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Research Article

Enhancement of Used Temple Oil Biofuel Blends Using Artificial Intelligence for Eco-Friendly Cities Medium Duty Commercial Vehicles in India

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Abstract:
The efficiency of bio-blends made from seeds for medium-duty urban commercial vehicles is the subject of a study whose results are presented in this article. The analysis took into account a number of variables, such as engine specifications, economic consequences, and production capacity. An artificial intelligence algorithm was trained to predict emission characteristics, combustion, and performance using experimental data. The findings showed that while brake-specific fuel consumption (BSFC) increased at full load, brake thermal efficiency (BTE) dropped for both diesel and bio-fuel combinations as engine speed increased. In particular, there was an 11.9% increase in BSFC when diesel was used instead of mixtures of biofuel and diesel. The bio fuel-diesel blends also reduced maximum cylinder pressure and NOx emissions, with maximum reductions of 9.8% and 22.2% at specific RPMs, respectively. Additionally, these blends significantly decreased emissions of carbon dioxide (CO_2) and smoke. Overall, biofuel blends provide substantial benefits by reducing exhaust pollutants and improving engine efficiency.

Keywords: *Artificial Intelligence, Used Temple Oil, Medium Duty Commercial Vehicles, Diesel Engine, Emission Reduction*

1. Introduction

Over the past ten years, the automobile industry has advanced significantly as a result of the incorporation of artificial intelligence (AI) into numerous vehicle designs, functions, and optimization. Predicting and analyzing engine performance and exhaust emissions is a popular use of artificial intelligence (AI), which is essential for improving engine efficiency and minimizing environmental effects [1]. Diesel engines are praised for their torque and efficiency, but they are also frequently linked to increased emissions of dangerous pollutants, such as nitrogen oxides (NOx), particulate matter (PM), and other hazardous substances. There are a number of drawbacks to the time-consuming, expensive, and conventional methods now used to assess engine performance, emissions, and combustion parameters. As a result, there is an increasing need for accurate and trustworthy predictive models that can estimate emissions and engine performance in a range of operating conditions [2]. Artificial intelligence techniques like machine learning and neural networks have become interesting substitutes. These machine learning models can be calibrated with empirical data from prior studies to predict key operational parameters such as energy output, fuel efficiency, and exhaust emissions (carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter) [3]. There has been a lot of study done in this area as a result of the increased interest in the application of AI to forecast engine performance. To develop dependable and accurate models for forecasting emissions and performance indicators in a range of operational scenarios, Numerous scholarly investigations have been conducted to explore the applicability

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of machine learning and neural network methodologies, is given in Table 1. According to the study, artificial neural network (ANN) models demonstrate notable effectiveness in emissions control and performance monitoring, yielding achievable standards and encouraging outcomes [5]. AI techniques have surpassed traditional fuzzy logic methods in engine control and diagnosis. Moreover, advancements in methods such as reinforcement learning and specialized algorithms hold promise for further enhancements in engine control and diagnostics [6]. This study expands on earlier studies that looked at how several blends of used temple oil biofuel D95TO5, D80TO20, and D60TO40 affect a compression direct injection diesel engine. It looks into how engine speed affects the direct injection diesel engine's combustion, emissions, and operation by using artificial intelligence to forecast emissions and operating performance at various speeds [7]. Accurate forecasting models can improve engine architecture, increasing efficiency and reducing environmental effects [8]. Furthermore, precise exhaust emission estimations can help lawmakers create more stringent rules and pollution prevention plans. By 2025–2026, the Indian government wants gasoline to contain 20% ethanol, and by 2030, it wants to contain 5% biodiesel. Furthermore, by giving financial resources, the government is encouraging the production, analysis, and development of biodiesel [9].

The present investigation aims to develop and validate AI-based Fortified Models to predict the performance parameters and exhaust emissions of a direct injection diesel engine fuelled with various blends of biodiesel from used temple oil. By utilizing machine learning methods, this study aims to offer inexpensive and reliable alternatives to traditional experimentation that could improve engine design optimisation and fuel blend configurations. This study has implications for both scholars and practitioners, as it opens up pathways of clean propulsion technologies, helps shape future emission regulations and aligns with India's vision of adopting cleaner fuels by 2025–2030.

2. Materials And Methods

2.1 Production of Biodiesel

The fuel derived from Used temple oil using transesterification to obtain the biodiesel in figure 1. Methanol-induced transesterification of triglycerides, the primary constituents of oils and fats, is facilitated by a catalyst and characterized as an endothermic process, resulting in the synthesis of esters and glycerol [10]. It is a process to make the properties of oil similar to diesel. The process of Transesterification is depicted in Figure 2. A mixture of Used temple oil and methanol of 16:1 molar ratio was prepared and KOH was used as catalyst. The reaction involved heating the mixture for an hour to 60 °C in a conical flask, the whole being stirred at 700 rpm. Methanol has a boiling point of 64.7 °C and hence the mixture’s temperature was maintained to be 60 °C. To prevent the escaping of the volatile components, the top of the conical flask was covered with aluminium foil [11]. To settle the broken-down fats, the stir-heated mixture was shifted into a separating funnel and rested for 4 hours. In a conical flask, methoxide was mixed with the fats that settled down, and the mixture was rested for 18 hours to settle. The biodiesel was obtained at the top of the mixture [12].

Fig. 1. Used temple oil

Fig. 2. Biodiese

The moisture removal was attained by continuous heating, while the removal of glycerine was achieved via water washing. Used temple oil biodiesel was collected with a higher yield rate of 95%. Processed raw oil biodiesel based on the above-mentioned method was procured from a local vendor [13]. Further, diesel, used temple oil biodiesel, and its blend, 20% biodiesel with 80% of diesel (TOB20) were prepared and the properties examined as per ASTM standards are shown in Table 1.

Table 1. Properties of Used temple oil biodiesel

Properties	Biodiesel obtained from used temple oil	ASTM Standard for Biodiesel	Equipment utilized
Density	0.855	0.875	Hydrometer
Viscosity	3.9	1.9-6.0	Brook field viscometer
Flash point	105	100.0 min.	Pensky Marten Apparatus
Fire point	122	130	Pensky Marten Apparatus
Cloud point	9	-3 to 12	PE-7200I
Pour point	56	-10 to 12	PE-7200I
Calorific value	40129 kJ/kg	-	Bomb calorimeter
Acid value	0.52	0.80 max.	pH meter
Solubility in H_2O	Insoluble	Insoluble	-
Colour	Light golden	Light golden	-
Odour	Light soapy order	-	-

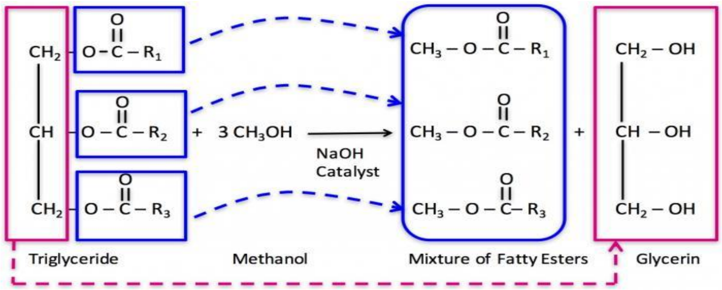

Fig. 3. Transesterification process

2.2 Engine Experimental Setup

Research operations were conducted within the I.C. Engine Laboratory situated at the Department of Mechanical Engineering within the University of Visvesvaraya College of Engineering, located in Bangalore. The study employed diesel/biofuel blends D95TO5, D80TO20, and D60TO40. The engine was operated with the injection pump fully open at two different loads and speeds. Diesel (D) and D0TO100 were also included in the study due to their stability in the examined situations. A four-stroke, single-cylinder, water-cooled diesel engine was employed for the study, featuring a common-rail fuel injection system. Detailed engine characteristics are presented in Table 2. Under varied operating conditions, the performance of the engines and exhaust pollutants were measured using simple instrumentation. Performance and combustion data were analyzed using a computer fitted with software for ignition control in internal combustion engines. The software utilized enabled the calculation of various parameters associated with the calorimeter, including cylinder pressure, fuel flow, air flow, water flow, and heat transfer. Measuring equipment consisted of an AVL 437C smoke meter for quantifying smoke levels and an AVL 444 gas analyzer for monitoring carbon dioxide and nitrogen oxide emissions. To guarantee accuracy, the instrumentation underwent routine calibration.

A total of 75 experimental runs were conducted across five distinct engine revolutions per minute: 1,200, 1,500, 1,800, 2,100 and 2,400. The dynamometer load cell's kilogram-force readings were substantiated by a corresponding torque value of 12.5 N·m. The engine was warmed up for five minutes using the particular gasoline blend that would be tested before each test. To prevent contamination and ensure test accuracy, the gasoline supply tank was cleaned in between blend transfers. Once the exhaust emissions settled, a gas analyzer recorded and examined the test results.

Table 2. Specifications of the Test Engine

Manufacturer	Kirloskar TV1
Power range	3.5 kW with 1500 rpm
Displacement Volume	661 cm^3
Compression Ratio	17.5:1
Standard Injection timing	23° bTDC
Cooling Type	Water-cooled

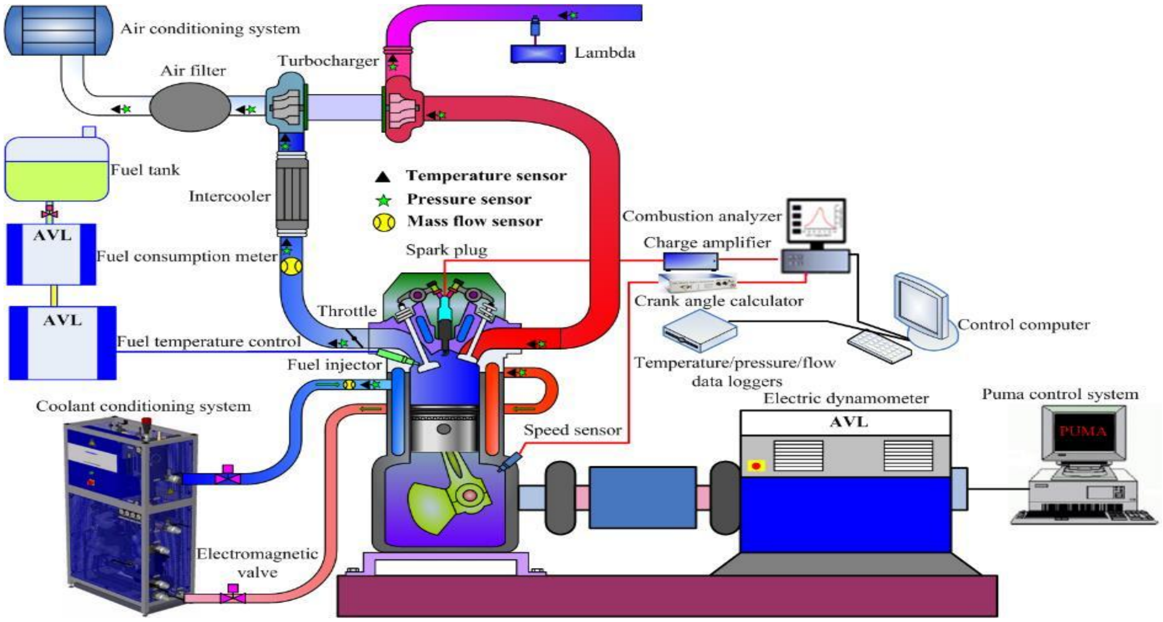

Fig. 4. Experimental Setup Diagram

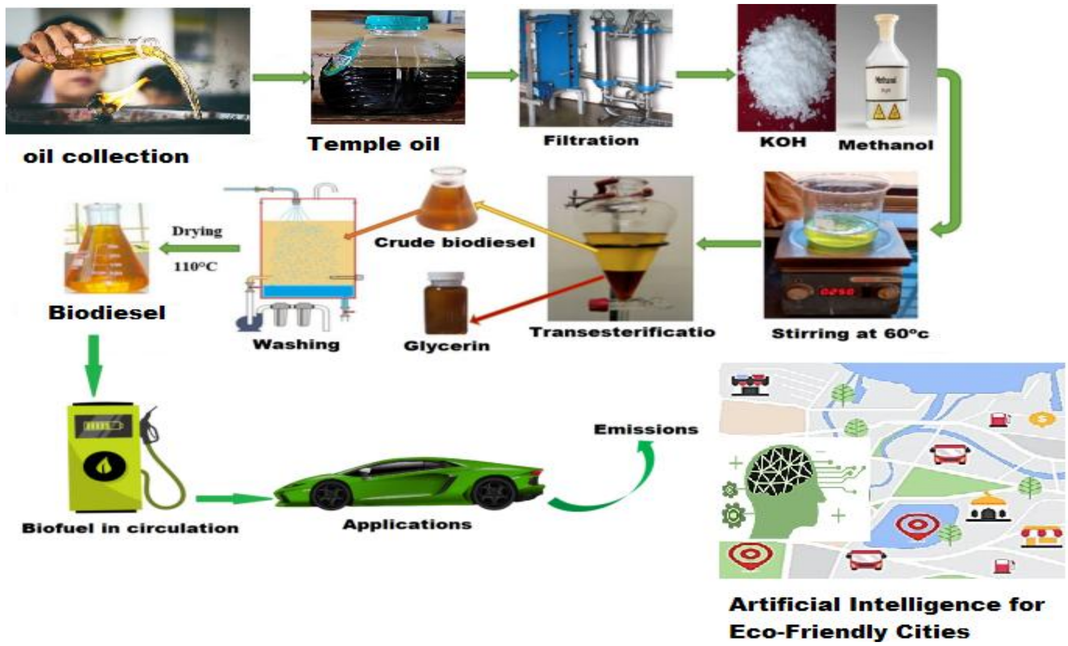

Fig. 5. schematic diagram of experimental work.

2.3 Heat release rate calculation

In the context of a direct injection engine, fuel constitutes the singular mass input to the system. Given the negligible enthalpy and the assumption of an ideal gas within the combustion chamber, the rate of heat release can be formulated using the equation (1) [14].

$$\frac{dQ}{d\theta} = \frac{1}{(\gamma - 1)}.V\frac{dP}{d\theta} + \frac{\gamma}{(\gamma - 1)}.P\frac{dV}{d\theta} \quad (1)$$

Variation in volume (V) influences temperatures derived from these measurements, whilst pressure (P) within the cylinder dictates conditions. Additionally, the rate of heat release (dQ/dθ) is contingent upon crank angle (θ) [15].

$$\gamma = 1338 - 6 \times 10-5Tcc + 1 \times 10-8T2cc \quad (2)$$

Equation (3) can be used to calculate the temperature inside the combustion chamber, which is represented by the symbol Tcc:

$$Tcc = \frac{P.V.Tair}{PairVic} \quad (3)$$

T_{air} P_{air} V_{ic} in Equation (3), where Vic is the volume of compressed air at top dead center and T_{air}, P_{air}, is the air intake temperature and pressure.

2.4 Artificial Neural Network

Specialized computational models called artificial neural networks, or ANNs can solve challenging and nonlinear modeling problems. An ANN learns from vast amounts of input and output data, unlike empirical computations [17]. An activation function controls an ANN's output [19]. This function's output is affected by a threshold as well as the input value. A weight is assigned to each connected input to a node, signifying its importance. Furthermore, an offset element can modify the input strength to facilitate the transfer mechanism of the activation function [20].

Table 3. The Y-Values of Instruments.

Parameters	**Uncertainty in %**
Pressure sensor	± 0.5
Encoder	± 0.2
Speed sensor	± 1.0
Temperature sensore	± 0.15
Burette reading	± 1.0
Load cell	± 0.2
CO_2	± 1.0
O_2	± 0.3
CO	± 0.3
NO_x	± 0.5
HC	± 0.1
BTE	± 1.5
BSC	± 2.0
EGT	± 1.5

During the experiments, due to various elements such as environmental operating conditions, instrument selection and calibration, apparatus quality and experiment order, etc., the same results could not be obtained. Therefore, it is crucial to evaluate the reliability of the measured results. The study was performed thrice and the values were averaged for the graphical representation. The uncertainty percentage along with the accuracy of the measuring equipment was employed. The overall uncertainty of ± 2.53% was obtained using the expression derived by Holman as follows:

Total uncertainty = [(encoder)2 + (pressure sensor)2 + (NOx)2 + (O_2)2 + (CO)2 + (CO_2)2 + (opacimeter)2 + (HC)2 + (K2 thermo couple)2 + (manometer)2 + (stop watch)2 + (burette)2]$^{1/2}$

= [(0.3)2 + (0.01)2 + (0.5)2 + (0.35)2 + (0.02)2 + (0.2)2 + (0.3)2 + (1.1)2 + (1.5)2 + (0.3)2+(1.5)2]$^{1/2}$

= $\sqrt{6.393}$

= ± 2.53 %

Fig. 6 shows the construction of an ANN. The human brain's neurons are modeled using advanced techniques called artificial neural networks (ANNs), which facilitate the identification of nonlinear correlations between input and output elements. ANNs have the benefit of being quickly trained through a variety of techniques [21].

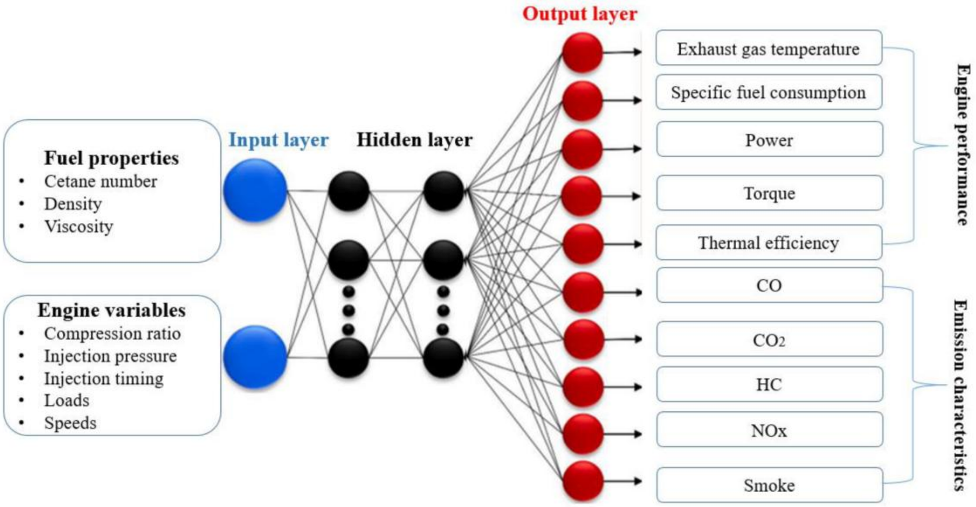

Fig. 6. Structure of ANN model

An ANN was used in this investigation to forecast the anticipated rise in efficiency. Figure 6 illustrates the architectural configuration of a neural network incorporating concealed layers engaged in processing input and output variables. The artificial neural network was trained utilizing the Traindx algorithm, a variant of feed-forward backpropagation. which incorporates adaptive learning from big datasets [22]. MSE, or mean squared error, was used to assess the outcomes.

In order to ensure diverse data collection, the dataset was partitioned randomly into subsets utilising a 70:15:15 proportion favouring training, testing, and validation sets respectively. Subsequently, the Artificial Neural Network model achieved convergence following an iterative process spanning 1000 epochs, which permitted the attainment of a gradient of 10-1 and a resultant error rate of zero. [23]. Additionally, the validation results were confirmed after 1,000 rounds. The learning network model was subjected to training, validation, testing, and regression analysis, as shown in Figs. 7a, b, c and d. The data exhibits a high degree of correlation between predicted and actual values with a coefficient of determination of approximately 0.9. [24].

3. Results and Discussions

3.1 Brake specific fuel consumption

Figure 8 shows the trend of the brake-specific fuel consumption BSFC for the diesel and different blends of biodiesel at different engine speeds. Due to the addition of blends in biodiesel like biodiesel derived from used temple oil, the results showed that it has a higher BSFC value than from diesel as usual. This is due to the genetically physicochemical properties of biodiesel itself (lower calorific value and higher viscosity), which result in decreasing combustion efficiency and energy output per kilogram of biodiesel [25]. The elevated oxygen content in biodiesel combustion serves a dual purpose. While it allows for more complete combustion, it also leads to a longer ignition delay, which increases in-cylinder temperatures. This increased combustion temperature leads to higher fuel consumption, particularly for highly loaded engines that operate at high speeds [18]. At lower speeds, this result was more desirable because of the lowered Engine-Tool Specific Fuel Consumption (BSFC), which is characteristic of more efficient fuel combustion. Nonetheless, in the higher engine speeds, fuel consumption increased drastically, confirming the direct relationship between engine speed and BSFC. The increase in BSFC at higher speeds can have direct operational cost implications, particularly for commercial or industrial diesel engines where fuel economy is paramount. D95TO5 and D80TO20 biodiesel blends perform relatively better than the other biodiesel blends with a BSFC reading closer to the diesel. On the other hand D60TO40 and D0TO100 showed relatively high BSFC for all speed ranges. According to previous results, at 2400 rpm and full load, which is the most severe working state in this research, the largest BSFC of D0TO100 is 0.38 kg/kWh while the minimal BSFC of diesel is 0.265 kg/kWh. Such a difference indicates, under high-load conditions, the energy efficiency constraints of high-concentration biodiesel blends. Were it not for its maximum at lower speed, the trained behavior is such that a peak BSFC at 2400 rpm indicates a potential transitional behavior of the efficiency transfer from low, to moderate speeds. Indeed, this begot the well-known fact that if engine speed rises beyond certain threshold, the air-fuel homogeneity and mixing would become inefficient for combustion, especially for low volatility fuels, biodiesel being one. The boiling specific fuel consumption (BSFC) is recognized as the essential parameter for performance assessment of biodiesel blends in terms of economy and environmental with the highest statistical significance. D95TO5 blends hold promise for real-world applications with acceptable compromises in fuel economy, but at higher concentrations, biodiesel (particularly D0TO100) may require the adjustment of engine parameters or the addition of an additive to offset the increased BSFC.

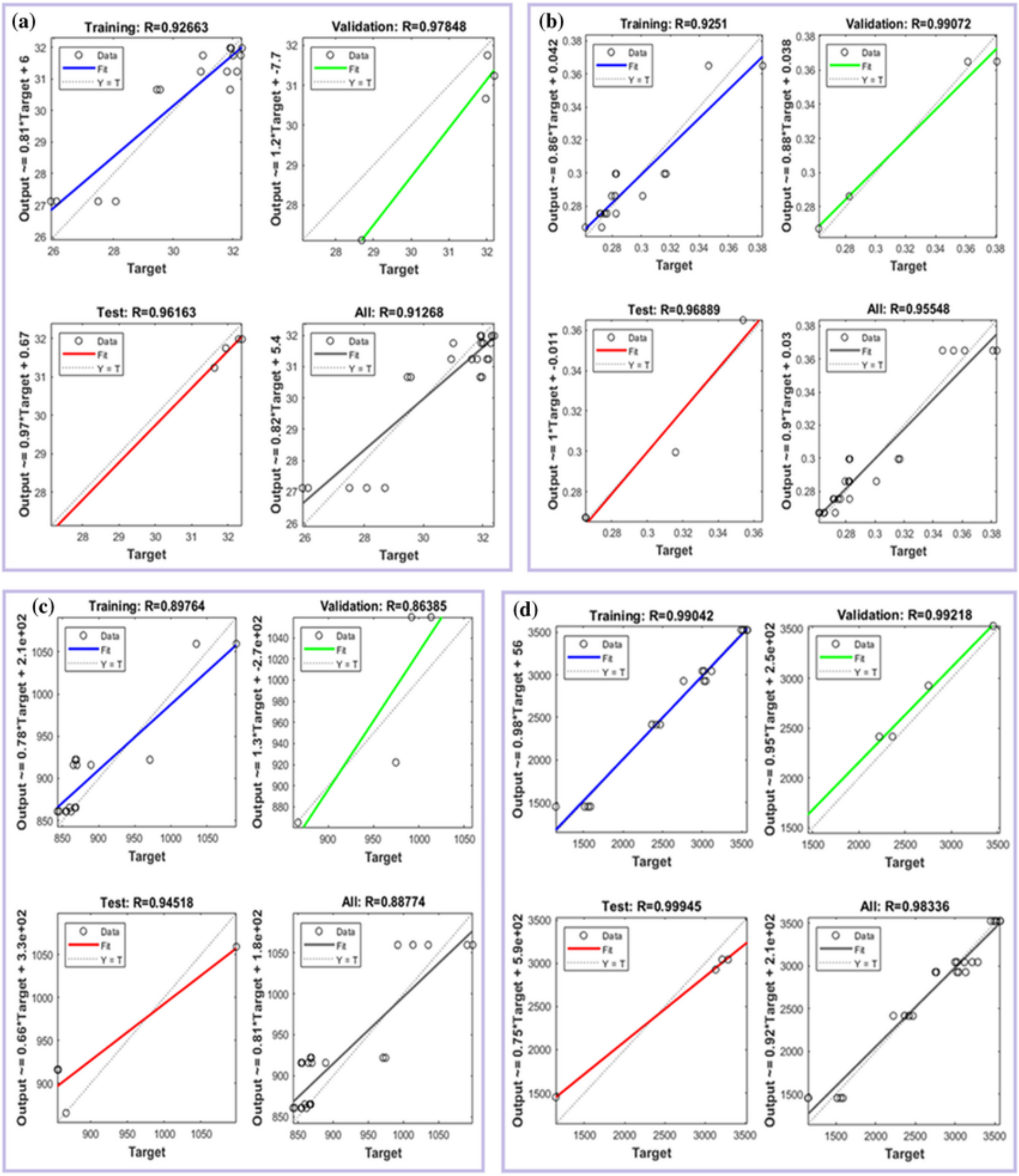

Fig. 7. Regression, test, validation, and training The emission of BTE, SFC, CO_2 and NO_x, respectively.

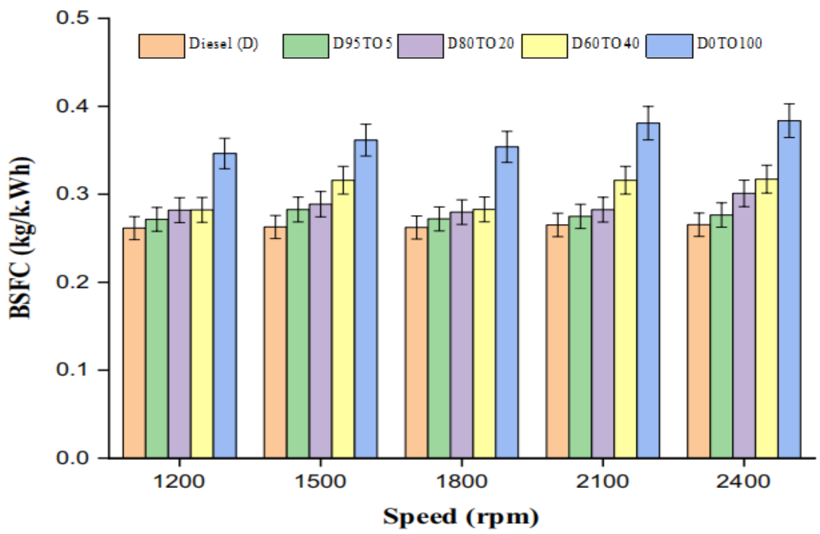

Fig. 8. BSFC with speed for blends

3.2 Brake Thermal Efficiency

Brake thermal efficiency serves as a crucial benchmark for assessing engine performance, with particular relevance in evaluating the comparative efficacy of various biodiesel compositions within diesel engines. This investigation examines the engine's load conditions alongside various fuel blends to calculate BTE. Two significant factors influencing a fuel's thermal efficiency (BTE) are calorific value and cetane number [19]. Notably, diesel fuel exhibits a superior cetane rating in comparison to other biodiesel blends as a direct consequence of its elevated viscosity. Furthermore, the calorific density of the fuel also has a significant impact on its combustion rate. Compared to diesel, biodiesel exhibits poorer thermal efficiency, primarily due to its relatively high viscosity. Consequently, pure biodiesel blends are rarely used in diesel engines because of their inefficiency. This section evaluates several diesel blends (D95TO5, D80TO20, D60TO40 and D0TO100) at different engine speeds while the engine operates at full load. As engine speed reaches 1500 rpm, increased combustion rates lead to a decline in thermal efficiency. However, as engine load conditions intensify, the BTE of the blends increases. The maximum BTE values for the diesel blends were 32.2%, 32.1%, 32.2%, 31.9% and 28.1%, respectively. The blend containing 20% biodiesel and 80% diesel (D80TO20) performed the best due to the influence of diesel and its low biodiesel concentration. As the biodiesel content in the blends increases, thermal efficiency typically decreases. As shown in figure 8, there is a correlation between BTE and the fuel viscosity that confirm the fuel with a higher viscosity is difficult to be atomized and mixed with the air, and thus there would be less combustion efficiency. In addition, despite pure biodiesel (D0TO100) showing the lowest efficiency, it still registered in a usable range, possibly allowing for tunable engine parameters or the addition of performance-enhancing additives. Overall, moderate blending of biodiesel, notably at 20% blending level, appears to establish an optimal tradeoff between environmental improvements with respect to the fossil fuel baseline on one hand, and the impact to performance on the other hand. The results established the feasibility of using biodiesel as a partial substitute for diesel fuel in compression ignition engines, subject to optimal selection of blend ratios and operating conditions.

3.3 Volumetric Efficiency

A key factor in assessing the effectiveness of fuel combinations in diesel engines is their volumetric efficiency. This study compared the engine's performance with different fuel blends under various load levels in order to assess VE. Fuel VE is mostly determined by the cetane number and calorific value. Diesel is more viscous than mixes of biofuel, which results in a lower cetane number. Density is one of the most important physiochemical variables that affects how quickly fuel burns.The differences in VE at various engine speeds are depicted in the figure. The higher oxygen concentration found in biofuel made them more volumetrically efficient than traditional diesel fuels. Because doing so would increase efficiency, direct mixes are not commonly used in diesel engines. For diesel, the test mixes included D95TO5, D80TO20, D60TO40 and D0TO100. The corresponding VEs that were obtained were 90.4%, 90.0%, 91.2%, 91.7% and 92.4%. The engines were driven at different speeds while they were at maximum capacity to get these data (see Fig. 10). This marginally lower VE seen in biodiesel blends is likely due to their lower calorific value and increased viscosity, which can affect atomization and combustion efficiency. At the same time, the increased oxygen content provides additional support for more complete combustion and is likely a reason why biofuels are more volumetrically efficient than might otherwise be expected given their physical property characteristics. In addition, the differences in VE with engine speed demonstrated the blends' flexibility throughout the range of operational conditions. The biofuel blends present high VE levels even under high engine speed regime, which reflects an important characteristic of the material, possibly related to efficient enginedynmic behavior.

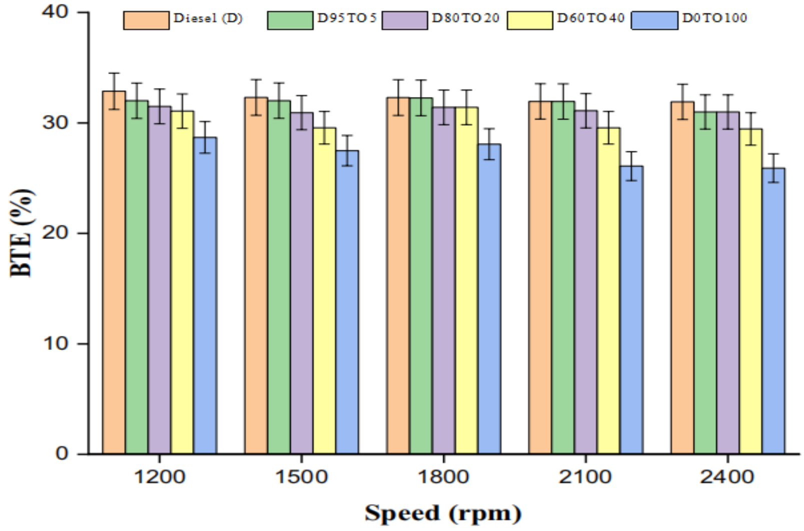

Fig. 9. BTE with Speed blends

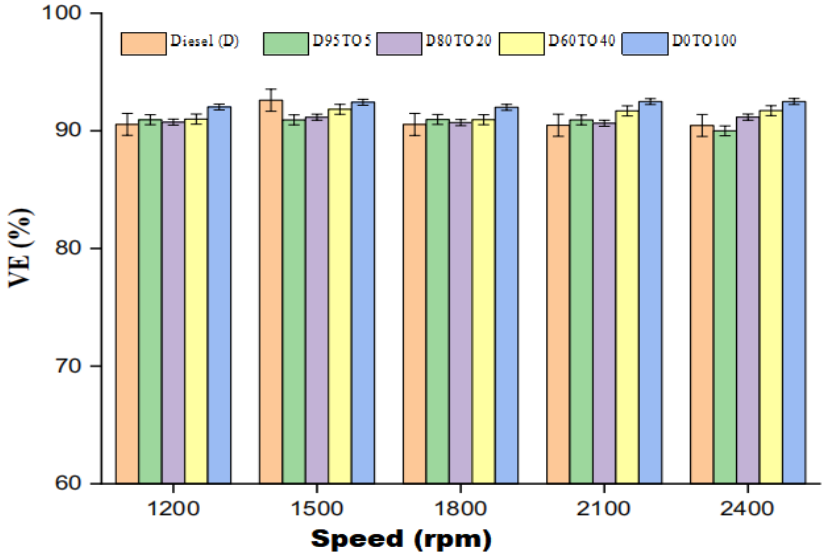

Fig. 10. VE with Speed blends

3.4 Exhaust Gas Temperature

Utilizing a K-type thermocouple enables the quantification of exhaust gas temperature in internal combustion engines. This measure is susceptible to fluctuations in the air-fuel mixture, manifesting as alterations in exhaust gas temperature readings. Biofuel ignite more quickly during exhaust strokes than conventional gasoline due to their higher ester content, leading to an increase in EGT as engine speed rises[20]. The average exhaust temperature (AET) increased for all biofuel blends; however, the rise was 5% to 20% lower than that of diesel. In opposition, the incorporation of small to medium-sized enterprises (SMEs) yielded a 20% reduction in air-exhaust temperature (AET). The diesel blends D95TO5, D80TO20, D60TO40, and D0TO100, evaluated at a rotational speed of 2400 rpm, exhibited distinct thermal properties, including temperatures of 411°C, 408°C, 439.5°C, 454°C and 430.3°C, respectively. The EGT for D95TO5 showed a significant decrease compared to diesel and the other blends (D80TO20, D60TO40, and D0TO100) (Fig. 11). D95TO5 blend fuel exhibited the least EGT due to better thermal efficiency and combustion characteristics among the tested fuels. Hence, the EGT in the nHR for E1 is less than nHR of E2 and hence corresponding to NOx emissions, EGT reduction can be critical in achieving engine durability requirements in compliance with stringent emission norms and getting better fuel economy. As shown in Figure 11, these differences reveal that even small adjustment in blend ratios can have large changes in thermal behavior.

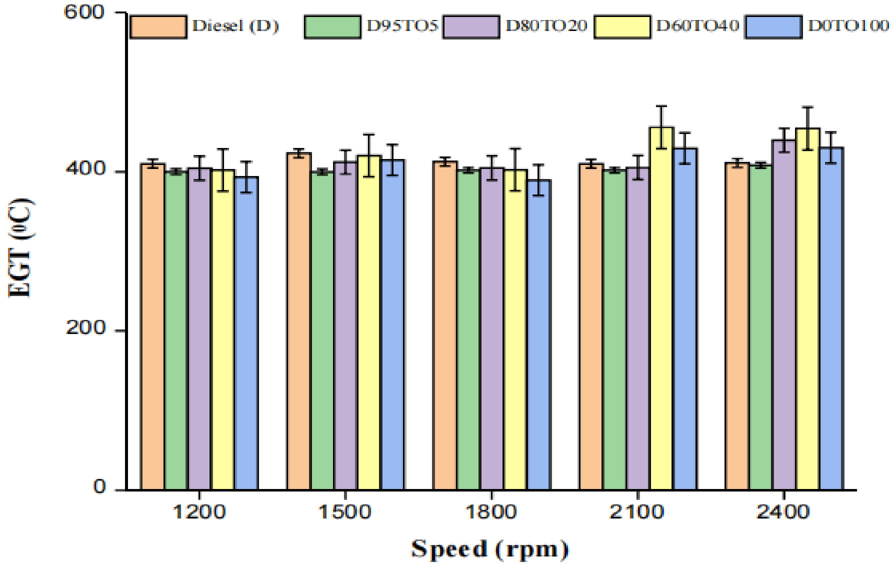

Fig. 11. EGT with Speed blends

3.5 Maximum Cylinder Pressure

In-cylinder pressure is directly correlated to the fuel burn rate and is influenced by several variables including the fuel-air mixture, combustion characteristics, and environmental factors such as thermal energy [21]. Fuel blends and pure diesel fuel can vary remarkably by MCP and RPM in fuel injected motors. For other fuel blends and for diesel fuel but with the pressure of 122 bar, the in-cylinder pressure range was also higher. On the other hand, under higher loads, diesel fuel blends D95TO5, D80TO20, D60TO40, and D0TO100 showed an engine speed of 2400 RPM and a shorter pressure rise range. In these studies, multiple operational pressures were consistently applied to each experimental mixture, corresponding to readings of 115 bar, 110 bar, 99 bar, and 81.5 bar.. Blends D95TO5 and D80TO20 have in-cylinder pressure ranges that are closer to pure diesel fuel due to a number of characteristics, such as the heat value of biodiesel, Advanced premixed combustion configurations, extended ignition latencies, dual-fuel operating modes, and accelerated combustion kinetics. When comparing blend D95TO5 to diesel fuel, the cylinder pressure was 5.7% lower under elevated load conditions. Additionally, the pressure loss for blends D80TO20 and D60TO40 during peak load at 2400 RPM was 9.8% and 18.0%, respectively. Faster combustion in a dual-fuel engine generates more heat, raising the temperature and pressure within the cylinder [22]. Lower gas supply pressure at reduced loads can lead to incomplete combustion, resulting from a richer fuel mixture. Consequently, certain fuel samples fail to combust entirely, raising concerns about emissions[23].

3.6 Rate of Pressure Rise

One important metric to consider when evaluating a biofuel blend's efficiency is the rate of pressure rise, or ROPR. The ROPR has been greatly decreased when diesel fuel and Used temple oil biofuel are combined in a diesel engine. In the current investigation, adding 5%,20%, and 40% Used temple oil biofuel to diesel fuel resulted in a drop in the ROPR for all investigated engine conditions. In particular, the lower ROPR of 14% was seen for the 5% Used temple oil mix and 7.4% for the 20% blend. This can be attributed to the Used temple oil biofuel's early burning and increased oxygen concentration (Fig. 13).

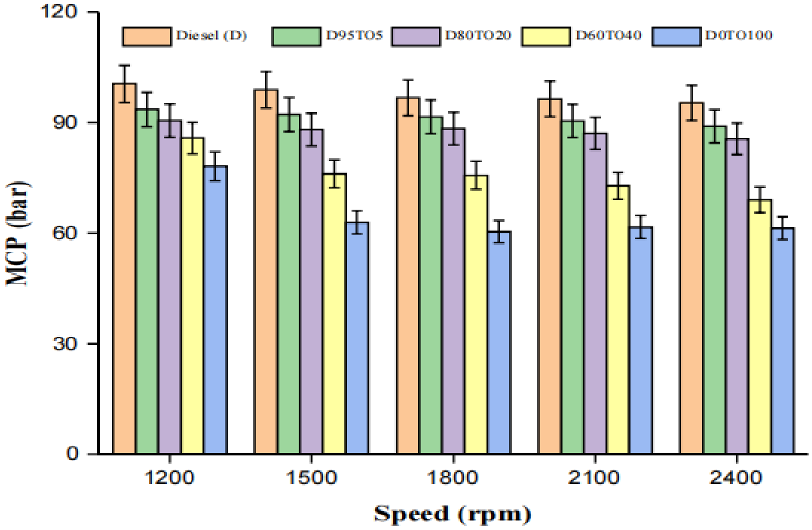

Fig. 12. MCP with Speed blends

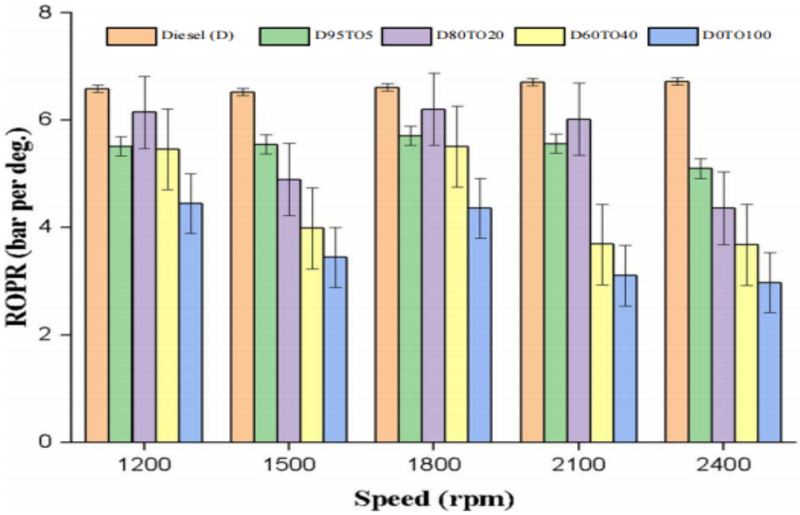

Fig. 13. ROPR with Speed blends

3.7 Smoke Emission

When assessing biofuel blends, smoke emission is a crucial issue to consider. It has been demonstrated that using UTO biofuel in diesel engines can improve combustion kinetics and drastically cut smoke emissions[24]. Notably, this investigation reveals a substantial diminution in smoke emissions, with a more pronounced reduction observed when a 20% ethanol additive is integrated into a conventional gasoline blend [25]. Conversely, the incorporation of diesel, biodiesel, and ethanol into diesel fuel results in elevated emissions and diminished combustion engine performance. It is thought that adding oxygenates to diesel fuel may oxygenate the burning diesel spray's pyrolysis zone, which will reduce smoke [26]. In the current study, smoke emissions were reduced in all evaluated engine boundary conditions when diesel was supplemented with 5% and 20% UTO biofuel. On the other hand, as the biofuel level went above 20%, smoke emissions rose. Because of the greater oxygen content of the biofuel, there was a specific 10% reduction in smoke emission for the 5% S fuel blend and a 4% reduction for the 20% S fuel blend (Fig. 14).

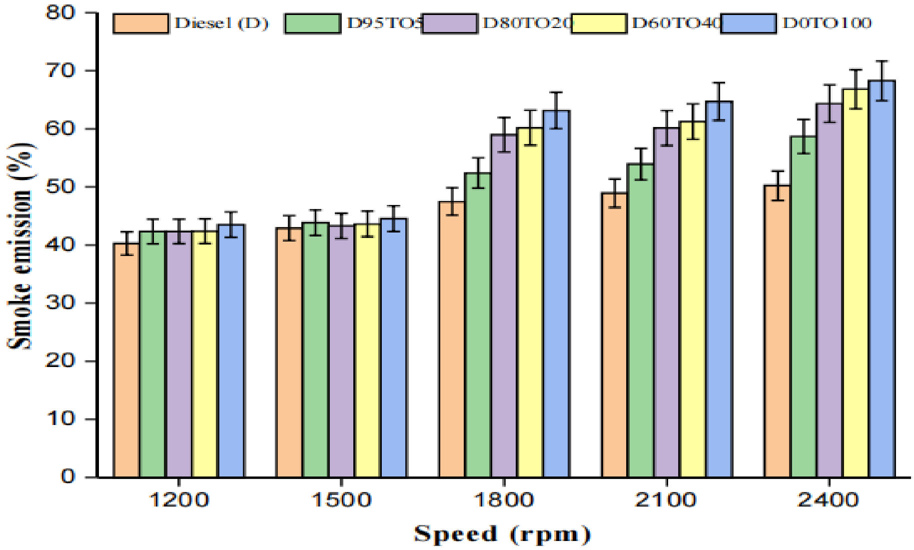

Fig. 14. Smoke emission with Speed blends

3.8 CO_2 Emission

Emissions of carbon dioxide (CO_2) are a significant parameter in evaluating the efficacy of biofuel blends. Research indicates that the incorporation of UTO biofuel into diesel engines modestly increases CO_2 emissions, implying an enhancement of combustion kinetics. [27]. This study reveals a significant improvement in CO_2 emissions released into the atmosphere, contrasting with other research indicating that adding biofuel to diesel significantly increases emissions. By implementing innovations, the operational attributes of a compression ignition engine are improved [28]. For pure diesel, the measured CO_2 emissions in this study were 855.3 g/kWh; for blends of D95S5 (95% diesel, 5% S biofuel), 869.7 g/kWh; for blends of D80TO20 (80% diesel, 20% UTO biofuel), 974.4 g/kWh; and for blends of D60TO40 (60% diesel, 40% UTO biofuel), 1098 g/kWh. Adding 5%, 20%, or 40% UTO biofuel to diesel increased CO_2 emissions under all engine conditions tested. The 5% and 20% UTO blends in particular increased CO_2 emissions by 1.3% and 1.6%, respectively, because of the biofuel's higher oxygen content.

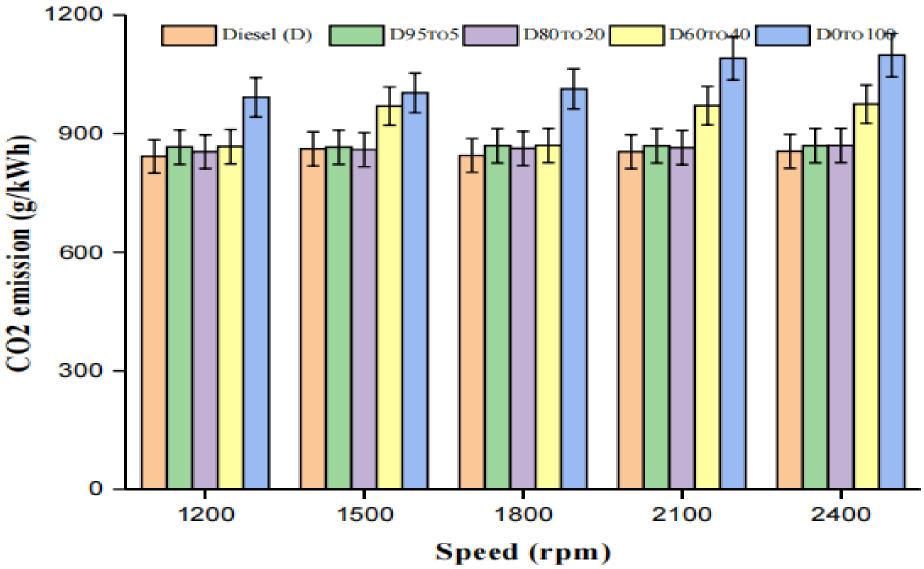

Fig. 15. CO_2 with Speed blends

3.9 NO_x Emission

At engine speeds of 1200, 1500, 1800, 2100 and 2400 rpm under full load conditions, low nitrogen oxides are produced when different percentages of biofuel are blended with diesel fuel. The Zeldovich reaction occurs when nitrogen and fuel molecules interact during combustion, producing NOx emission. found that because biofuels contain oxygen, engines running on biofuel typically emit substantial amounts of NOx[29]. However, low-temperature combustion can lead to reduced NOx emissions [30]. The D95TO5 and D80TO20 blends, comprising 5% and 20% Used temple oil biofuel, respectively, yielded exceptionally low NOx emissions across all scenarios examined in this study. The D80TO20 blend (20% Used temple oil biofuel) showed NOx emissions that were 22.2% lower at 2400 rpm compared to pure diesel. The addition of oxygenated Used temple oil biofuel enhances fuel properties, resulting in a shorter ignition delay and residence time. This phenomenon enables combustion at reduced temperatures, resulting in a decrease in the adiabatic flame temperature and mitigation of thermal gradients within the surrounding environment [31]. Consequently, the D80TO20 blend exhibits significantly diminished NOx emissions. The increased oxygen content and moisture levels in the D80TO20 blend contribute to the significant reduction in NOx emissions. Elevated moisture content in biodiesel reduces temperatures in the combustion chamber, subsequently limiting NOx production [32].

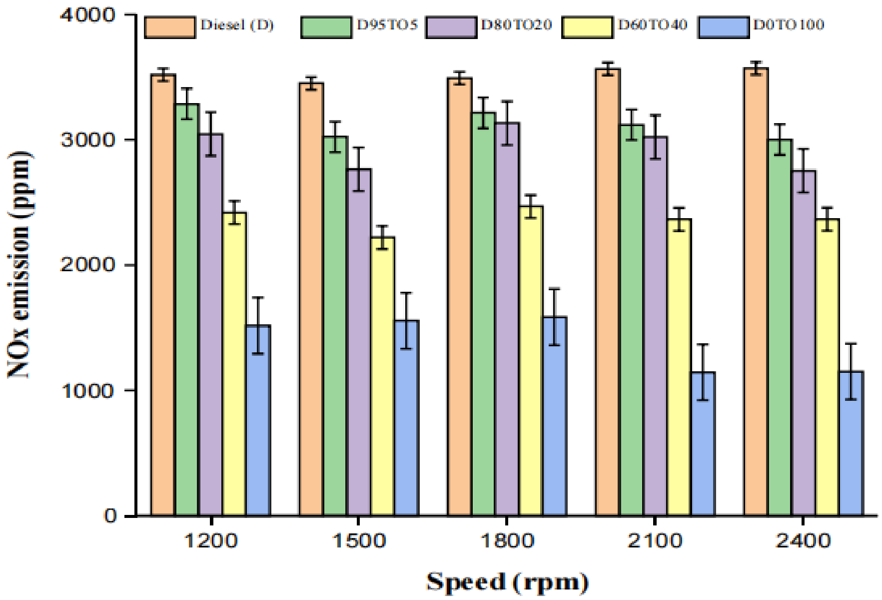

Fig. 16. NOx with Speed blends

4. Conclusion

The following is a summary of the main experimental findings from this study:

- The brake thermal efficiency (BTE) of diesel fuel at 1500 rpm is 1.5% greater than that of fuel operating at 2400 rpm, with a better BTE of 32.4%. Under all examined settings, using Used temple oil biofuel leads to a small decrease in BTE. When running at different speeds, the BTE of the D80TO20 engine is marginally lower than that of diesel in all rpm ranges.
- The relationship between engine speed and Brake-Specific Fuel Consumption (BSFC) is characterised by a noticeable disparity. Notably, a rise in engine speed from 1500 rpm to 2400 rpm is accompanied by a corresponding 1.8% increase in BSFC. Furthermore, the introduction of a 20% blend of used temple oil biofuel in combination with diesel fuel results in a 7.1% rise in BSFC at a constant speed of 1500 rpm.
- Preliminary investigations into the combustion dynamics of diverse fuel formulations have revealed distinct pressure profiles under controlled conditions. Specifically, at a compression ratio of 18 and full engine load, operating at 1500 rpm, intra-cylinder pressures achieved 98 bar with diesel fuel and 92.2 bar with D80UTO0. The introduction of 5% and 20% used temple oil-derived biofuel blends elicited commensurate reductions in

- rate of pressure rise of 14% and 7.4%, respectively, likely an outcomes of the biofuel's enhanced oxygen content facilitating more rapid combustion.
- An analysis of carbon dioxide emissions yielded the following results for pure diesel and biodiesel blends: diesel emitted 855.3 g /kWh of CO_2 at maximum load and 2400 rpm. Alternatively, CO_2 emissions from D95TO5, D80TO20, D60TO40, and D0TO100 were 867 g/kWh, 869.7 g/kWh, 974.4 g/kWh, and 1098 g/kWh, for 5% and 20% UTO blends, these increases were 1.3% and 1.5%, respectively.
- NOx Emissions: In every test scenario, the D95TO5 and D80TO20 mixtures with 5% and 20% biofuel, respectively, showed the lowest levels of NOx emissions. The 20% biofuel blend in the D80TO20 blend yielded less NOx emissions at 2400 rpm than diesel fuel.

An ensemble of distinct computational methodologies, comprising artificial neural networks, the Taguchi method, and response surface modelling, will be leveraged to fine-tune engine parameters. This will facilitate an enhanced exploration of the resultant effects occasioned by the incorporation of disparate nanoparticle types into the D80TO20 blend.

Declaration of competing interest

The authors declare the they have no known competing financial interests in this paper or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration of generative AI in scientific writing

The authors declare the they didn't use AI tools to analyse and data as Part of the research work.

References

[1] Abishek MS, Kachhap S, Rajak U, Verma TN, Singh TS, Saboor S, Cuce E, Saleel CA. Alumina and titanium nanoparticles to diesel–Guizotia abyssinica (L.) biodiesel blends on MFVCR engine performance and emissions. Sustainable Energy Technologies and Assessments. 2024;61:103580.

[2] Afzal A, V SH, Agbulut U, Alahmadi AA, Gowda AC. Poultry fat biodiesel as a fuel substitute in diesel–ethanol blends for direct injection compression ignition engine: experimental, modeling and optimization. Energy. 2023;270:126826.

[3] Agbulut U, Karagöz M, Saridemir S, Öztürk A. Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a compression ignition engine. Fuel. 2020;270:117521.

[4] Altun Ş, Fırat M, Varol Y, Okcu M. Comparison of direct and port injection of methanol in a reactivity controlled compression ignition engine using diesel and biodiesel as high reactivity fuels. Process Safety and Environmental Protection. 2023;174:681–693.

[5] Aslan V. Fuel characterization, engine performance characteristics and emissions analysis of different mustard seed biodiesel: an overview. Journal of Biotechnology. 2023;370:12–30.

[6] Ayd H. An innovative research on variable compression ratio in reactivity controlled compression ignition strategy on a power generator diesel engine using CNG–safflower biodiesel. Energy. 2021;231:121002.

[7] Bibin C, Sheeja R, Devarajan Y, Ponnappan VS. Environmental impact assessment of agricultural diesel engines utilizing biodiesel derived from *Phoenix sylvestris* oil. Environmental Research. 2023;224:115432.

[8] Bitire SO, Jen TC. An optimization study on a biosynthesized nanoparticle and its effect on the performance–emission characteristics of a diesel engine fueled with parsley biodiesel blend. Energy Reports. 2023;9:2185–2200.

[9] Chen Y, Liang C, Liu D, Niu Q, Miao X, Dong G, Li L, Liao S, Ni X, Huang X. Embedding graph neural network for transient nitrogen oxides emissions prediction. Energies. 2023;16(1):3.

[10] Dasore A, Rajak U, Panchal M. Prediction of overall characteristics of a dual fuel compression ignition engine working on low-density ethanol and diesel blends at varying compression ratios. Arabian Journal for Science and Engineering. 2022;47:15323–15330.
[11] Efendy M, Surono A, Saputra E, Nugraha NA. Performance and smoke opacity of compression ignition engine using used waste oil. Case Studies in Thermal Engineering. 2021;26:101063.
[12] Elumalai PV, Krishna Moorthy R, Parthasarathy M, Samuel OD, Owamah HI, Saleel CA, Enweremadu CC, Sreenivasa Reddy M, Afzal A. Artificial neural networks model for predicting the behavior of different injection pressure characteristics powered by blend of biofuel–nano emulsion. Energy Science and Engineering. 2022;10:2367–2396.
[13] Fan M, Li Z, Song S, Alahmadi TA, Alharbi SA, Shanmugam S, Brindhadevi K. Optimizing biodiesel blends with green hydrogen fuel: a study on combustion duration, fuel mass burnt, engine performance and emissions. Fuel. 2023;346:128340.
[14] Gavaskar T, Ramanan MV, Arun K, Arivazhagan S. The combined effect of green synthesized nitrogen-doped carbon quantum dots blended jackfruit seed biodiesel and acetylene gas tested on the dual fuel engine. Energy. 2023;275:127296.
[15] Gowrishankar S, Krishnasamy A. Emulsification – a promising approach to improve performance and reduce exhaust emissions of a biodiesel fuelled light-duty diesel engine. Energy. 2023;263:125782.
[16] Ineza Havugimana LF, Liu B, Liu F, Zhang J, Li B, Wan P. Review of artificial intelligent algorithms for engine performance, control, and diagnosis. Energies. 2023;16:1206.
[17] Jeyaseelan T, El Samad T, Rajkumar S, Chatterjee A, Al-Zaili J. A techno-economic assessment of waste oil biodiesel blends for automotive applications in urban areas: case of India. Energy. 2023;271:127021.
[18] Jiahong F, Yang R, Li X, Sun X, Li Y, Liu YZ, Zhang BS. Application of artificial neural network to forecast engine performance and emissions of a spark ignition engine. Applied Thermal Engineering. 2022;201(Part A):117749.
[19] Kalyani T, Prasad LSV, Kolakoti A. Effect of triacetin as an oxygenated additive in algae biodiesel fuelled compression ignition engine combustion, performance, and exhaust emission analysis. Fuel. 2023;338:127366.
[20] Kesgin U. Genetic algorithm and artificial neural network for engine optimisation of efficiency and nitrogen oxides emission. Fuel. 2004;83(7–8):885–895.
[21] Khatri KK, Singh M, Khatri N. An artificial neural network model for the prediction of performance and emission parameters of a compression ignition engine-operated micro-tri-generation system fueled with diesel, Karanja oil, and Karanja biodiesel. Fuel. 2023;334:126549.
[22] Mrityunjayaswamy KM, Deepak Kumar T, Tejas KS, Ramesha DK. Experimental investigation on influence of metal based additives on performance, combustion and emission parameters of diesel engine. Materials Today: Proceedings. 2022;54(2):264–269.
[23] Lalsangi S, Yaliwal VS, Banapurmath NR, Soudagar MEM, Agbulut Ü, Kalam MA. Analysis of common rail direct injection diesel engine characteristics operated on dual fuel mode fueled with biodiesel–hydrogen enriched producer gas under the single and multi-injection scheme. International Journal of Hydrogen Energy. 2023;48(74):28927–28944.
[24] Masera K, Hossain AK. Advancement of biodiesel fuel quality and nitrogen oxides emission control techniques. Renewable and Sustainable Energy Reviews. 2023;178:113235.
[25] Musthafa B, Saravanan B, Asokan MA, Devendiran S, Venkatesan K. Effect of ethanol, propanol and butanol on karanja biodiesel with vegetable oil fuelled in a single cylinder diesel engine. Egyptian Journal of Petroleum. 2023;32:35–40.
[26] Prabhu C, Navaneetha Krishnan B, Prakash T, Rajasekar V, Balasubramanian D, Le VV. Biodiesel unsaturation and the synergic effects of hydrogen sharing rate on the characteristics of a compression ignition engine in dual-fuel mode. Fuel. 2023;334:126699.
[27] Prakash P, Dhanasekaran C. Influencing parameter optimisation of common rail direct injection engine fuelled with lemongrass biodiesel blends. International Journal of Ambient Energy. 2023;44(1):719–738.
[28] Sharma P, Sharma AK, Balakrishnan D, Manivannan A, Chia WY, Awasthi MK. Model prediction and optimization of the performance of a biodiesel–producer gas powered dual-fuel engine. Fuel. 2023;348:128405.
[29] Thodda G, Madhavan VR, Thangavelu L. Predictive modelling and optimization of performance and emissions of acetylene fuelled compression ignition engine using artificial neural network and response surface methodology. Energy Sources, Part A: Recovery, Utilization and Environmental Effects. 2023;45(2):3544–3562.

[30] Zandie M, Ng HK, Said MF, Cheng X, Gan S. Performance of a compression ignition engine fuelled with diesel–palm biodiesel–gasoline mixtures: computational fluid dynamics and multi-parameter optimisation studies. Energy. 2023;274:127346.

[31] Zapata-Mina J, Restrepo A, Tibaquira JE. Assessment of the exergy, emissions, and combustion characteristics of a diesel engine operating on low-glyceride biodiesel blended with diesel fuel. Case Studies in Thermal Engineering. 2023;41.

[32] Anjappa S, Ramesha D. Experimental investigation of the effects of a reduced exhaust gas recirculation rate on the performance and emissions of compression ignition engines running on biodiesel made from dairy waste scum oil. Journal of Research and Applications in Mechanical Engineering. 2024;13(1)