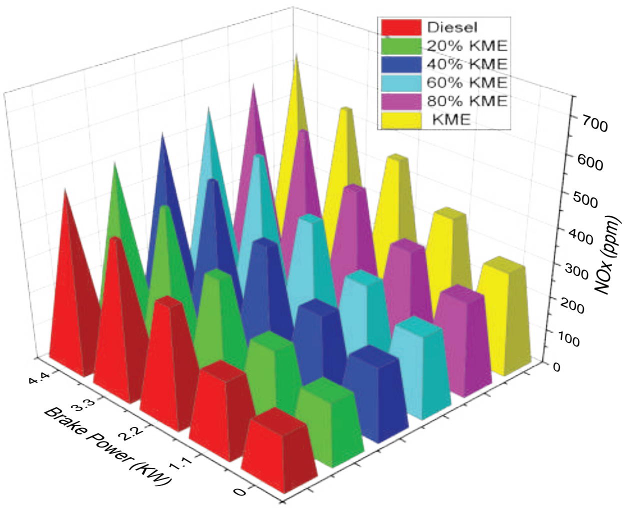


Figure 35. Nitrogen oxide comparison for KME/diesel blends.

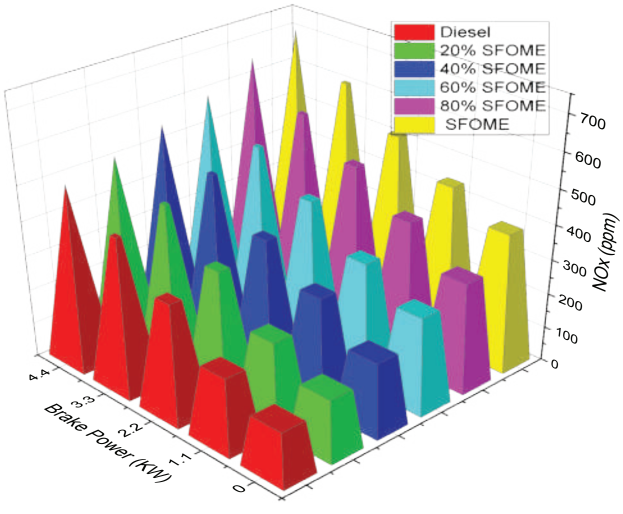


Figure 38. Nitrogen oxide comparison for SFOME/diesel blends.

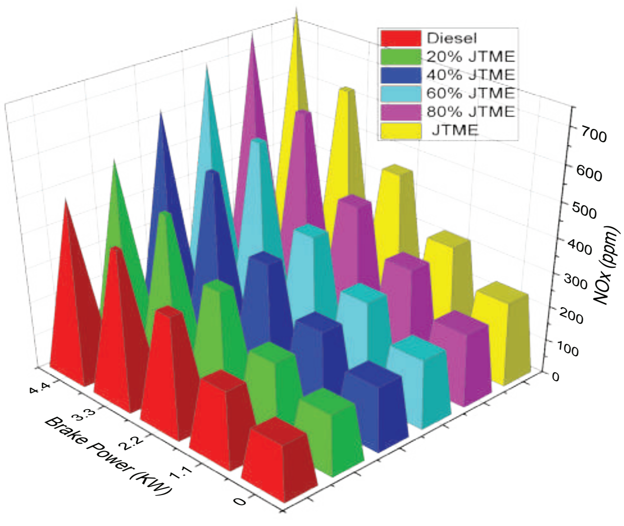


Figure 36. Nitrogen oxide comparison for JTME/diesel blends.

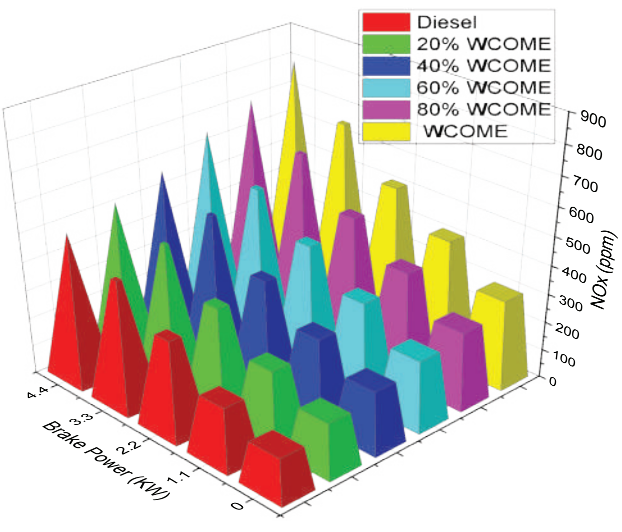


Figure 39. Nitrogen oxide comparison for WCOME/diesel blends.

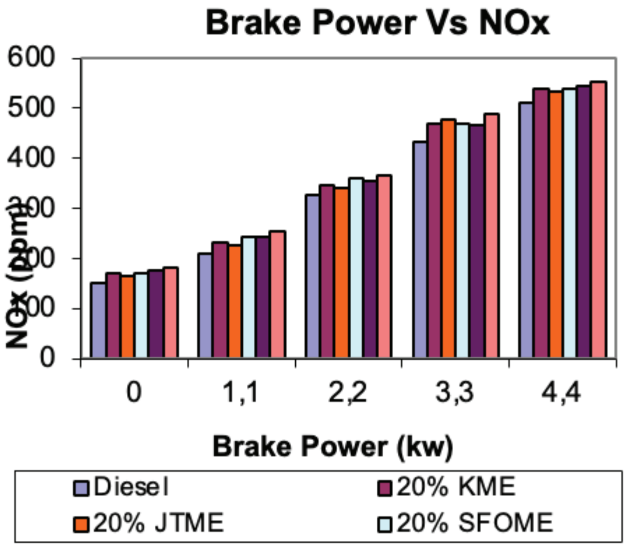


Figure 40. Brake Power Vs nitrogen oxides for B20 Blends of all methyl esters/diesel.

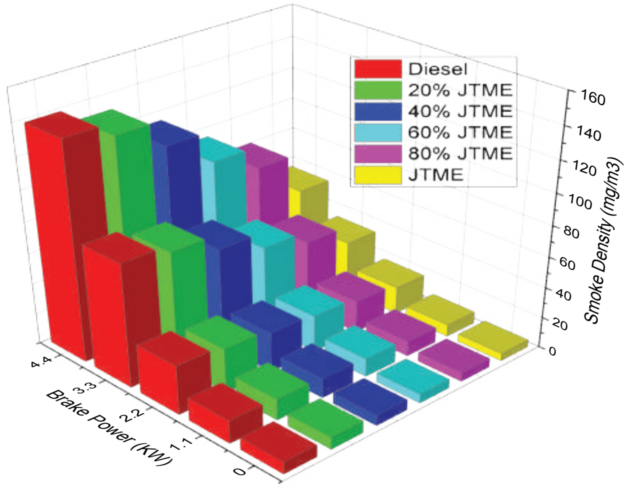


Figure 42. Comparison of the smoke density for blends of JTME and diesel.

Smoke Density

Figures 41 to 45 illustrate how the smoke density varies for different methyl ester blends at varying brake powers. These figures indicate that as the proportion of methyl ester in the fuel blend increases, smoke density decreases. At rated load, smoke density for 20% KME, 40% KME, 60% KME, 80% KME, and pure KME is 126, 112, 96, 82, and 68 mg/m^3, respectively, as shown in Figure 41. Methyl esters increased oxygen content and reduced aromatic and short-chain paraffin hydrocarbon content are responsible for their particulate-reducing properties. For other methyl esters, a similar pattern is seen.

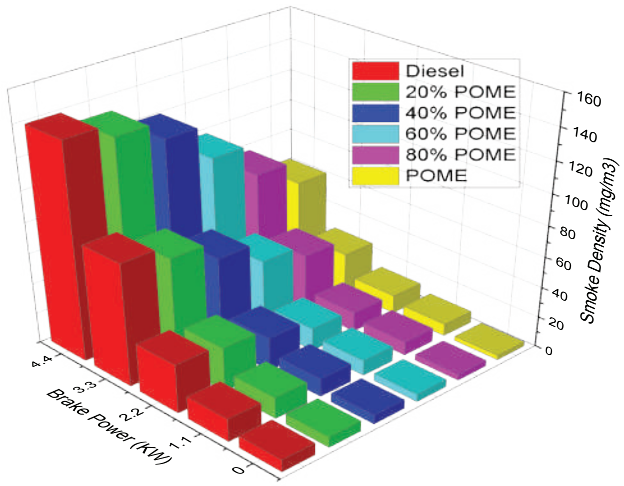


Figure 43. Comparison of the smoke density for blends of POME and diesel.

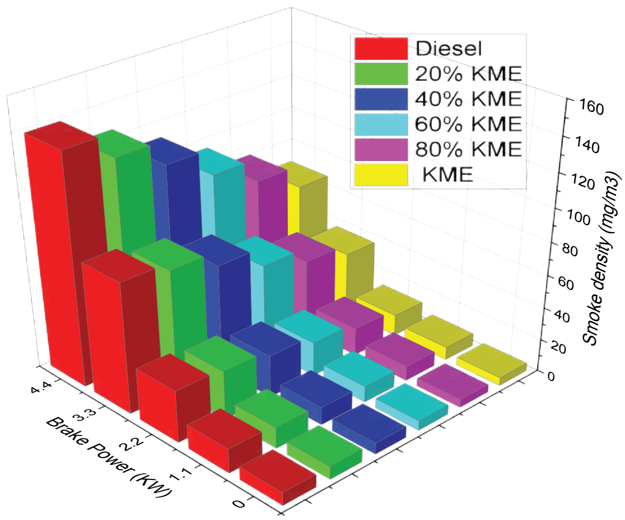


Figure 41. Comparison of the smoke density for blends of KME and diesel.

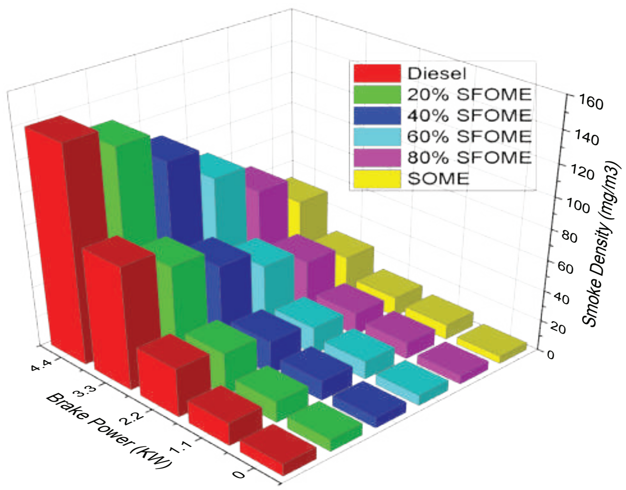


Figure 44. Comparison of the smoke density for blends of SFOME and diesel.

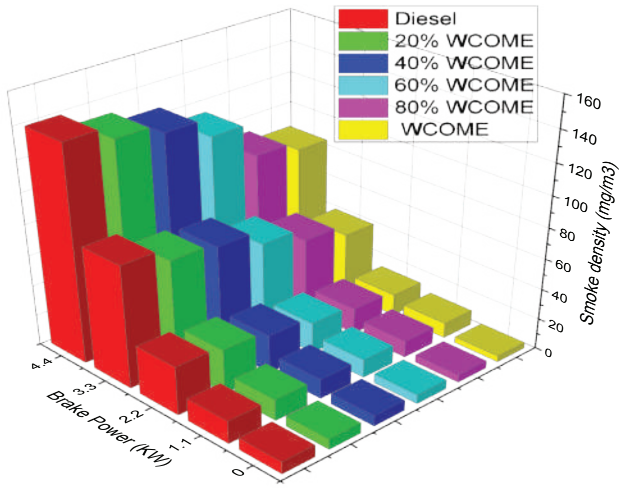


Figure 45. Comparison of the smoke density for blends of WCOME and diesel.

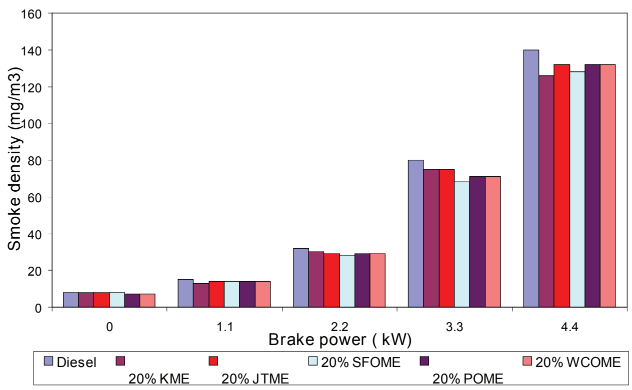


Figure 46. Brake Power Vs Smoke density for B20 Blends of all methyl esters/diesel.

CONCLUSION

In conclusion, the current study describes how to prepare methyl esters from particular vegetable oils and forecasts how well they will burn, operate, and emit when used in C.I. engines.

This study explores the preparation of methyl esters from various vegetable oils and evaluates their performance, combustion characteristics, and emissions when used in compression ignition (C.I) engines.

- Methyl esters from karanja, jatropha, sunflower, palm, and waste cooking oil can be used directly in diesel engines without needing any modifications to the engine.
- Blends B20 and B40 outperform B100 but remain below diesel in terms of brake thermal efficiency. When compared to diesel (33.36%), and various mixes of methyl esters of karanja (32.26%), sunflower (32.24%), palm (31.96%), and waste cooking oil (31.5%), 20% blend of jatropha methyl ester (JTME) showed higher brake thermal efficiency, reaching 32.8%, at maximum braking power.
- Diesel was found to have higher emissions of smoke, HC, and CO at varying loads than other fuels.
- When comparing 20% WCOME (38 ppm) to the other B20 methyl esters, KME (45 ppm), JTME (43 ppm), SFOME (41 ppm), POME (40 ppm), and diesel (48 ppm), the HC emission is lower.
- Based on NOx emissions at varying loads, diesel was shown to have lower emissions (510 ppm) for all mixes of diesel and methyl esters.However, as compared to all other 20% methyl esters, KME (538 ppm), SFOME (540 ppm), POME (544 ppm), and WCOME (552 ppm), NOx emission is quite high and about identical to diesel for 20% JTME (534 ppm).
- When compared to all other B20 methyl esters, including diesel (140 mg/m^3), JTME (132 mg/m^3), SFOME (128 mg/m^3), POME (132 mg/m^3), and WCOME (134 mg/m^3), the smoke density for 20% KME (126 mg/m^3) is lower.
- As the ignition delay interval lengthens, the percentage of methyl ester in the fuel decreases. The peak pressure values for methyl ester and its blends are slightly lower compared to those for diesel. Additionally, the peak pressure for methyl esters and their blends occurs slightly further from TDC. With an increase in the methyl ester content in the fuel, the maximum heat release rate diminishes in magnitude. Furthermore, as the proportion of methyl ester in the fuel rises, the frequency of the maximum heat release rate increases.
- The brake thermal efficiency of methyl esters and their blends with diesel is slightly lower compared to pure diesel. As the proportion of methyl ester in the fuel increases, there is a reduction in unburned hydrocarbons, carbon monoxide, and particulate matter in the exhaust. However, this also leads to an increase in nitrogen oxide emissions and exhaust gas temperature.

This research work pave way for reduction in consumption of fossil fuels by blending methyl esters and decrease in emissions.

The following are suggested as future work for the investigations on the use of biodiesel in a DI diesel engine.

- Study on retarding the fuel injection timing for the optimum blends to reduce the emissions without compromising much in thermal efficiency.
- Study on the effect of additives (DME or DEE) on the combustion, performance and emission characteristics of the biodiesel.
- Study on the effect of compression ratio on the combustion and exhaust gas analysis of the biodiesel.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

Authors confirm that the data that supports the findings of this study are available within the article. The raw data

that supports the findings of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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