Analysis of performance, combustion and emission characteristics of a CI engine fueled with blends of diesel-biodiesel-nitromethane

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ABSTRACT

In order to improve the performance and emissions of internal combustion engines as a consequence of the growing cost of fossil fuels and the increase in pollution, scientists are searching for alternative fuels made from renewable sources. The objective of this research was to replace conventional diesel with blended fuels by testing mixtures of biodiesel, methanol, and nitromethane in an engine at different engine speed (1200-2100). The tested fuels were Diesel (D100), B10, B10NM1, B10NM2, and B10NM3, and the highest ratio of Millettia pinnata to diesel is 10%. Experiments were done on a VCR diesel engine using diesel, methanol, and nitromethane mixtures to determine the optimal blending ratio and engine operating conditions for enhancing performance and reducing emissions. The findings indicated that improve thermal efficiency, lower smoke, CO_2 emission but higher NO emission for blend of B10NM1

Keywords: Nitromethane, Biofuel, Performance, Combustion, NO_x Emission

1. Introduction

The increased use of fossil fuels contributes to human environmental degradation by releasing dangerous chemicals into the atmosphere, such as benzene (C6H6), polyaromatic hydrocarbons (PAH), nitrogen oxides (NOx), aldehydes, particulate matter, and sulphate oxides of sulphur (SOx) [1-3]. In recent years, efforts have been made to reduce vehicular pollution by improving fuel quality and vehicle technology. However, there is little space for development here. Therefore, we must develop and promote the appropriate technology for capturing unconventional renewable energy sources in order to satisfy our energy demands [4]. Due to the increase in fuel costs, depletion of global hydrocarbon reserves, increase in pollution, and shortage of traditional petroleum-based goods, everyone is now seeking for new technologies and alternative fuels [5–6]. Methanol, Hydrogen, LPG, Ethanol, LPG, and trans-esterified vegetable oils (Biodiesel) are examples of alternative fuels that have been studied or used commercially in engines [7].

Because crude vegetable oil is difficult to use as a fuel, it must be converted into a more practical fuel, such as biodiesel. Over the years, researchers and scientists have given particular attention to biodiesel to establish if using biodiesel and a biodiesel mix is feasible [8]. Numerous studies [9–10] have been conducted on the topic of its preparation, combustion, and performance. Due to its bigger triglyceride molecule and greater molecular mass, edible oil has a greater viscosity. Utilizing spent cooking oil as fuel in a diesel engine, which converts the oil into biodiesel, a monoalkyl ester with a reduced viscosity, is the most effective method for addressing the problem. Due to the almost 11–13% oxygen availability of biodiesel, the fuel may be entirely burned during cylinder combustion. Additionally, biodiesel has a higher cetane number than diesel. The primary drawback of pure plant oils is that their viscosity is greater than diesel. Using pure vegetable oil in diesel engines necessitates changes to the engine or fuel. Other engine modifications include dual fueling, better injection systems, heated fuel lines, and others. Among the adjustments to fuel is the addition of vegetable oil to diesel. Compared to conventional diesel, vegetable oils have various advantages. Vegetable oils are liquid fuels generated from plants that don't impose significant environmental impact. Producing vegetable oil takes less energy. Vegetable oils contain around 90% of the heat content of diesel and a ratio of 2-4:1 for output to input. Burning vegetable oil produces cleaner emissions [11-12].

This study combines an ideal binary bio-alcohol fuel mix with a minimal percentage of an oxygenated addition to produce an outstanding ternary blend (D-B-N-M). This study varies from previous studies in the sector since few suitable ternary fuel mixes have yet to be established. Using the results of the present experimental investigation at engine speeds ranging from 1200 to 2100, the optimal DBNM blending ratio is identified. This will result in less emissions and enhanced performance. Additional study in this area might save significant time and money for future projects of this kind.

2. Material and experimental setup

2.1 Fuel specification

It is largely for the purpose of optimising the impact that the compounds have on improving the combustion efficiency of liquid fuels that biodiesel or diesel should have the correct distribution of nitro methane emulsion. Biodiesel is a feasible alternative fuel since it offers similar fuel properties to diesel. The acronym DBNM refers to a fuel mixture that contains diesel, biodiesel, nitromethane, and methanol. The most important of nitromethane (NM) chemical features are outlined in Table 1. The biodiesel, nitromethane, and diesel components of each and every DBNM (diesel-biodiesel-nitromethane-methanol) combination were mixed together in the appropriate proportions and concentrations. After initially filling a glass container with diesel fuel in accordance with the mixing ratio, the container was followed by the addition of biodiesel in accordance with the mixing ratio. After that, a magnetic stirrer was used to make the mixture as uniform as possible. After that, the diesel-biodiesel combination was similarly mixed with nitromethane at concentrations of 1%, 2%, and 3% respectively. The fuel sample, which can be seen in Figure 1, as well as the fuel's attributes, which can be found in Table 2.

Table 1
Properties of nitro methane (NM).

Sr. No.	Properties of fuel	value
1	Molar formula	CH3NO_2
2	Molar mass	61.04 g/mol
3	Appearance	Colorless liquid
4	Density	1.1371 g/cm^3
5	Melting point	-29 °C
6	Boiling point	100-103 °C
7	Solubility in water	Ca.10g/100 mL
8	Acidity (pKa)	10.2
9	Viscosity	0.61 mPa-s @25 °C
10	Flash point	35 °C
11	Calorific value	11.3 MJ/kg

Fig. 1. Diesel fuel.

Table 2
Properties of various fuels and its blend.

Properties	Diesel	Millettia Pinnata biodiesel	Nitromethane
Viscosity, centistokes at 40 °C	3.2	4.2	4.1
Pour point °C	-20	2	-28.6
Lower heating value (MJ/kg) *	42.0	34.2	11.4
Flash point °C	185	155	34
Density(g/ml) at 15 °C	830	880	1138
Cetane number *	49	51	-
Cloud point °C	6	4	-25

2.2 Experimentation

In the tests, an air-cooled eddy current dynamometer and a single-cylinder, four-stroke, constant speed, water-cooled, direct-injection, 661 cc, 5.2 kW diesel engine were employed. Table 3 is a list of the technical specifications for the engines and associated measuring apparatus. The essential input signals from the load measurement sensors, the fuel, water, and air flow sensors, as well as the temperatures sensors, were connected to the computer using a piezo powering cum amplifier unit. LABVIEW software was used to evaluate engine performance in real-time. Fig. 2 depicts the experimental setup schematically. The configuration for the engine test bed is designed to analyse the engine's performance under various operating conditions. In this configuration, an eddy current dynamometer is linked to a single-cylinder, four-stroke, and direct-injection diesel engine. It has the equipment needed to measure combustion pressure, crank angle, load, temperatures, airflow, and fuel flow. These signals are interfaced with computers to track engine performance and other operating characteristics.

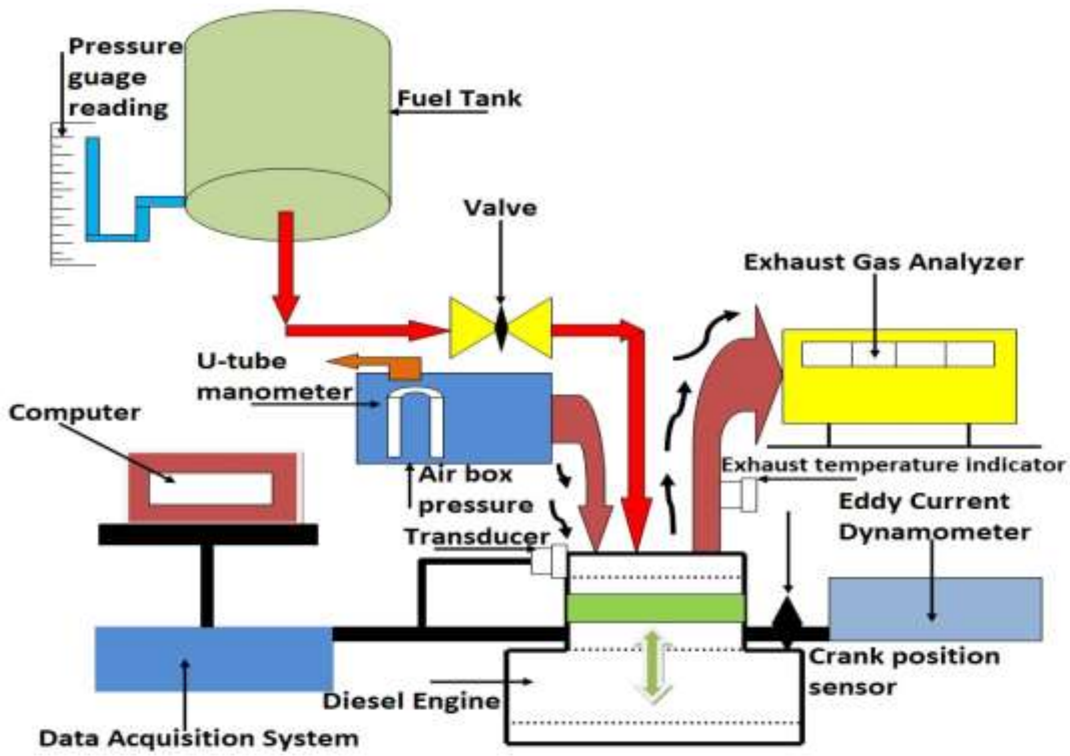

Fig. 2. Experimental setup.

Table 3
Engine specifications

Name of specification	Values
Type	Vertical, Water cooled, Four stroke
Speed, cylinder	1200-2100 rpm, one
Bore, Stroke (mm)	87.5, 110

Model	TV-1
Maximum power	5.2 kW
Injection opening angle	23° b TDC
Dynamometer	Eddy current dynamometer
Cubic Capacity (ltr)	0.661
Compression ratio	17.5:1

2.3 Uncertainty Analysis

Any experimental research is susceptible to errors because of the way the engine operates, human error, the precision of the measurement tools, the test protocol, etc. During the collection of experimental data, there is a chance for uncertainty or inaccuracy. Equation was used to determine the uncertainty for all equipment and devices utilised in the test configuration. The root-square sum approach was used to determine the precision for a specified parameter. Table 4 displays the findings of the uncertainty analysis of the various performance metrics and exhaust emissions. Analysis' range of uncertainty fell well within an acceptable range compared to other studies in this sector.

$$\text{Total uncertainty} = \text{square root of } [\,BTE^2 + BSFC^2 + smoke^2 + CO^2 + {CO_2}^2 + UHC^2 + NOx^2 + {O_2}^2]$$

Table 4
Uncertainty of parameters

Parameter	Range	Resolution	Uncertainty (%)
BTE	13-29 %	-	±1.25
BSFC	0.25-1.42 kg/kW-h	-	±1.3
Smoke	7-68 HSU %	0.1 %	±0.05
CO	0.025-0.22 %	0.01 % volume	±1.5
CO_2	0.016-0.25	0.03	±2.3
UHC	10-15 ppm	1 ppm volume	±2.5
NOx	20-575 ppm	1 ppm volume	±3
O_2	0.001-0.015	0.005 %	±0.8

3. Results and discussions
3.1 Performance parameter

3.1.1 Brake thermal efficiency

The variation of BTE with speed is represented in the performance prediction made by the current research **Fig.3** for D, B10, B10NM1, B10NM2, B10NM3, and they were conducted at different speeds of 1200-2100 rpm with full load. For all test fuels, the BTE of the engine increased with engine speed. Nitromethane-enriched biodiesel blends have a greater BTE than B10 due to the higher flame travel velocity. Even while the B10 blend had lower BTE than D100 at all the speed due to variables such improper fuel mixing, incomplete combustion, and early combustion.

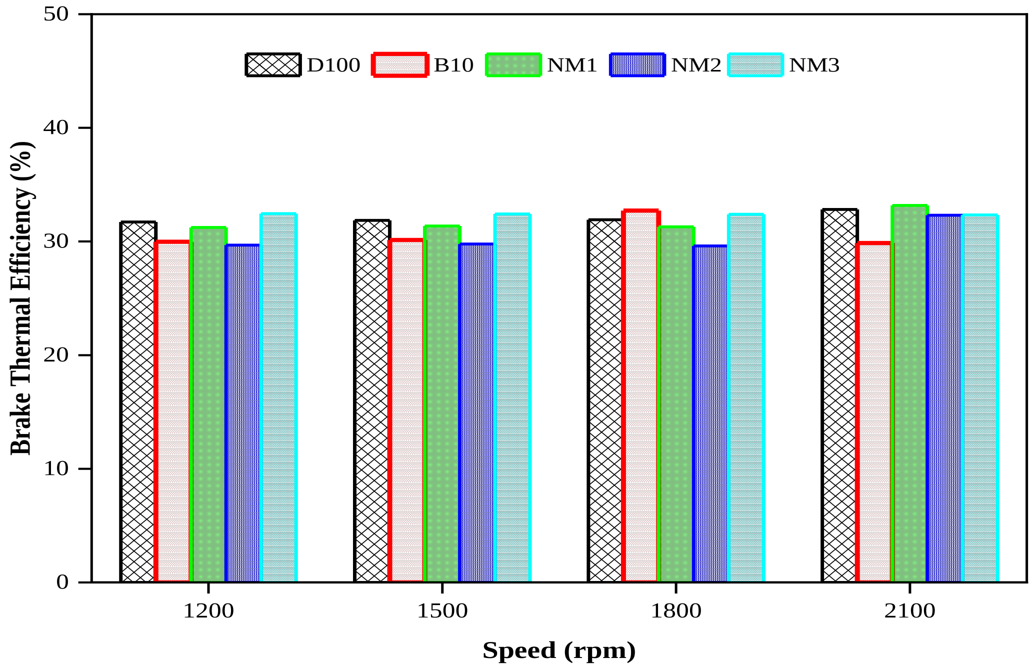

Fig. 4. BTE vs rpm for D-B10-B10NM1- B10NM2- B10NM3.

3.1.2 Brake specific fuel consumption

The variation of brake specific fuel consumption (SFC) with engine speed (1200-2100 rpm) is represented in the performance prediction made by the current research **Fig.4** for D100, B10, B10NM1, B10NM2, and B10NM3 with full load. For all test fuels, the SFC of the engine decreased with engine speed. Nitromethane-enriched biodiesel blends have a greater SFC than B10 and D100 due to the lower calorific value. Even while the blend (B10) had lower SFC than B10NM1, B10NM2, and B10NM3 blends at all the speed. As a result of methanol lower density (791 kg/m3) compared to diesel (830 kg/m3), it may be simpler to produce stable mix solutions. Due to methanol and nitro-methane increased oxygen content compared to diesel, these fuels have higher BTE and lower BSFC values.

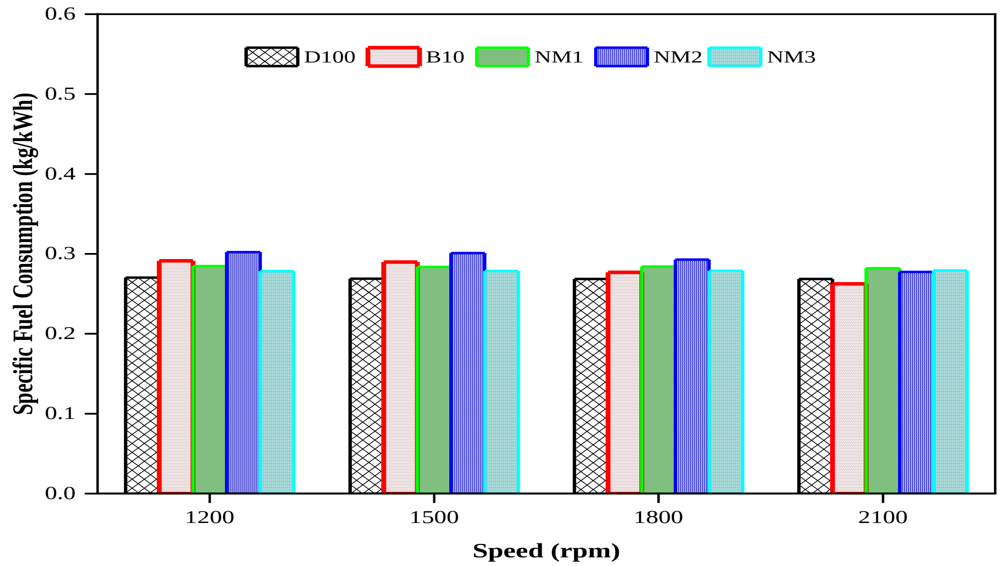

Fig.4. Brake specific fuel consumption vs rpm for D-B10-B10NM1- B10NM2- B10NM3.

3.1.3 Exhaust gas temperature

Exhaust gas temperature (EGT) change with engine speed (1200-2100 rpm) is shown in **Fig.5** of the current research performance prediction for D100, B10, B10NM1, B10NM2, and B10NM3 under full load. Similar to BTE, EGT rises as engine rpm increases due to higher thermal efficiency. Despite the decrease in BSFC as engine speed increased, the EGT grew dramatically due to growing cylinder temperatures and pressure. Due to their high vaporisation temperatures and high heating values, NM blends generated lower EGT than diesel fuel and B10 at 2100 rpm and 100 percent engine load. In contrast, the B10NM2 and B10NM3 have a lower EGT than the B10NM1 due to inadequate fuel mixing and lower calorific values. In addition to the aforementioned features, auto ignition temperature is a key factor for NM mixed fuels with higher EGT values.

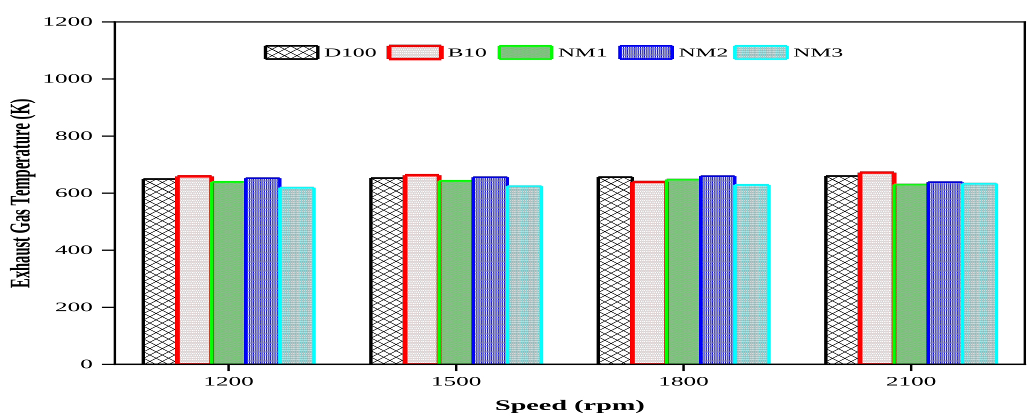

Fig. 5. Exhaust gas temrature vs rpm for D-B10-B10NM1- B10NM2- B10NM3.

3.2 Combustion parameter

3.2.1 Cylinder pressure

Figure 6 illustrates the relationship between cylinder pressure and crank angle for different engine loads. At 2100 rpm, B10NM1 had a greater cylinder pressure than the other mixtures. B10NM1 was discovered to have the greatest cylinder pressure besides diesel, followed by B10NM2, B10NM3, and B10. Compared to B10, the cylinder pressure rises when NM is added to the fuel, but it decreases when the strength of the NM mix is raised. The findings demonstrated that a decrease in cylinder pressure occurs from an increase in NM content. Due to fuel characteristics, NM enhanced blends have a greater cylinder pressure than ordinary blends. An explosion in the intake manifold was another important contributor to the alarming pressure rise.

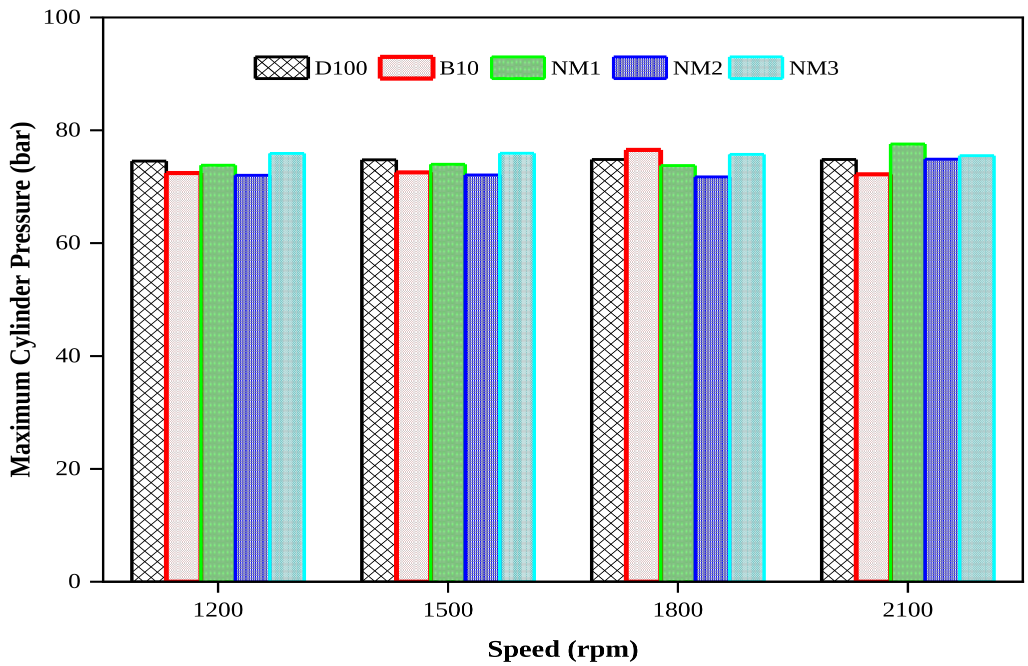

Fig. 6. Inline cylinder pressure vs rpm for D-B10-B10NM1- B10NM2- B10NM3.

3.2.2 Ignition delay

Figure 7 depicts the variability of ignition delay with load in the performance estimate generated by the present study. Diesel had the longest ignition delay values of all the loads examined. This behaviour may be due to the fact that diesel has a lower cetane number than mix, which makes it simpler to manufacture stable blend solutions. Despite including biodiesel fuel with a lower calorific value and a higher cetane number, the B10NM1, B10NM2, and B10NM3 blends had a longer ignition delay. When the cetane number is high, less combustible fuel is produced during the ignition delay, hence reducing the ignition delay. The ignition delay was determined to be 12.7, 10.44, 13, 13.2, and 11.3 degrees for diesel, B10, B10NM1, B10NM2, and B10NM3, respectively, at 100% load at 2100 rpm.

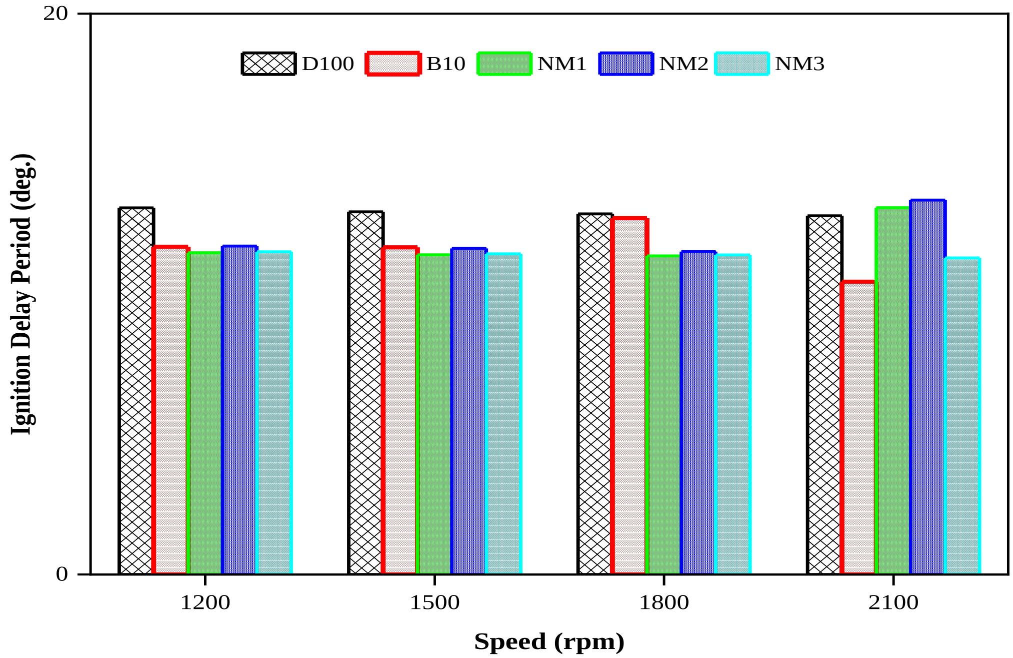

Fig. 7. Ignition delay vs rpm for D-B10-B10NM1- B10NM2- B10NM3.

3.3 Emission parameter

3.3.1 CO_2 emission

Figure 8 displays the variation in CO_2 emission with load for the performance estimate derived from this investigation. CO_2 emissions mostly rose from 1200 to 2200 revolutions per minute. It is mostly owing to methanol's lower density, which makes the blend solution more homogenous, as well as nitro-methane and methanol's greater volatility compared to diesel, both of which improve combustion quality. The high oxygen concentration, which ensures there is sufficient oxygen in the fuel-rich zone that oxidises the smoke, is an additional factor that favours a better outcome. Diesel, B10, B10NM1, B10NM2, and B10NM3 had CO_2 emissions of 865.4, 931.87, 837.3, 860, and 858.8 g/kWh, respectively, at 100% load and 2100 rpm. The higher value of CO2 associated with the B10 blend may have been produced by the higher latent heat and auto-ignition temperature of methanol. Because methanol has a greater latent heat than other fuels, it cools the air-fuel combination prior to combustion, resulting in incomplete combustion. By delaying combustion, a greater methanol self-ignition temperature may result in incomplete combustion and increased CO2 emissions.

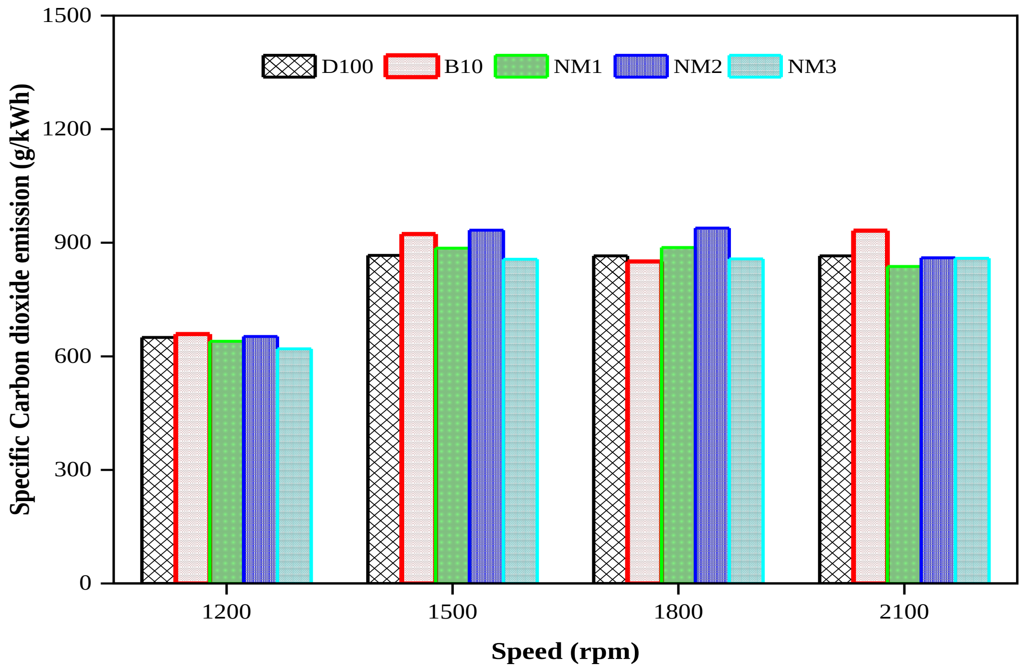

Fig. 8. % CO_2 emission vs. rpm for D-B10-B10NM1- B10NM2- B10NM3.

3.3.2 Smoke emission (HSL)

The fluctuation in HSL emission with load for the performance estimate produced from this experiment is shown in Figure 9. The majority of HSL emissions increased from 1200 to 2200 revolutions per minute. It is mostly due to methanol's lower density, which makes the blend solution more homogeneous, and nitro-methane and methanol's increased volatility compared to diesel, both of which enhance combustion quality. The high oxygen content, which guarantees that there is enough oxygen in the fuel-rich zone to oxidise the smoke, is an additional aspect that favours a favourable result. Diesel B10, B10NM1, B10NM2, and B10NM3 exhibited respective HSL emissions of 41.101, 49.241, 30.013, 37.197, and 36.808 at 2100 rpm and 100 percent load.

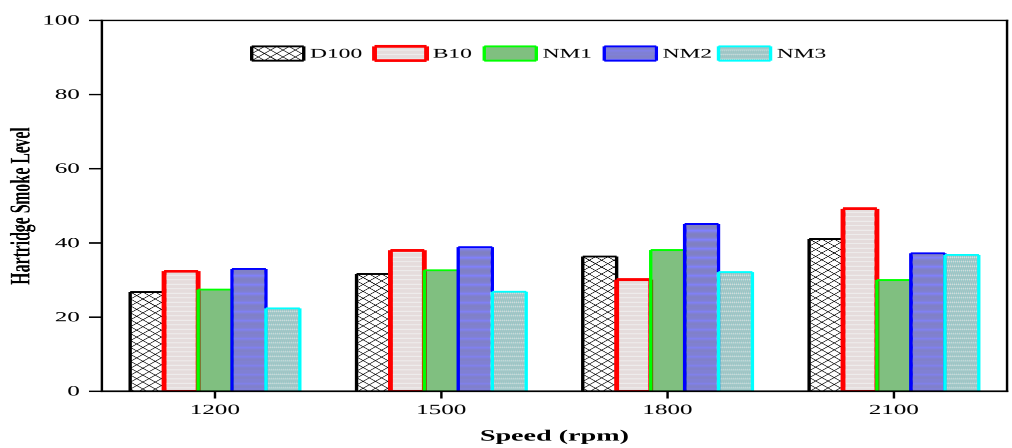

Fig. 9. Smoke emission vs. rpm for D-B10-B10NM1- B10NM2- B10NM3.

3.3.4 NO_x emission

Figure 10 illustrates the fluctuation in NO (g/kWh) under different speed situations. The NO from the fuel nitrogen present in the nitro-paraffin structure is low compared to the NO produced by heat. Consequently, the present research solely examined thermal NO. It was discovered that the B10NM3 mixture had the greatest thermal NO level compared to the B10 mixture. As engine speed rises, nitrogen oxide levels significantly fall down. Nitrogen oxidation is caused by the incomplete combustion of the mixtures, which increases heat flow and causes a large temperature rise. Extremely high cylinder temperatures help in NO generation. NOx generation may be considerably minimise by regulating the flame temperature, cylinder pressure, combustion duration, and oxygen content in the mixes.

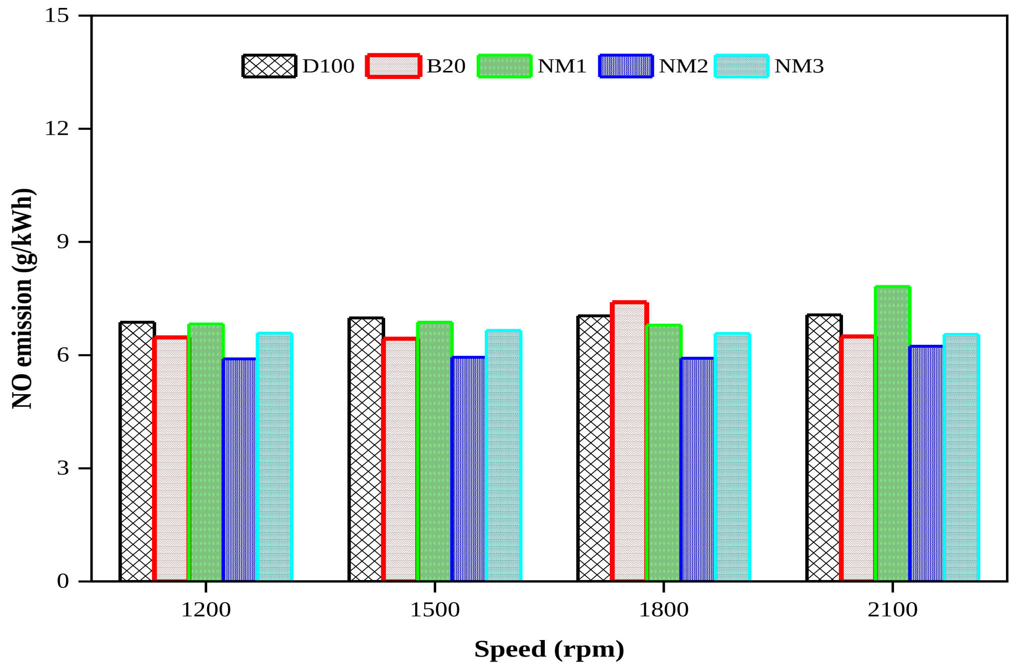

Fig. 10. NO emission vs. rpm for D-B10-B10NM1- B10NM2- B10NM3.

4. Conclusions

In experimental tests, a stationary VCR CI engine functioning and exhaust emission properties were investigated using mixtures of diesel, biodiesel, methanol, and nitro methane.

- Since a result of its high oxygen concentration, the B10NM3 combination was shown to be the most helpful, as its combustion capabilities were enhanced.
- At full load conditions, B10NM1 considerably improves engine performance (greater BTE and 2.0% higher pressure than B10).
- Significant improvements were seen in exhaust gas temperature, ignition delay, and BSFC at CR 18 when comparing the B10NM3 mix to B10. Under same operating

conditions, conventional CI engines driven by B10NM emit more nitrogen oxide than engines fuelled by diesel or biodiesel.

Nomenclature

BTE	Brake thermal efficiency
BSFC	Brake specific fuel consumption
B10	10% Millettia pinnata biodiesel and 90% diesel
B10NM1	10% Millettia pinnata biodiesel, 1% nitromethane, 2% methanol and 87% diesel
B10NM2	10% Millettia pinnata biodiesel, 2% nitromethane, 2% methanol and 86% diesel
B10NM3	10% Millettia pinnata biodiesel, 3% nitromethane, 2% methanol and 85% diesel
CR	Compression ratio
CO	Carbon monoxide
CO2	Carbon dioxide
EGT	Exhaust gas temperature
HC	Hydrocarbons
CI	Compression ignition
IP	Injection pressure
NOx	Nitric oxide
PPM	Part per million
VCR	Variable compression ratio

Conflict of interest

The authors declare that they have no conflict of interest.

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Authors' contributions

- **Md Ashfaque Alam:** Methodology; Writing original draft.
- **Anil Kumar Prasad:** Reviewing & final drafting.

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