Received: 1 October 2021 | Revised: 20 June 2022 | Accepted: 24 July 2022
DOI: 10.1002/ep.13958

ORIGINAL RESEARCH
Sustainable Energy

ENVIRONMENTAL PROGRESS & SUSTAINABLE ENERGY

An experimental study on synthesis of ternary biodiesel through potassium hydroxide catalyst transesterification

Elango Murugesan[1] | G. Radhakrishnan Kannan[2]

[1]Department of Mechanical Engineering, RVS Technical Campus Coimbatore, Coimbatore, Tamilnadu, India

[2]Department of Mechanical Engineering, PSNA College of Engineering and Technology, Dindigul, Tamilnadu, India

Correspondence
Elango Murugesan, Department of Mechanical Engineering, RVS Technical Campus Coimbatore, Coimbatore, Tamilnadu 641402, India.
Email: elango3088@gmail.com

Abstract

The novelty of this study is synthesis fuel of biodiesel from the *Brassica napus* seed oil (BN-B), *Linum usitatissimum* seed oil (LU-B) and diesel to improve the performance of SCDE and minimize the CO_2 emissions. BN-B and LU-B were produced using a 0.1 N potassium hydroxide catalyst and methanol to synthesis biodiesel from *B. napus* and *L. usitatissimum* seed oil. The glycerine and biodiesel are separated using the transesterification filtration process. The research was carried out without any modifications with the objective of analyzing performance and emissions in a SCDE at variable load and constant speed. SCDE investigates the impact of five different triple combinations of BN-B and LU-B blended with diesel. The experiments yielded the following results, B1-B and B2-B have calorific values of 42.2 and 41.6 MJ/kg, respectively. The fuel consumption of the triple blend combination was lower than that of the diesel at full load and constant speed. The triple blend combination emits less nitrogen dioxide (NO_2) and carbon monoxide (CO) than diesel, according to the results of the emission tests.

KEYWORDS
biodiesel, *Brassica napus*, *Linum usitatissimum*, potassium hydroxide catalyst, seed oil, transesterification filtration

1 | INTRODUCTION

Energy supply and demand are intertwined with India's core economic grade. The consistent growth of the Indian economy is dependent on the availability of primary energy sources. Diesel fuel has an impact on the Indian economy because it is widely used in automobiles, power generation, and agriculture. The single-cylinder diesel engine (SCDE) is widely used in both domestic and electric power generation applications.[1] Low fuel consumption, high thermal efficiency, lower pumping, and a higher compression ratio are all desirable characteristics for a high-performance engine.

Energy availability is inversely proportional to the requirement of energy in recent years. The growth of urbanization and industrialization were resulting in massive exhaust of greenhouse gases and hazards to the health of all living things.[2] Finding a suitable fuel to replace diesel while also improving the performance of diesel engines reduces emissions due to unburned hydrocarbons (UBHC).[3] The most recent technology suitable for an alternative is bio-diesel, which is blended with diesel to power the SCDE. It provides the opportunity to reduce emissions because of characteristics such as renewable, locally available, environmentally friendly, non-toxic, bio-decomposable, and non-contaminated.[4] Biodiesel is made from vegetable oils and has standard SCDE performance and emission reductions.[5]

Biodiesel blends are oxygenated fuels that help to reduce pollution in the environment.[6,7] It was made from the recycling of engine waste oil and cooking waste oil. This will reduce the complexity of dumping waste oil into the environment.[8] The use of these blends resulted in longer ignition delays.[9,10] It was containing more than 10% vegetable oil have a shorter ignition delay.[11] The biodiesel blends reduced CO_2, CO, HC, and smoke opacity emissions.[12] It was used to have higher NOx emissions. At low and medium loads, it was remarkably similar to diesel.[13] The lower calorific value and higher viscosity of biodiesel blends may result in higher brake specific fuel consumption (SFC).[14]

Biodiesel was produced from vegetable oils, including edible, inedible, waste, and animal fat. Biodiesel was produced from non-edible plants such as Jatropha, Mahua, Pongamia, Neem, Passion seed, Rape seed, Rubber seed, Linseed, Coffee ground, Cotton seed, Karanja, or honge, and Pachira glabra worldwide.[15] Because of its high viscosity, low volatility, and unsaturated composition, the seed oil is difficult to use as a fuel for diesel engines.[16] There are at least four different ways to change these: dilution, transesterification, pyrolysis, and microemulsion.[17]

To produce biodiesel from seed oil, researchers used the transesterification method, which produces a higher yield.[18] The factors considered for the biodiesel yield to depend on the reaction temperature, reaction time, preheat time, molar ratio, preheat temperature, and catalyst concentration.[19] The transesterification filtration process increases the yield of seed oil. The following steps are used to produce biodiesel: transesterification, filtration, esterification, and alcohol catalyzer.[20] Fatty acid esters and glycerine are the main by-products of the process.[21] Methanol, ethanol, butanol, and amyl are different types of alcohol, which is used in the transesterification process.[22]

The catalytic treatments used in biodiesel help to reduce nitrogen oxide and particulate matter emissions.[23,24] Ethanol combined with diesel at a volume ratio of 10%–15% improved SCDE performance.[25] The BTE was increased by 2%, while CO emissions were reduced by 16%. The UBHC was increased by 40% when compared to using 100% diesel fuel in the engine.[26] Methanol-to-diesel blending reduced nitrogen oxides (NOx) emissions compared to ethanol-to-diesel blending.[27,28] Rape seed oil (*Brassica napus*) and linseed oil (*Linum usitatissimum*) contain non-edible vegetable oil and biopesticide chemicals.[29,30] In comparison to the diesel, the *B. napus* (BN-B) and *L. usitatissimum* (LU-B) have similar physical characteristics.[31,32]

Ragit et al.,[33] used methanol and potassium hydroxide (KOH) as a catalyst to investigate the best conditions for NOS transesterification filtering. The maximum NOS yield was 83%, with a kinematic viscosity of 2.7 cSt. Similarly, Karmakar et al.,[34] used the transesterification process with methanol or ethanol as a catalyst and obtained a maximum NOS output of 94% for methanol and 88% for ethanol. Dixit et al.[35] studied the transesterification filtration biodiesel extraction process. The maximum yield was obtained under optimal conditions, and LOS is a promising biodiesel source.

Linum usitatissimum availability in India ranges from 33% to 47%. Transesterification filtration produced the lower level of kinematic viscosity.[36] Dhamodaran et al.,[37] investigated the performance of biodiesel in an air-cooled SCDE at a 1:5 by volume ratio. SCDE was subjected to five different loads during the experiments: no-load, 25%, 50%, 75%, and full load. In comparison to diesel, the brake thermal efficiency (BTE) was reduced by 10.3% at full load. The temperature of the exhaust gas (EGT) was also raised by 5.6%. Nair et al.,[38] investigated the performance of various biodiesel blends of 10%, 20%, and 30% on SCDE water-cooled SCDE. Biodiesel produces higher BTE than diesel in all load conditions, according to the results of the experiments.

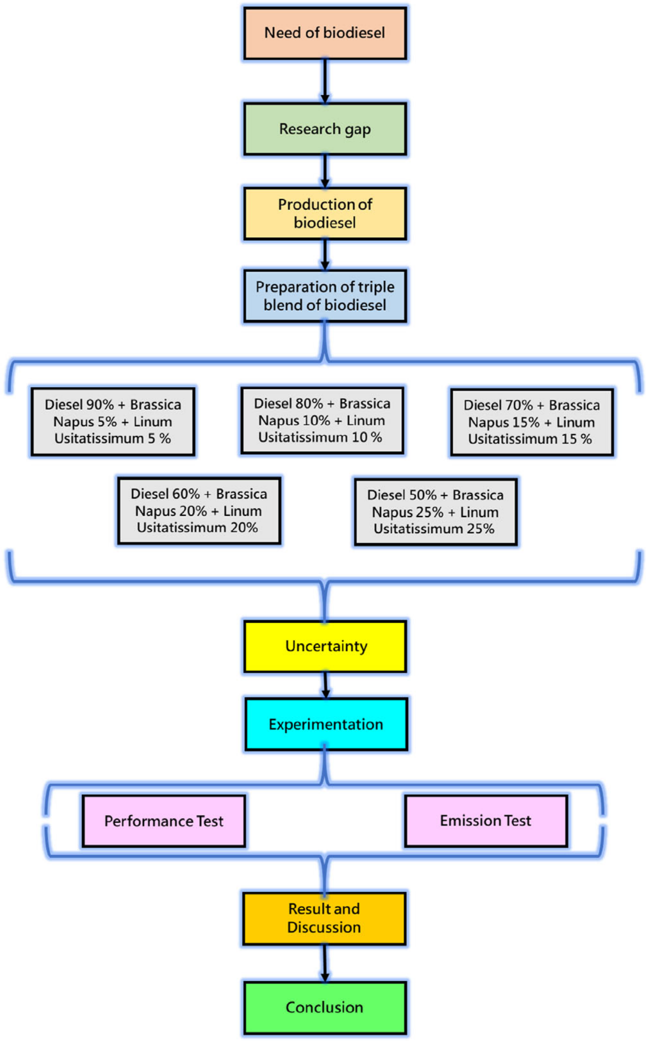

FIGURE 1 Flow chart of the methodology for this research

Karthikeyan et al.,[39] investigated the effects of two different LU-B-to-diesel blends at 1:10 and 1:5 for different injection timings. The experiments were carried out on SCDE, which recorded an increase in BTE and a decrease in SFC when compared to fuelled with 100% diesel.

According to Atabani et al.,[15] the cost of feedstock production alone accounts for 75% of the total cost of biodiesel production. To achieve a low manufacturing cost, it is difficult to select the optimal feedstock. Consistency in the transesterification process was also discovered to be an alternative for lowering manufacturing costs. Biodiesel is now uneconomical; it is necessitating to have further research and development to reduce the production cost. Biodiesel has the potential to be used as a fuel in traditional diesel engines, according to research.

Brassica napus and *L. usitatissimum* seeds are available all over the world. BN-B and LU-B from *B. napus* and *L. usitatissimum* are blended with diesel in various proportions to produce biodiesel blend. The novelty of this study is triple blending BN-B, LU-B, diesel to compared the emission and performance characteristics of a stationary SCDE water-cooled engine with diesel. A laboratory-scale biodiesel processor produces triple combinations. Biodiesel from 5%, 10%, 15%, 20%, and 25% of BN-B and LU-B is blended with pure diesel.

All triple biodiesel blend and diesel were tested in a naturally aspirated four-stroke SCDE loaded by the eddy current dynamometer at a constant engine speed of 1500 rpm. The results of the experiments were compared to 100% diesel.

2 | MATERIALS AND PROCEDURES

The purpose of this research is to use a transesterification filtering method to make biodiesel from *B. napus* and *L. usitatissimum*.[31,33,40–42] The biodiesel used in the SCDE water cooling had a higher BTE than the biodiesel used in the air cooling.[37,38] As a result, the experiments were carried out on a SCDE water-cooled (four-stroke, direct injection computed Kirloskar make) was powered by prepared biodiesel. The general layout of the methodology is shown in Figure 1.

2.1 | Synthesis of biodiesel

The *B. napus* and *L. usitatissimum* seeds used in this study were purchased from a local Coimbatore market. Methane-based transesterification filtration process separates glycerol and esters from *B. napus* and *L. usitatissimum* seed oil. A KOH catalyst was commonly used to increase the yield and reaction rate. Extra methane pushes the equilibrium toward the product because the reaction is reversible.[17]

2.2 | Method for production of biodiesel

The raw oil was extracted using a standard method that included mechanical pressing and a solvent extraction process. The *B. napus* and *L. usitatissimum* seeds were first filtered to remove small particles before being heated with blower air to 35–45°C. The initial moisture of seeds is removed during the heating process. The seed's hardness was reduced, and its elasticity was improved. The outer cells of the seed are removed by flaking. Seeds with a diameter of 0.3 mm were fed into the flaking machine. The flaked seeds were heated to 70–100°C in the heating bunker to remove any remaining moisture content. Preliminary flaked seed was pressed using a screw press. The oil extracted from preliminary pressing accounts for 70% of the total amount of oil extracted. The oil extracted from the press cake in the range of 20%–30%.

The crushed press cake was heated to 100°C. The 70% hexane solvent was mixed with the 30% oil obtained by extrusion from press cakes. The distillation process was used to remove the solvent after processing. The extracted oil was refined further by removing gum particles, then neutralized and bleached to improve purity. LU-B was also alkali refined to neutralize the citric acid and free fatty acids. The remaining water after alkali refining was removed by vacuum drying.

Dissolve 4 g KOH pellet in 1000 ml distilled water to make a 0.1 N KOH dilution. The fresh oil was mixed with methanol and diluted in 0.1 N KOH in the following proportions: In a three-way flask, combine 400 ml of fresh LU-B/BN-B + 9 ml of dilute 0.1 N KOH solution +100 ml of methanol. This mixture was kept at 60° for 1 h and 30 min. The mixture can be left to cool at room temperature for up to 24 h after it has been heated. Figure 2 shows the flow chart for the transesterification process. Glycerine separation: Glycerine is detected near the bottom of the flask and must be manually removed. The quantity of glycerine separated after transesterification was measured using an electronic balance. Table 1 depicts the blending of the triple composition of diesel, BN-B, and LU-B. Figure 3 shows the sample of triple blended biodiesel used in SCDE experiments.

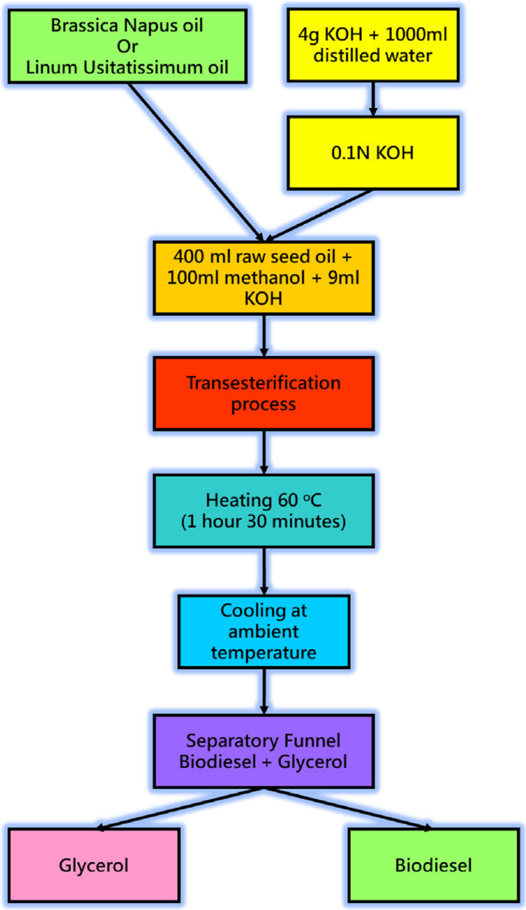

FIGURE 2 Process of production of biodiesel

TABLE 1 The triple biodiesel blend combination

Fuel	Combination of blending		
	Diesel (%)	*Brassica napus* (%)	*Linum usitatissimum* (%)
Diesel	100	0	0
B1-B	90	5	5
B2-B	80	10	10
B3-B	70	15	15
B4-B	60	20	20
B5-B	50	25	25

FIGURE 3 Sample of triple blended biodiesel

The qualitative analysis of percent of yield was found by EN 14103 (European standard). The percent of yield from the BN-B and LU-B was calculated Equation (1). The equipment used for determination of the methyl ester formation from BN-B and LU-B by gas chromatograph. The carrier gas used was nitrogen. The capillary column used to inject the sample and oven temperature at 230°C (5°C/min).

$$\text{Percent of yield} = \frac{\sum A_t - A_p}{A_p} \times \frac{C - V}{m} \times 100, \tag{1}$$

where, A_t is the total peak area, A_p is the corresponding peak area of methyl heptadecanoate, C is the concentration (mg/ml), V is the volume (ml), and m is the mass (mg).

The viscosity was measured by using viscometer and followed by standard EN ISO 3104. The calorific values were measured by using bomb calorimeter and followed by standard D240. The density was calculated by mass/volume and followed by standard EN ISO 12185. The mass was measured by digital balance. The flash point value was measured by using Penske–Marten apparatus and followed by standard EN ISO 2719. The cetane number calculated by Equation (2) and followed by standard EN ISO 5165.[43,44]

$$\text{CN} = \sum_i \text{CN}_i \times x_i, \tag{2}$$

where, CN is the cetane number of blend, CN_i is the cetane number of each oil mixed in blend, and x_i is the molar fraction.

The saponification value (SV) and acid value (AV) were found out by below equations.[45,46]

$$\text{SV} = \frac{(V_b - V_s) \times 56.1 \times 0.5}{m}, \tag{3}$$

where, V_b is the volume of blank titration (ml), V_s is the volume of the oil titration (ml) and m is the mass of the oil (g).

Acid value (AV) (mg KOH/g)

$$\text{AV} = \frac{56.1 \times V_{\text{KOH}} \times C_{\text{KOH}}}{m}, \tag{4}$$

where, V_{KOH} is the volume of 0.1 mol/L KOH consumed (ml), C_{KOH} is the concentration of the titration KOH solution (g/mol) and m is the mass of the oil (g).

TABLE 2 Fatty acid (saturated and unsaturated) of *Brassica napus* and *Linum usitatissimum*

			Weight %	
Acid chain	**Structure**	**Type**	**RSO**	**LSO**
Palmitic acid	16:00	S	4.6	6.58
Stearic acid	18:00	S	3.2	4.43
Oleic acid	18:01	US	60.7	18.51
Linoleic acid	18:02	US	20.5	17.25
Linolenic acid	18:03	US	9.3	53.21
Saturated fatty acid			8.80%	11.01%
Unsaturated fatty acid			91.11%	88.97%

The FFA conversion rate

$$\text{FFA} = \frac{(F_i - F_f)}{F_i} \times 100\%. \tag{5}$$

BN-B and LU-B have nearly produced 97% and 96% of biodiesel from these seed oils. The average difference of viscosity between diesel and all blend was 0.4. So, blends have better atomization properties. Increases the economic return on biodiesel combining those two seed oils with diesel. Tables 2 and 3 are shows the saturated and unsaturated fatty acid composition and properties of BN-B and LU-B. The fatty acid content of *B. napus* and *L. usitatissimum* is shown in Figure 4.

2.3 | Experimental setup

The Kirloskar computerized CI engine was used in the experiment. This engine is more pressure resistant and can be used in agriculture and industry. Farmers in India also use it as irrigation pumps in their fields. Farmers currently use approximately 14.1 million of these pump sets. A load-bearing electrical dynamometer was coupled to the engine. A dynamometer was used to measure the engine's output. Before being used in experiments, the dynamometer is statistically calibrated. Figure 5 depicts the experimental setup scheme. The field current is used to control the load.

In the SCDE, the manufacturer provided a standard fuel injection system, which was used for this experiment.

TABLE 3 Properties of *Brassica napus* and *Linum usitatissimum*

Fuel properties	*Brassica napus*	*Linum usitatissimum*	EN 14214/ASTM limit	Test methods
Density @ 15°C (kg/m^3)	920	892	875–900	ASTM 1298, EN ISO 12185
Acid value (mg KOH/g)	0.6	0.8	0.5 max.	EN 14104, D 664
Viscosity @ 40°C (cSt)	2.6	2	3.5–5	ASTM D445, EN ISO 3104
Cetane number	53	44	51 min	EN ISO 5165
Calorific value (MJ/kg)	36	39.21		D240
Flash point (°C)	220	265	130 min	EN ISO 2719, D 93
Saponification	198	190	-	-

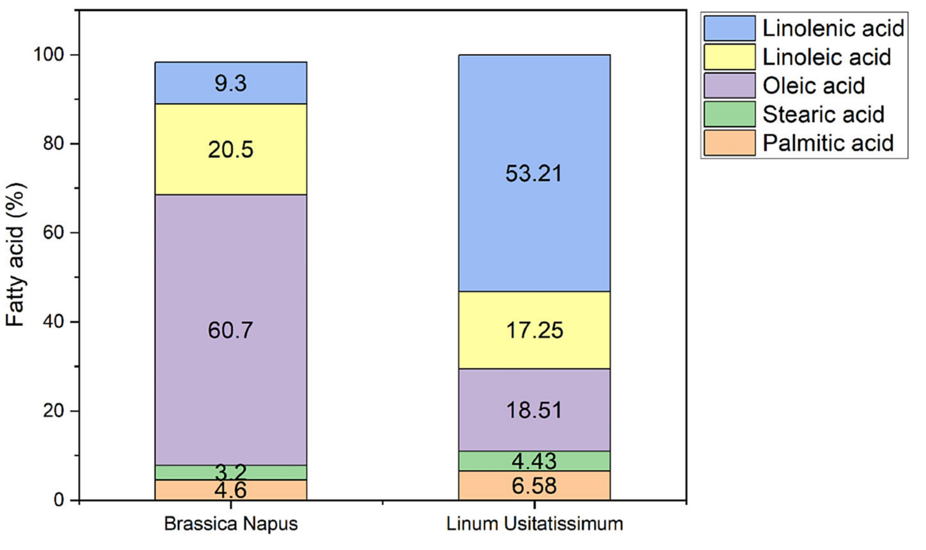

FIGURE 4 Fatty acid content of *Brassica napus* and *Linum usitatissimum*

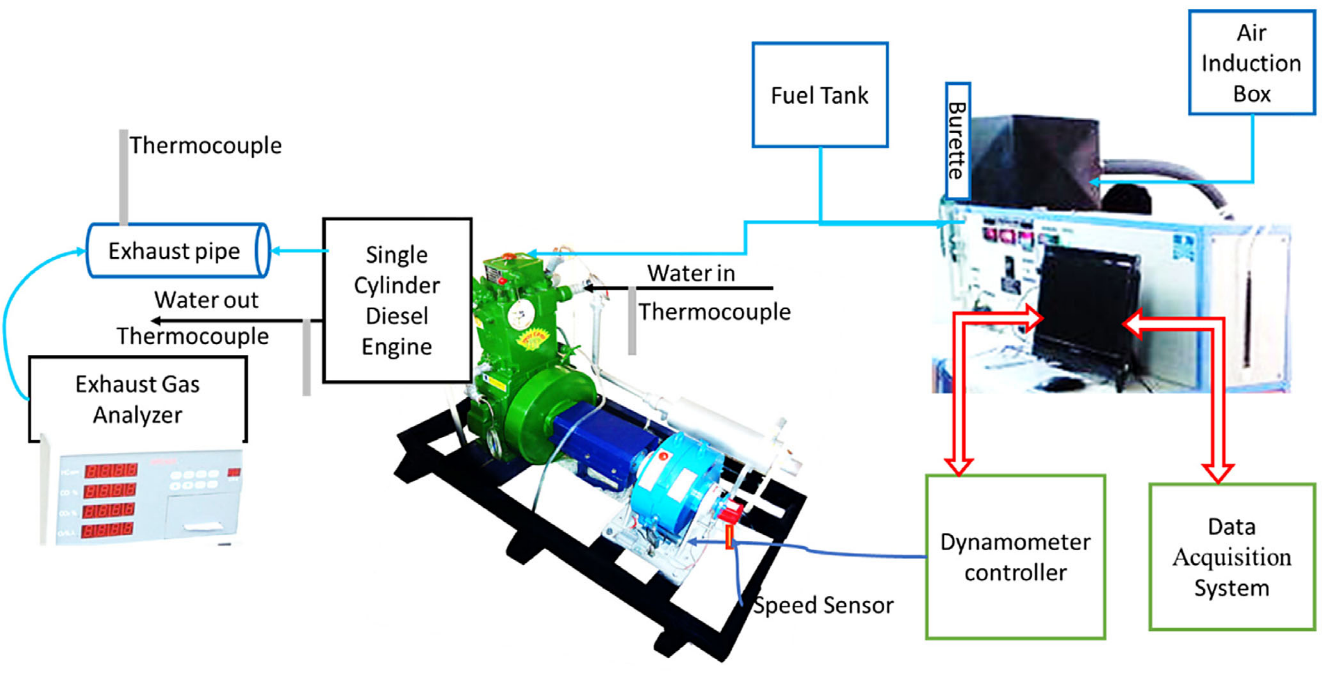

FIGURE 5 Schematic of SCDE

TABLE 4 Specification of the SCDE

Factors	Specification
Type	4-Stroke, 1-cylinder, diesel engine (water-cooled)
Made	Kirloskar
Ignition type	Compression-ignition
Brake horsepower	5 hp
Compression ratio	16:1
Loading	Eddy current dynamometer
SCDE speed	1500 rpm
Bore diameter "*d*"	0.08 m
Stroke length "*l*"	0.11 m
Power	3.72 kW
Starting method	Manual

Table 4 shows the specifications of the SCDE. The airbox gathered sufficient air for burning between the SCDE intake collector and the exhaust pipe.

Using a K-type thermocouple, EGT (exhaust gas temperature) was constantly monitored to ensure that the engine was being operated properly. Unburned HC, nitrogen dioxide, and carbon monoxide emissions were measured using an exhaust gas analyzer. Prior to emission testing, a routine leak check was performed. Emissions were measured by placing the sensor in a specially designed expansion pipe. On one end, the pipe connects to the analyzer inlet, and on the other, it connects to the exhaust gas output. Engine performance refers to how well an engine does its job, such as converting chemical energy into a mechanical operation that can be used.

A five-gas emission smoke analyzer was utilized to determine the density of the smoke under various loading conditions. The SFC, BP, IMEP, exhaust smoke, and other pollutants were used to evaluate the engine's performance by varying the load.

2.4 | Mathematical modeling

The SCDE's brake power (BP) is estimated by giving an eddy current loading to the SCDE.[41,47]

$$\mathrm{BP} = V \times I \times \frac{(\cos \varphi)}{1000}, \tag{6}$$

where, BP in kW, V is voltage in V, I is current in A, φ is resistive loading. Fuel consumption (FC) was monitored for a specific volume of fuel (50 ml) using a burette connected to the fuel pipeline through a cut-off valve. FC is calculated as follows:

$$\mathrm{FC} = \frac{B \times \rho \times 3600}{t \times 1000}, \tag{7}$$

where, FC in kg/h, B is the fuel burette reading (ml), ρ is the fuel density (g/ml), and t is the fuel consumption (s). The relationship is used to compute the SFC,

$$\mathrm{SFC} = \frac{\mathrm{FC}}{\mathrm{BP}}, \tag{8}$$

where, SFC in kg/h. Indicated mean effective pressure,

$$\mathrm{IMEP} = \frac{W_n}{V_d}, \tag{9}$$

where, W_n is the network in kW and V_d is the stroke volume in m^3.

$$W_n = \int p\, dV, \tag{10}$$

where, p is the cylinder pressure (N/m^2), and V is the volume (m^3).

$$V_d = \frac{\pi}{4} \times d^2 \times l, \tag{11}$$

where, d is the diameter of the bore in m and l is the stroke length in m. BTE is calculated using the relation,

$$\mathrm{BTE} = \frac{\mathrm{BP} \times t}{\mathrm{FC} \times \rho \times \mathrm{CV}}, \tag{12}$$

where, BP in kW, FC in kg/h, t in seconds, ρ in g/ml, CV is the calorific value of fuel in kJ/kg. Exhaust flow rate.[48]

$$\mathrm{EX}_g = I_a + \mathrm{FC}, \tag{13}$$

where, EX_g is the exhaust flow rate (kg/h), I_a is intake air (kg/h), and FC in kg/h. The following equations are used to compute the flow rate of NO′, NO′$_x$, CO′, HC′, and CO$_2$′ emissions in terms of g/h.[48,49]

$$\mathrm{NO}_2' = \mathrm{EX}_g \times \left(\frac{\mathrm{MW\ of\ NO_2}}{\mathrm{MW\ of\ air}}\right) \times \mathrm{NO}_2, \tag{14}$$

$$\mathrm{CO}' = \mathrm{EX}_g \times \left(\frac{\mathrm{MW\ of\ CO}}{\mathrm{MW\ of\ air}}\right) \times \mathrm{CO}, \tag{15}$$

$$\mathrm{HC}' = \mathrm{EX}_g \times \left(\frac{\mathrm{MW\ of\ HC}}{\mathrm{MW\ of\ air}}\right) \times \mathrm{HC}, \tag{16}$$

$$\mathrm{CO}_2' = \mathrm{EX}_g \times \left(\frac{\mathrm{MW\ of\ CO}}{\mathrm{MW\ of\ air}}\right) \times \mathrm{CO}_2, \tag{17}$$

where, MW is the molecular weight in g/mol. The overall emission in terms of g/kWh,

$$\text{Overall Emission} = \frac{\mathrm{NO}_2'}{\mathrm{BP}} + \frac{\mathrm{CO}'}{\mathrm{BP}} + \frac{\mathrm{HC}'}{\mathrm{BP}} + \frac{\mathrm{CO}_2'}{\mathrm{BP}}. \tag{18}$$

TABLE 5 Uncertainty results on Instrumentation

Instruments		Range	Accuracy	Uncertainty (%)
Exhaust gas analyzer	CO	0%–10% vol.	±0.1%	0.057
	CO_2	0%–20% vol.	±0.1%	0.057
	NO_2	0–5000 ppm	±1 ppm	0.57
	Smoke	1%–100%	±0.1%	0.057
	HC	0–30,000 ppm	±1 ppm	0.57
Viscometer (Redwood)		20–99°C	±1°C	0.57
Flash point apparatus (Penske Marten)		20–370°C	±0.5°C	0.2886
Bomb calorimeter		15–35°C	±0.01°C	0.0057
Voltmeter		0–300 V	±1 V	0.57
Ammeter		0–15 A	±0.1 A	0.06

3 | ANALYSIS OF EXPERIMENTAL UNCERTAINTY

Error is defined as the difference between the measured and actual value. If there are any irregularities or changes in physical quantity measurements during experimental testing, uncertainty calculations and analysis should address and validate the accuracy of experimental readings. All independent elements are distributed evenly and were measured based on the accuracy and calibration features of the equipment. The following properties are measured in the uncertainty tests: ρ, viscosity, current, voltage, exhaust gas analyzer, SFC, and IMEP.

If a measured quantity M is dependent on independent variables such as $x_1, x_2, x_3, \dots x_n$, then $M = M\,(x_1, x_2, x_3, \dots x_n)$. Let U_M represent the uncertainty in the measured quantity and $U_1, U_2, U_3, \dots U_n$ represents the uncertainties in the independent variables. The uncertainty in the measured quantity is then expressed as[50–52]

$$U_M = \sqrt{\sum_{i=1}^{n}\left(\frac{\partial M}{\partial x_i}U_i\right)^2}, \tag{19}$$

$$U_M = \sqrt{\left[\left(\frac{\partial M}{\partial x_1}U_1\right)^2 + \left(\frac{\partial M}{\partial x_2}U_2\right)^2 + \left(\frac{\partial M}{\partial x_3}U_3\right)^2 + \dots + \left(\frac{\partial M}{\partial x_n}U_n\right)^2\right]}, \tag{20}$$

$$\text{Exhaust gas uncertainty} = \sqrt{\left(CO^2 + CO_2{}^2 + NO^2 + NO_2{}^2 + HC^2 + \text{Smoke}^2\right)}. \tag{21}$$

The uncertainty of the exhaust gas is calculated using Equation (21) is 0.81%. The Equations (19) and (20) used to determine the uncertainty of each instrument and outcomes are tabulated in Table 5.

4 | RESULT AND DISCUSSION

4.1 | Triple blend biodiesel characterization

BN-B and LU-B were added to diesel in amounts of 5%, 10%, 15%, 20%, and 25% by volume, denoted as B1-B, B2-B, B3-B, B4-B, and B5-B. The physical properties such as density and kinematics improve as the seed oil blending ratio in the diesel increases, according to the results of the experiment. The triple combination of two seed oil and diesel were B1-B (90% diesel, 5% BN-B, and 5% LU-B), B2-B (80% diesel, 10% BN-B, and 10% LU-B), B3-B (70% diesel, 15% BN-B, and 15% LU-B), B4-B (60% diesel, 20% BN-B, and 20% LU-B), and B5-B (50% diesel, 250% BN-B, and 25% LU-B). In most cases, the mixing procedures have a feature that is comparable to what is required. The most important factor to consider when using fuel injection equipment is viscosity.

As the viscosity of the fuel fluid increases, it has a significant impact on fuel performance.

The viscosity of the B1-B and B2-B blends is comparable to that of diesel. Engine speed and power output were unstable when more than 10% BN-B and LU-B was combined with diesel. It could affect the performance of the engine.

The inconsistency could be due to the high volatility of BN-B and LU-B, which could cause vapor lock in a diesel line. As a result, the atomization of the fuel spray is reduced, and the activity of the injectors is affected. Figures 6 and 7 shows the characteristics of a blended biodiesel combination that has been tested with various instruments. The higher concentration of unsaturated fatty acids presents in BN-B and LU-B. The density value was increases rapidly in triple blends according to the proportion of BN-B and LU-B blended with diesel.

It is because of the presence of more saturated fatty acids in BN-B, which causes it to have a higher viscosity than LU-B. B1-B and B2-B have calorific values that are comparable to diesel. The calorific value is reduced from 0.02% to 6% when compared to diesel 100% fuelled because more oxygen molecules are added as the biodiesel proportion of BN-B and LU-B combined with the diesel was increased from 5% to 25%.

The flash point of triple blends was increasing from 70 to 83°C. the flash point of BN-B and LU-B was higher than diesel. So, the flash point was increasing with the proportion of BN-B and LU-B increasing in the triple blend. The pour point of the triple blend higher than the diesel. The cloud point of the triple blend lower than the diesel. The B3-B, B4-B, and B5-B has better fuel ignition at the cold temperature compare to B1-B and B2-B. The fire point of triple blend was varying from 280 to 302°C. The fire point temperature of B3-B, B4-B, and

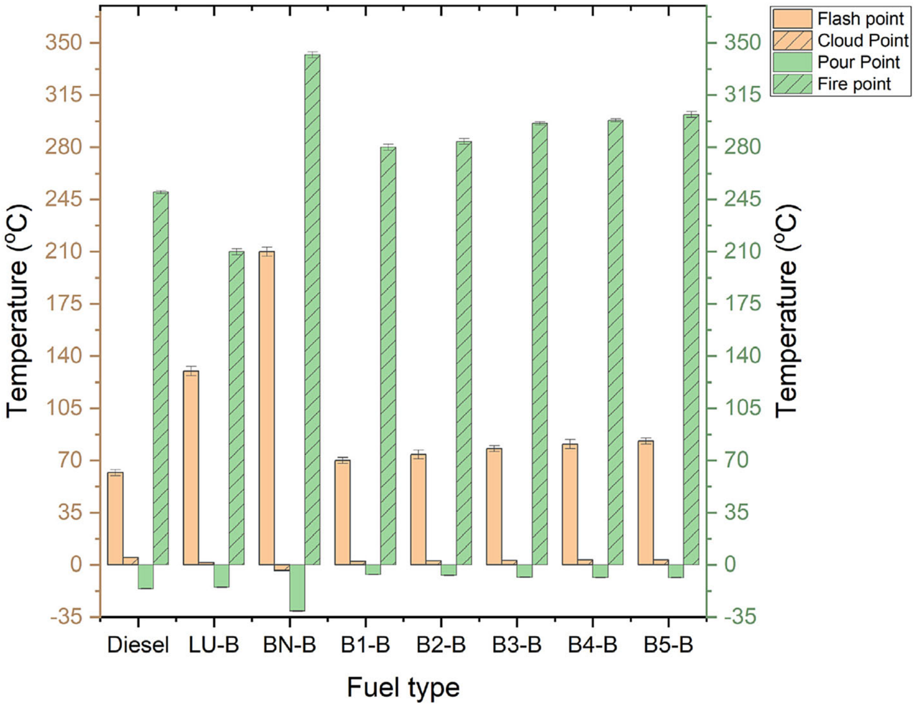

FIGURE 6 Flash, pour, cloud, and fire point of triple blend biodiesel

B5-B was higher than the B1-B and B2-B. The pre-ignition of B3-B, B4-B, and B5-B was significantly reduced in the higher load.

Fuel spray atomization is reduced as a result, and injector activity is affected due to the high volatility of BN-B and LU-B. The density of triple blends was varying from 819 to 852 kg/m^3. The percentage of diesel decrease in the triple blends was increases the density of B3-B, B4-B, and B5-B. The higher amount of unsaturated fatty acids present in BN-B and LU-B increases density value quickly with higher volume ratio blended in biodiesel. The kinematic viscosity of the blends B3-B, B4-B, and B5-B was increasing. This is due to viscosity property of BN-B and LU-B. BN-B has a higher viscosity than LU-B. This is because of the presence of more saturated fatty acids in the BN-B compared to LU-B. The kinematic viscosity of triple blends was varying from 1.6 to 2.2 cSt. The calorific values of the triple blends were decreasing from 0.02% to 6% compared to diesel. The oxygen content of BN-B and LU-B was higher compared to diesel. The proportion of 5% and 10% of BN-B and LU-B blended with diesel has the significantly similar values as diesel. The cetane value of triple blends were increasing from 48 to 52. The oxidation stability of BN-B and LU-B was higher compared to diesel. Although the unsaturated Fatty acid were higher in the BN-B and LU-B, the CN was 53 and 44. The BN-B and LU-B has higher oleic acid, linoleic acid, and linolenic acid composition in the fatty acid content was increasing CN number of B3-B, B4-B, and B5-B. The proportion of the diesel decreasing in the biodiesel blend (BN-B, LU-B, and diesel) has the oxidation stability and it improves the CN and combustion process.

Fuel homogeneity affects the flashpoint temperature, which implies that it has a low flash point when the fuel is homogenous. Because the combinations of triple blending are very homogenous, the biodiesel proportions of B1-B and B2-B have lower flash point temperatures than other blends.

The flashpoint temperature was pretentious by fuel homogeneity, implying that it has a low flash point. The biodiesel proportions of B1-B and B2-B have lower flash point temperatures than other blends because the triple blending combinations are very homogeneous.

The CN ranges from 48 to 52, as it has in diesel, because of the presence of diesel in the blend. Viscosity, flashpoint temperature, density, and heat values all influence the number of cetanes (CN). BN-B and LU-B have higher viscosity than diesel, which affects ignition delay.

4.2 | SCDE performance test

The results of diesel and five triple biodiesel blends tested in the SCDE. A performance test was performed in an SCDE without changing the engine settings. Our primary objective is to assess diesel quality and all mixed biodiesel in all sorts of the engine. This task is independent of any modifications to the engine. Indicated mean effective pressure (IMEP), total fuel consumption (TFC), specific fuel consumption (BSFC), and BTE all vary depends upon the load applied as shown in Figures 8–10.

The variation in IMEP for diesel and triple biodiesel blends was illustrated in Figure 8. IMEP increases for all biodiesel blends with the increase in applied load.

The IMEP of B1-B and B2-B values for loads up to 40% increased 1.6%, similar to diesel. The IMEP of B3-B, B4-B, and B5-B have lower values than diesel for all loading conditions. This is because of higher viscosity and lower calorific value of blends. In addition, the chamber

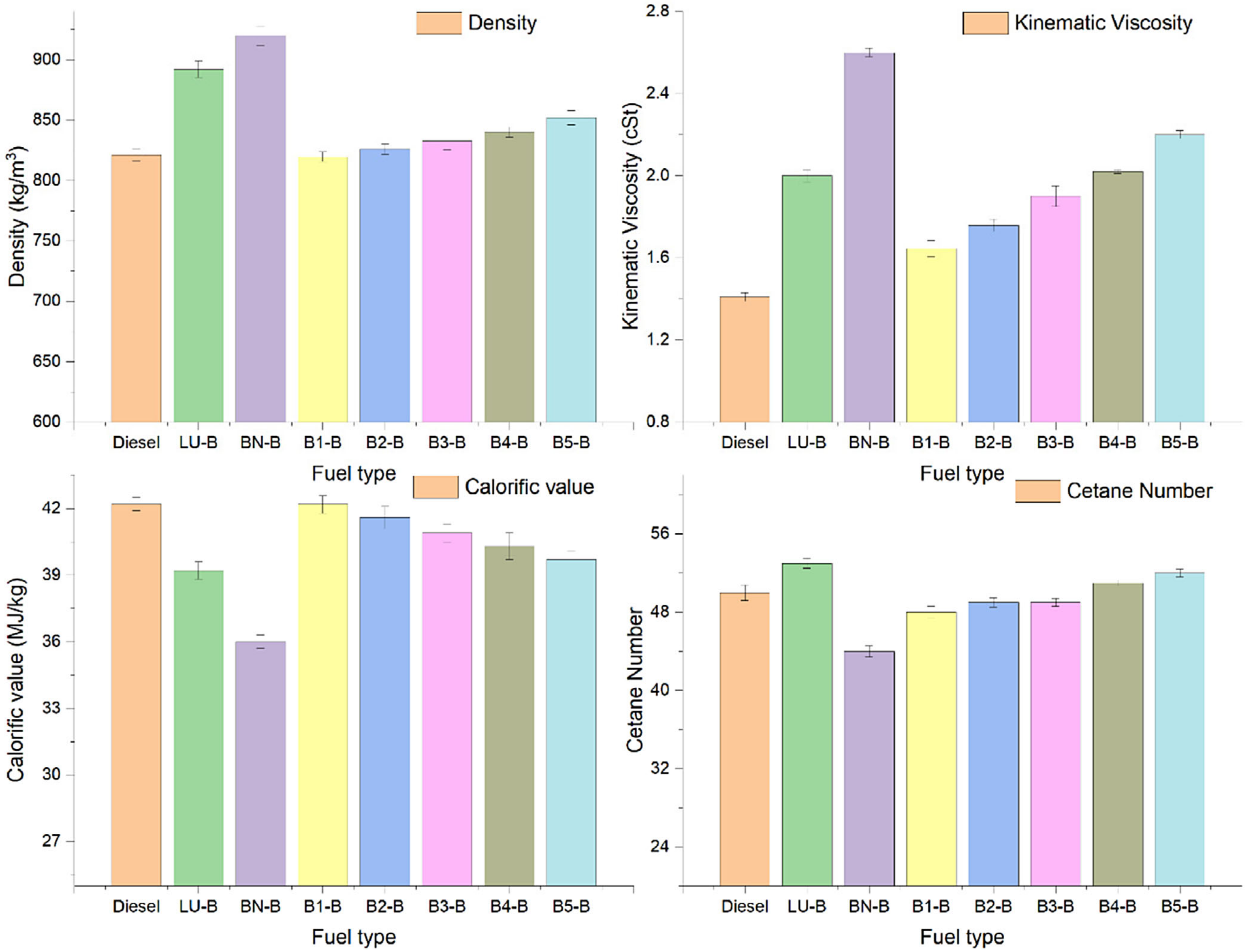

FIGURE 7 Characteristics of triple blended biodiesel

has accumulated with more fuel in order to maintain a consistent power output in biodiesel blends. The B1-B and B2-B ranges of CN are similar to diesel. As a result, those blends produce similar results to diesel for all loads.

The BTE is a measurement of where chemical energy from a fuel is converted into useful work. Figure 9 illustrates the variation in BTE with different load conditions for all biodiesel blends and diesel.

The BTE was increased as the load increased for all biodiesel blends. Diesel has the maximum BTE because it has a lower viscosity than the other biodiesel blends. Biodiesel blends with higher viscosities, lower calorific values, and higher densities affect fuel atomization during compression, resulting in lower BTE for all biodiesel blends. The viscosity of B1-B and B2-B was lower than that of all other biodiesel blends, and they produced the highest BTE. One of the reasons for this is that B1-B and B2-B have maximum oxygen content, which contributes to complete combustion and influencing BTE. The CN is essential in the fuel ignition process of these two biodiesel blends.

The mechanical efficiency of the triple blend was higher than that of the diesel. The mechanical efficiency of the triple blend decreased as the proportions of BN-B and LU-B in the triple blend increased (see Figure 10). At maximum load, B1-B, B2-B, and B5-B mechanical efficiency is 3.17%, 2.6%, 1.9%, 1.8%, and 1.4% lower than diesel. The triple blend's overall efficiency is based on its calorific value and cetane number. The calorific value of triple blends decreased slightly as the proportion of BN-B and LU-B in the blends increased. The CN increased as the proportion of BN-B and LU-B in the blends increased. The combustion process at maximum loads was improved by these two properties. In comparison to diesel, this improves mechanical efficiency by about 2%.

The BTE of this blend produces 3% lower compared to the diesel 100% fuelled in the maximum load condition. TFC increases in proportion to the applied load on all biodiesel blends and diesel (Figure 11) because diesel has a maximum calorific and viscosity value than other triple biodiesel blends. The TFC value of the diesel was lower than the B3-B, B4-B, and B5-B. The combination of B1-B and B2-B consists of higher diesel proportions, which produces similar TFC values as diesel. The SFC defines the fuel consumption and utilization in the SCDE to produce output per unit of load and time. The SFC reduces almost linearly with increasing applied loads, as seen in Figure 12.

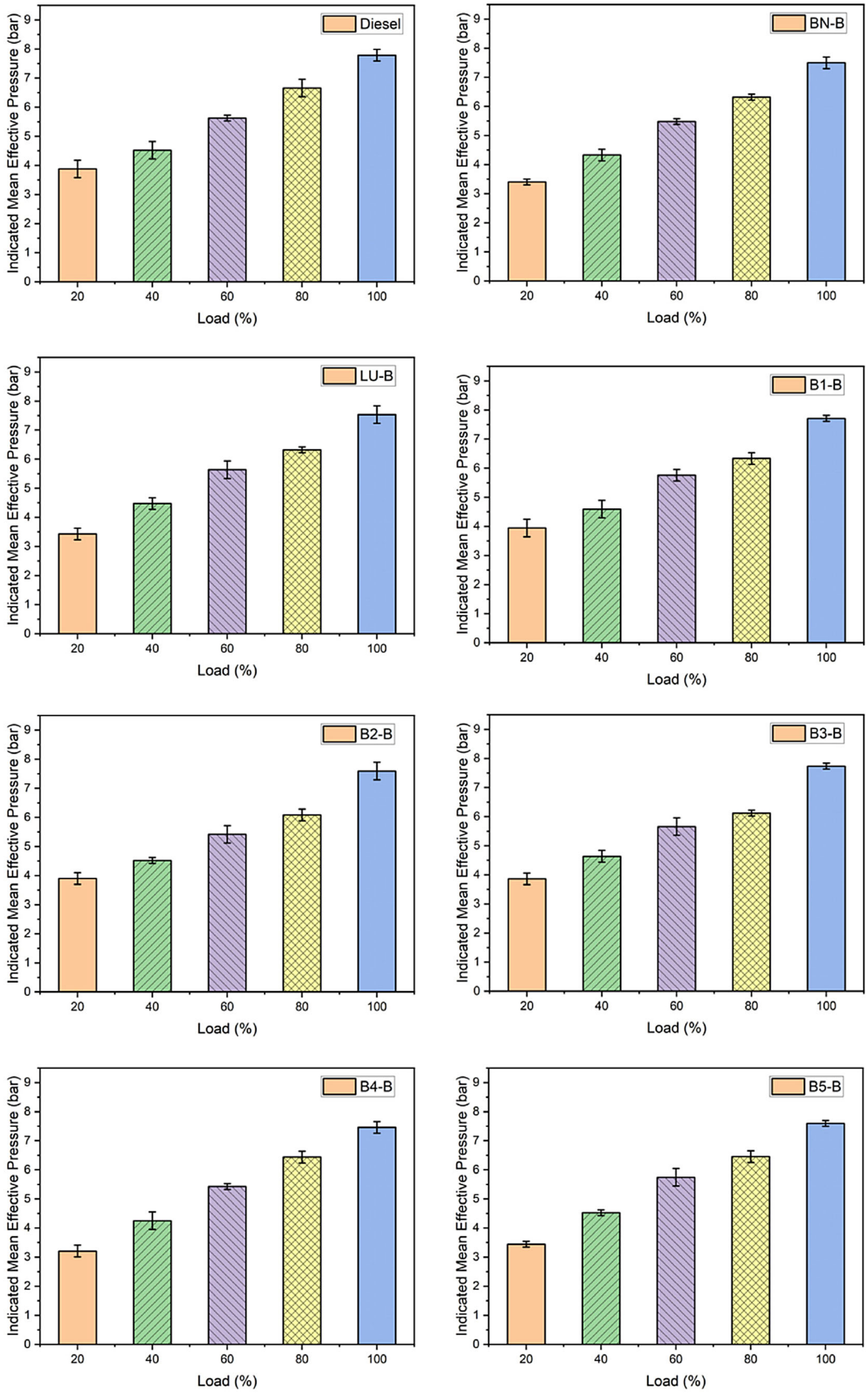

FIGURE 8 Variation in IMEP with different loads

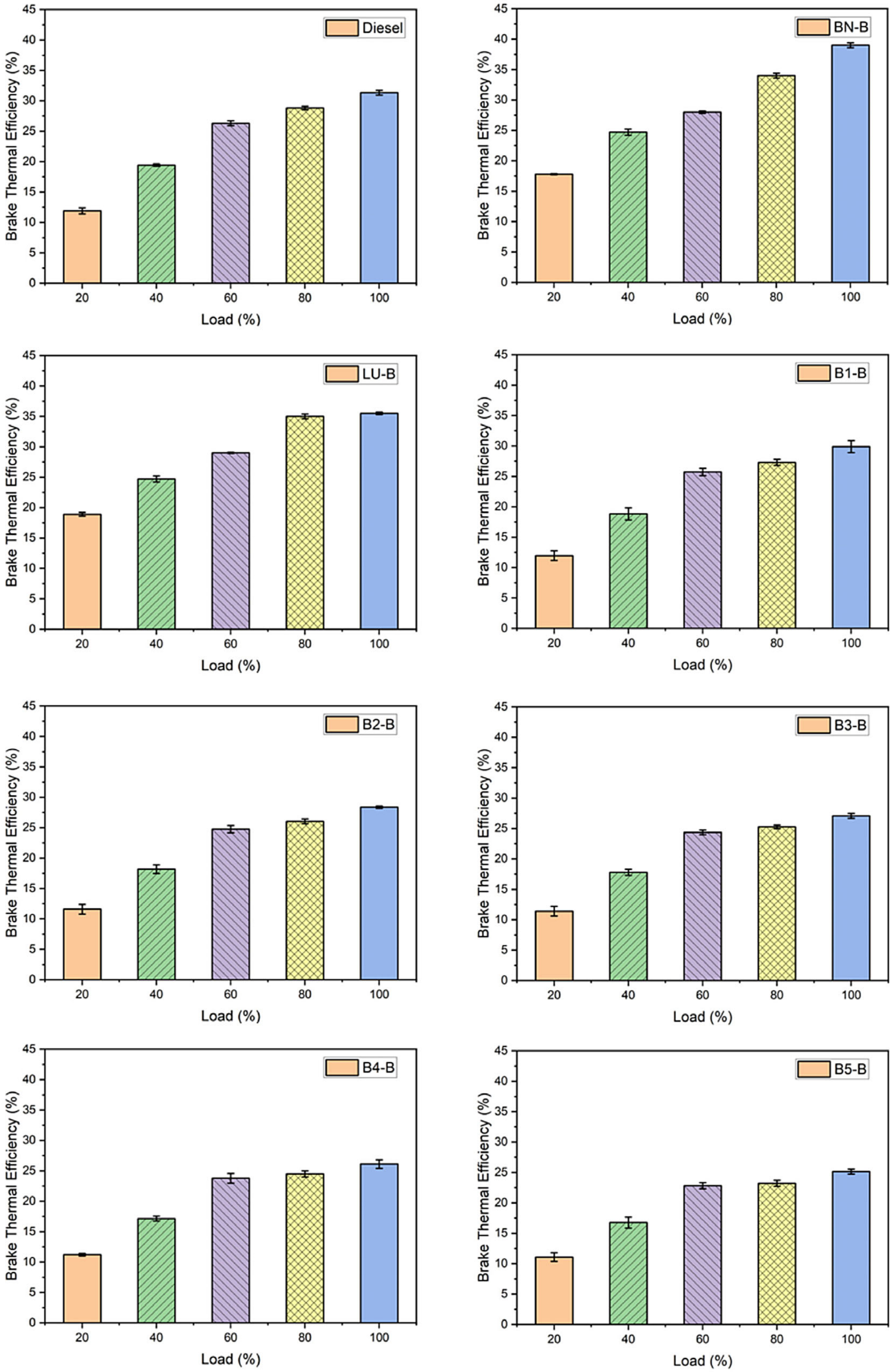

FIGURE 9 Variation in BTE with different applied loads

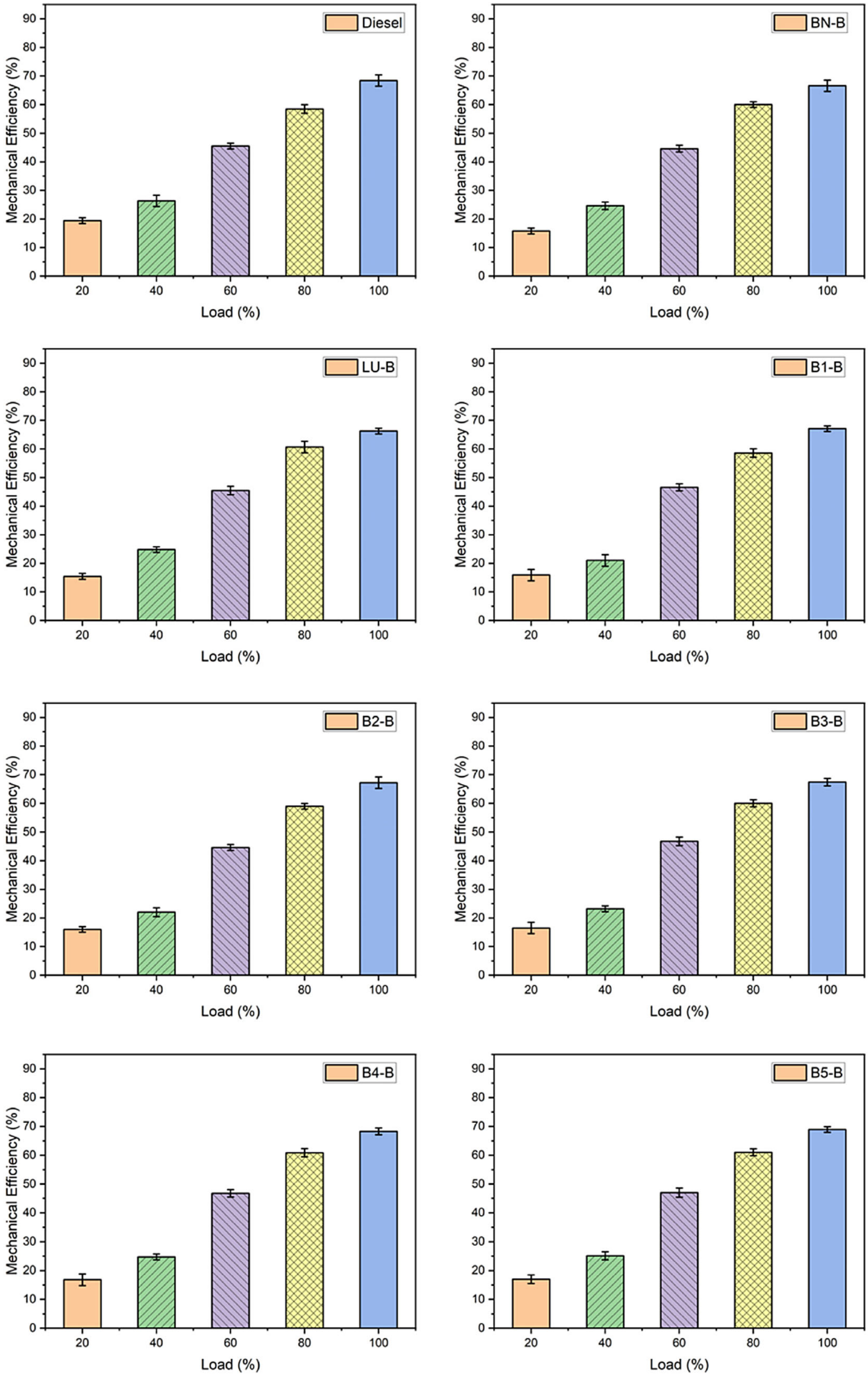

FIGURE 10 Variation in mechanical efficiency with different applied loads

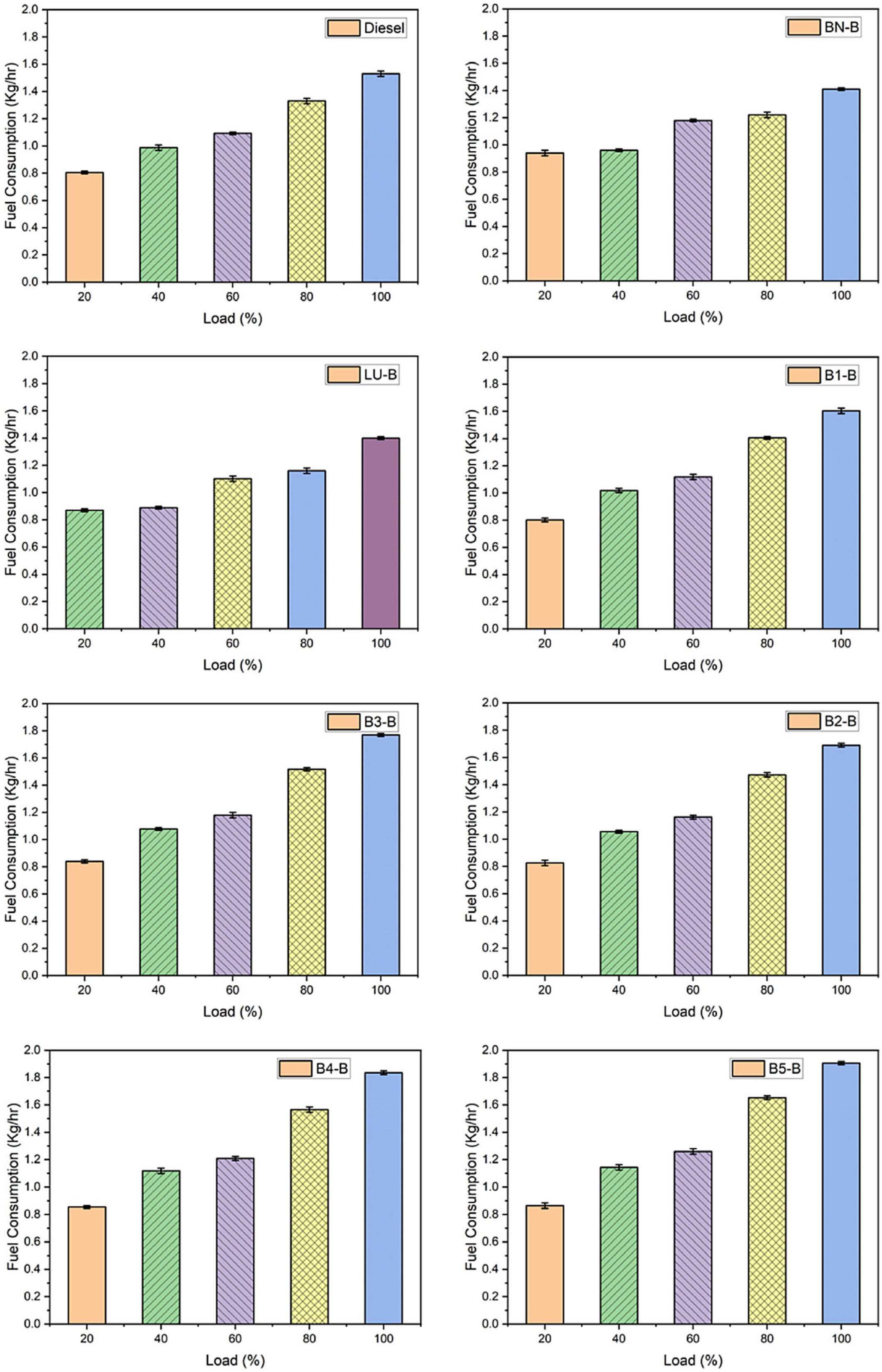

FIGURE 11 Variation in fuel consumption with different applied loads

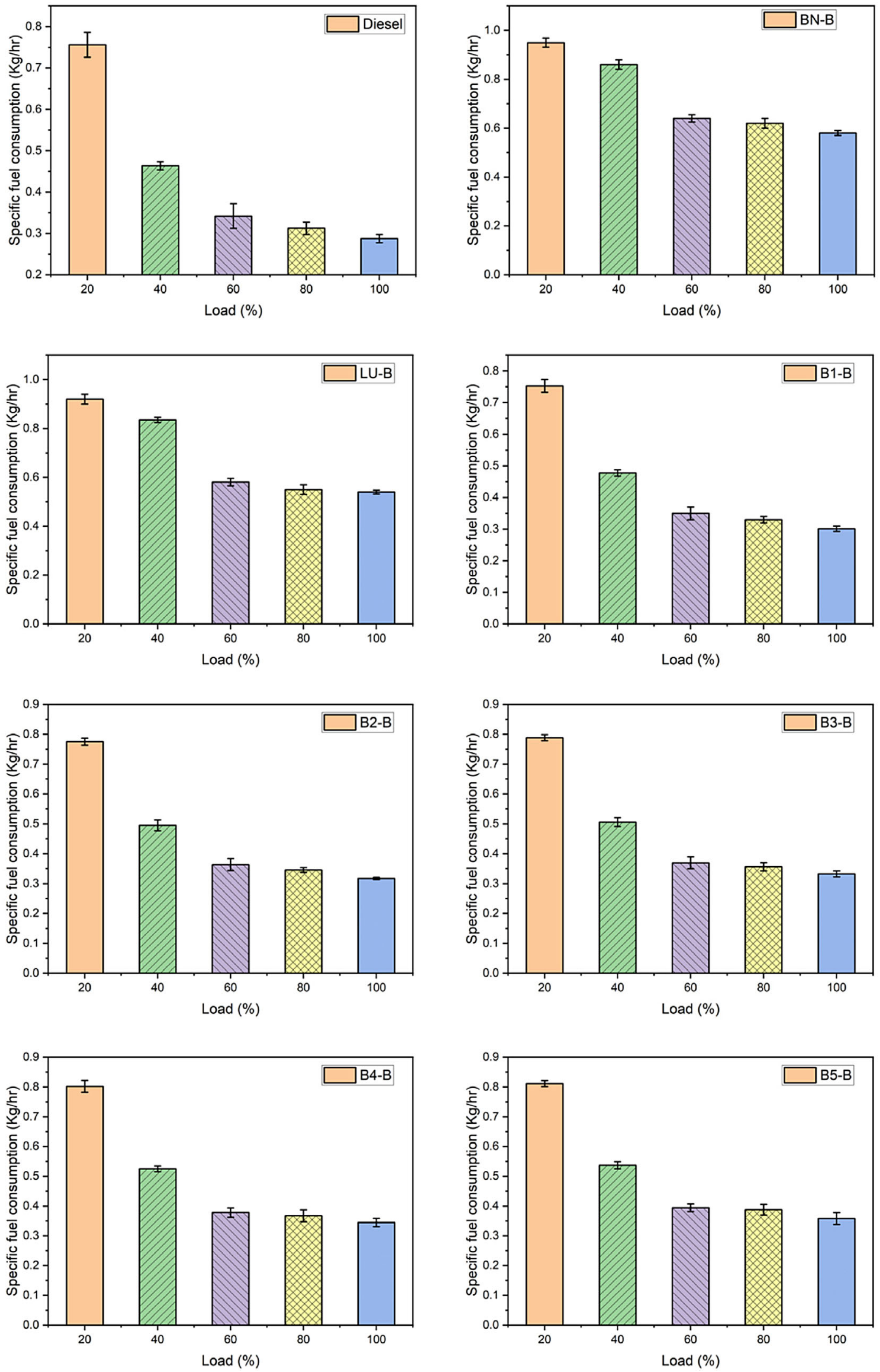

FIGURE 12 Variation in specific fuel consumption with different applied loads

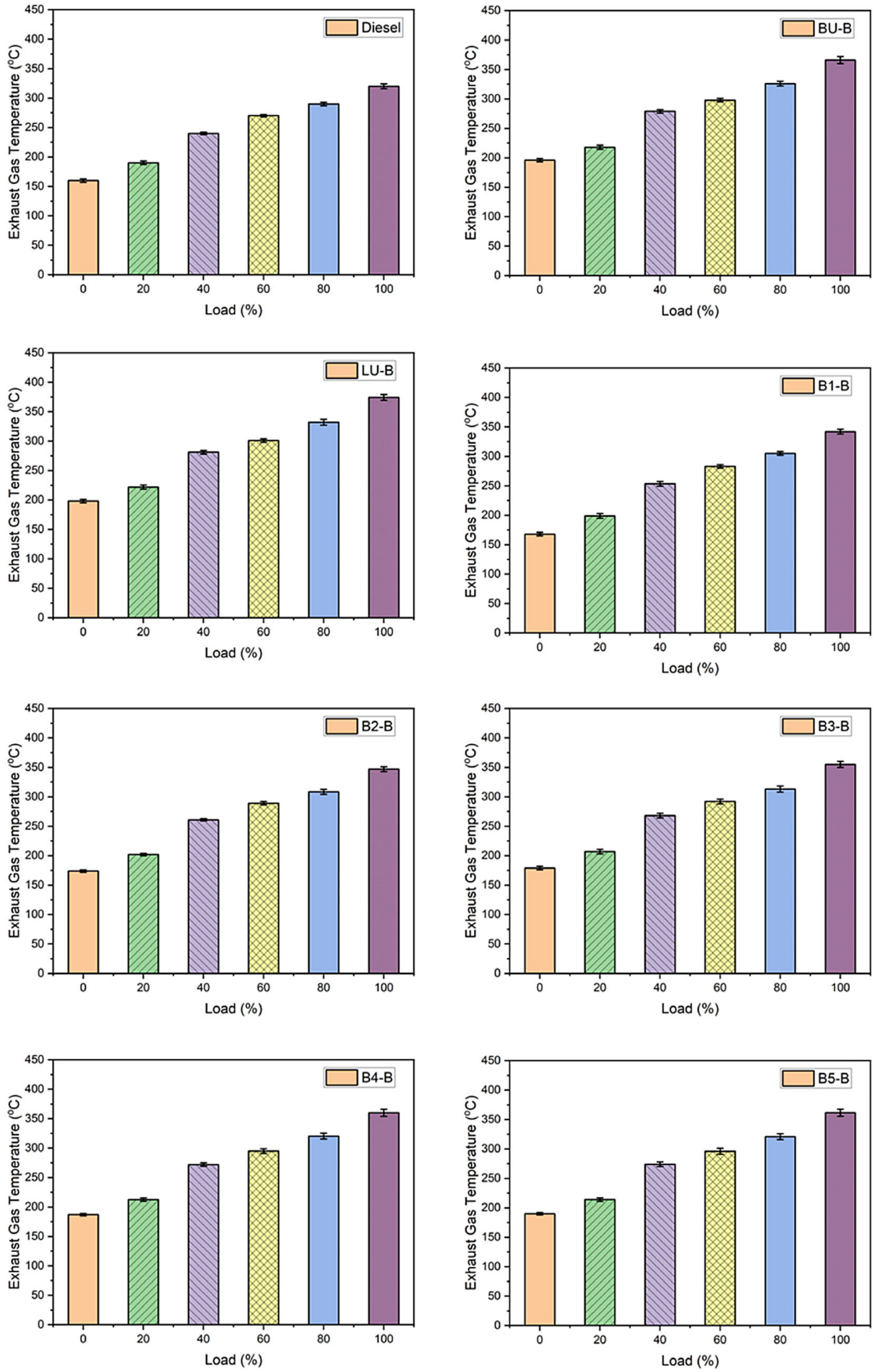

FIGURE 13 Variation in EGT with different applied loads

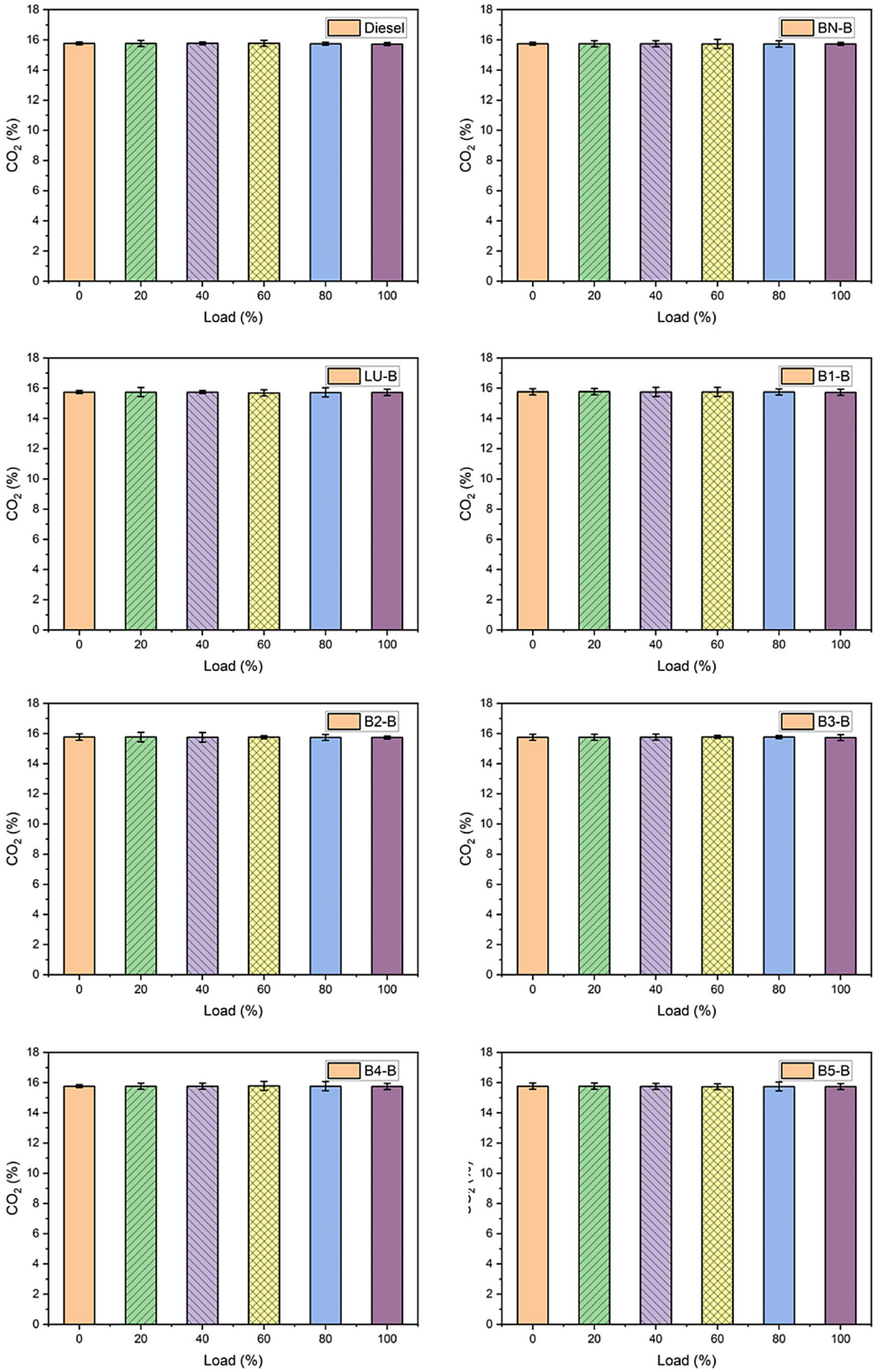

FIGURE 14 Variation in CO_2 with different loads

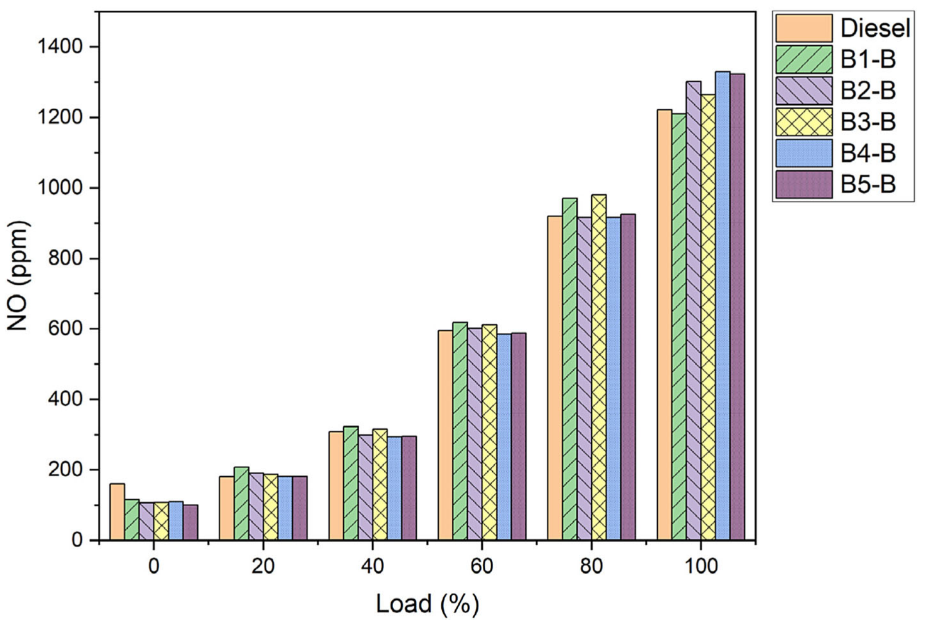

FIGURE 15 Variation in NO with different applied loads

The SFC was high at lower loads and produced lower engine efficiency. SFC is generated most effectively by selecting standard speed and load. B1-B has been generated a lower SFC of 1.4% at a load of 0%–20% compared to diesel. The SFC of B2-B, B3-B, B4-B, and B5-B was 1.8%, 4.3%, 5.6%, and 11% higher than the diesel. The addition of more than 5% of BN-B and LU-B proportionate in the diesel combination generated higher fuel consumption even further.

SFC was more effectively by selecting standard speed and load. SFC values of triple biodiesel blends were raised (excluding B1-B) at applied loads. This is because of the calorific value of BN-B and LU-B is lower than diesel. Similarly, biodiesel blends have a higher density, this was one of the reason to increasing SFC values than diesel. SFC has increased by blending seed oil in diesel.[53,54] Some operational factors, such as speed, load, injection pressure, and timing, impact the fuel consumption of SCDEs that use biodiesel.[55]

4.3 | Emission characteristics analysis

Figure 13 depicts the effect of increasing the load from 0% to 100% on the exhaust gas temperature (EGT). The EGT was rises, if the amount of diesel mixed in biodiesel blends is reduced. Due to the rapid increase in injection of biodiesel volume into the SCDE as the load increases, the EGT rises. EGT variance is influenced by the oxygen content of biodiesel blends. BN-B and LU-B have a higher oxygen content than diesel.[35,42,56] Higher oxygen content in the lower blends such as B1-B and B2-B improves the combustion process.

The carbon dioxide (CO_2) emission percent decreases as the load are applied, as seen in Figure 14. The CO_2 emissions were increases proportionally to the SFC in kg/h as load increases. The CO_2 percent and EGT have been divided into two groups in the high loads. The observation in the Figures 9, 13, and 14 shows that, BTE and EGT increases and CO_2 emission decreases gradually with increase in loads for blend B3-B, B4-B, and B5-B. The blends B3-B, B4-B, and B5-B has lower CO_2 emissions and SFC at higher loads.

The CO_2 emission percent of all triple blend biodiesel was also high for lower and maximum loads when compared to 100% diesel. CO_2 emissions were lower for intermediate loads compared to diesel.

CO_2 emissions are reduced at higher loads because of the presence of additional oxygen molecules in the triple biodiesel blends.

The maximum nitrogen oxides (NO) value was covered as a function of mass percent of diesel oxygen level and load applied to obtain a full-sized view of the total NO characteristic, as shown in Figure 15. The maximum NO emissions were increase proportionally with the mass percent of oxygen in the triple biodiesel blends, according to the test results. Biodiesel blends emit less NO than diesel at lower load conditions because the excess oxygen in the blend improves the combustion rate. The oxygen content increases in the blend during the proportion of BN-B and LU-B add in the diesel. Resulting in maximum NO values ranging from 1021 to 1323 ppm in the biodiesel blends. The NO values were depending on the proportion of diesel blended in the BN-B and LU-B, which is consistent with test results published by many researchers.[35,57–59]

The temperature of the combustion chamber rises simultaneously NO emission was produced. Resulting in production of CO_2 at relatively low temperature under higher load conditions. More oxygen molecules combine with high-temperature nitrogen molecules to produce NO and nitrogen dioxide (NO_2) during the combustion process when triple biodiesel blends were used in the combustion chamber.

Diesel has higher NO_2 levels than triple biodiesel blends, as shown in Figure 16. The NO_2 has significantly small increase with the load increases. The biodiesel blend exhibits the lower harmful to the atmosphere. The combustion process of the biodiesel blend decreases the NO_2 compare to diesel. The blends B1-B and B5-B has 18% and 4% lower NO_2 emission compared to diesel at maximum load. The proportion of diesel was lower in the B5-B. This increases the NO_2

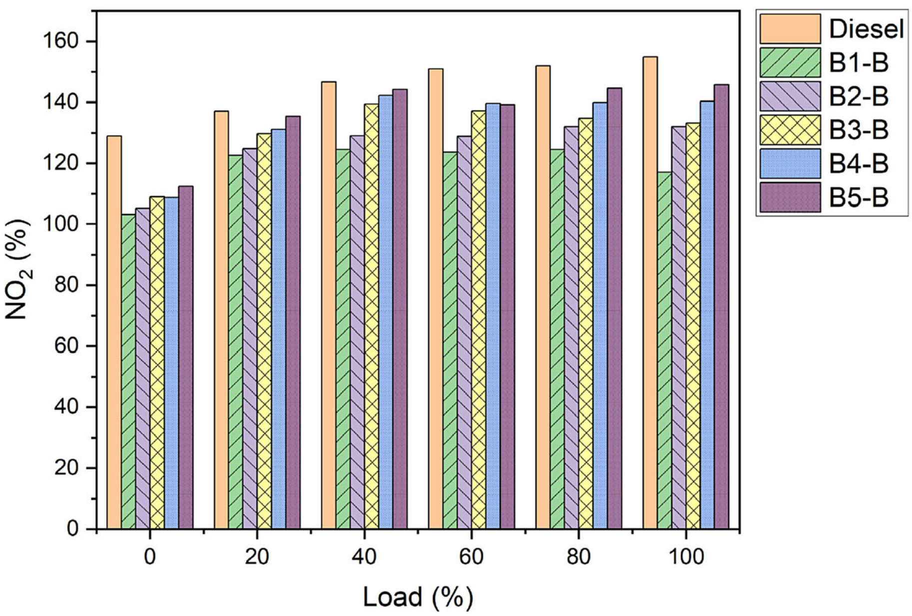

FIGURE 16 Variation in NO_2 with different applied loads

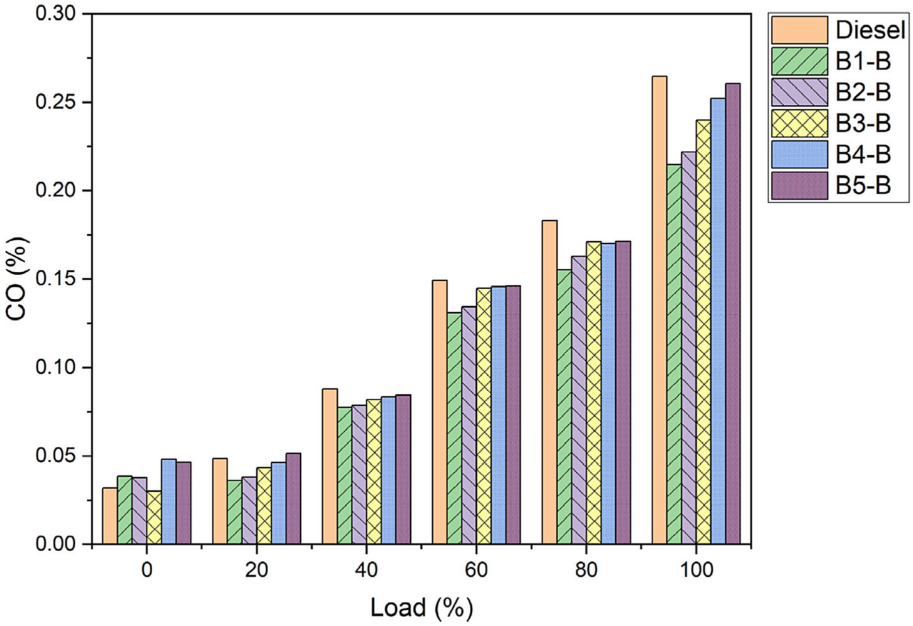

FIGURE 17 Variation in CO with different applied loads

emission in the B5-B compared to B1-B. This is because of B5-B has lower calorific values compare to B1-B.

Figure 17 shows the CO emission variations as a function of applied load. CO emissions increased as the applied load increased. They were caused by incomplete combustion products in the combustion chamber when the SCDE is subjected to higher loads.

The increased combustion temperature improves the completion of the combustion process at higher loads, lowering CO emissions in the triple biodiesel blend when compared to diesel.

The existence of additional oxygen molecules in triple biodiesel blends results in lower CO emissions. CO emissions are reduced by 35% when B1-B is used as a fuel instead of diesel. CO emissions at full load for all biodiesel blends decreased between 4.9% and 35% when compared to diesel. B1-B, B2-B, B3-B, B4-B, and B5-B biodiesel mixtures produced the highest CO emissions at full load of 19.4%, 20.1%, 23.9%, 25.2%, and 24%, respectively, while 100% diesel produced the highest CO emissions of 26.4%. The findings were in line with those of other researchers.[46,59]

Biodiesel contains more oxygen, which improves oxidation reactions and reduces CO while raising CO_2 emissions. The production of CO_2 is increased by increasing the applied load in the SCDE, which causes chemical reactions inside the combustion chamber due to higher fuel accumulation at maximum load.[17,35] As a result of the preceding, B1-B and B2-B have performance characteristics similar to those of a 100% diesel-fuelled vehicle. The SFC value of B1-B and

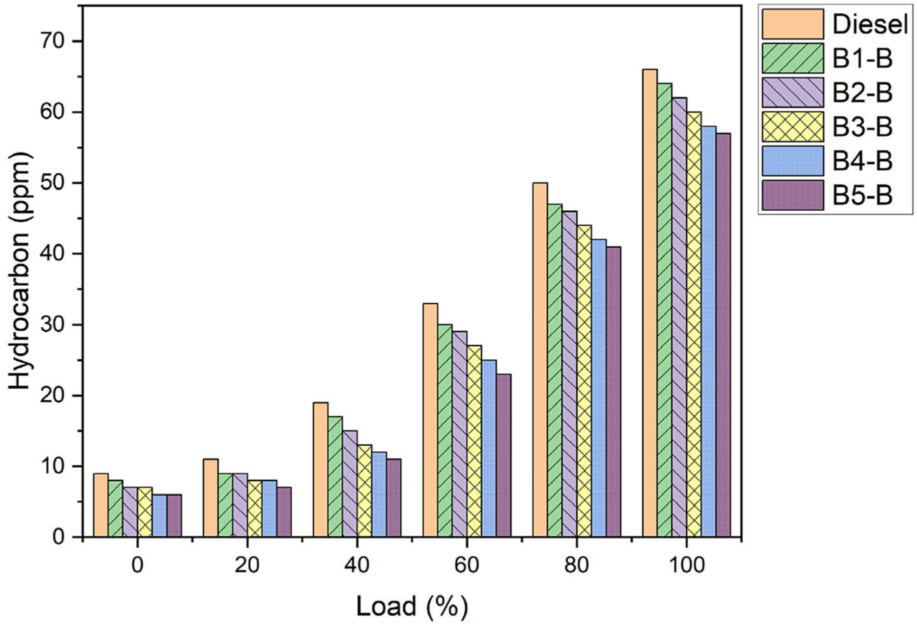

FIGURE 18 Variation in HC with different applied loads

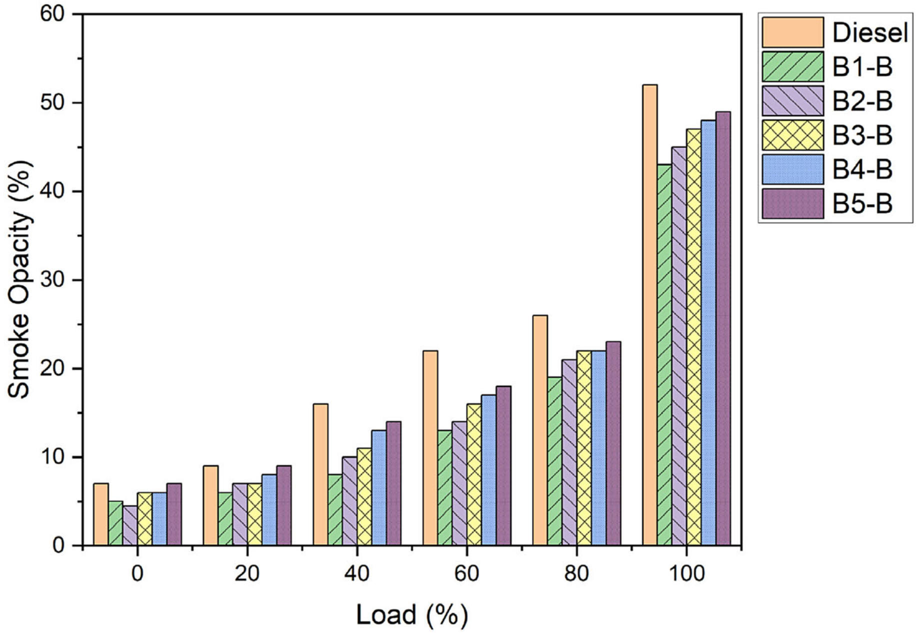

FIGURE 19 Variation in Smoke opacity with different applied loads

B2-B was much closer to diesel in maximum load. CO and NO_2 emissions were lower in these triple biodiesel blends than in diesel.

As a result, these two biodiesel blends of B1-B and B2-B can be used without modification the SCDE. LU-B contains more than 50% linolenic acid. It has a higher density than diesel, which has an impact on the atomization of the fuel during combustion. Similarly, the flash-point temperature of biodiesel increased and lowering the risk of pre-ignition due to high temperatures. The BN-B produced from *B. napus* has a lower linolenic acid content of 9.3%. Experiments with various biodiesel blends were carried out while the SCDE design remains unchanged. As a result, it works with every SCDE design.

SCDE fuelled with triple blend biodiesel that emits less HC than diesel. The variation of HC emissions with various loads for triple blend biodiesel was compared to diesel as shown in Figure 18. Low cylinder temperature and pressure result in significantly increase the HC emissions at low loads. The oxygen content of B5-B biodiesel promotes complete combustion, which reduces HC emissions. Because the oxygen content in biodiesel improves combustion, HC emissions decrease as the proportion of biodiesel (BN-B and LU-B) increases in the blend increases.

The use of triple blend biodiesel in SCDE was found to be an effective way to reduce smoke emissions. The smoke opacity of triple blended biodiesels was minimum than that of diesel at minimum and maximum loads (Figure 19). Smoke opacity decreases in biodiesel blends due to lower total volatile HC content and higher oxygen levels. B1-B and B2-B have a lower smoke opacity than other triple

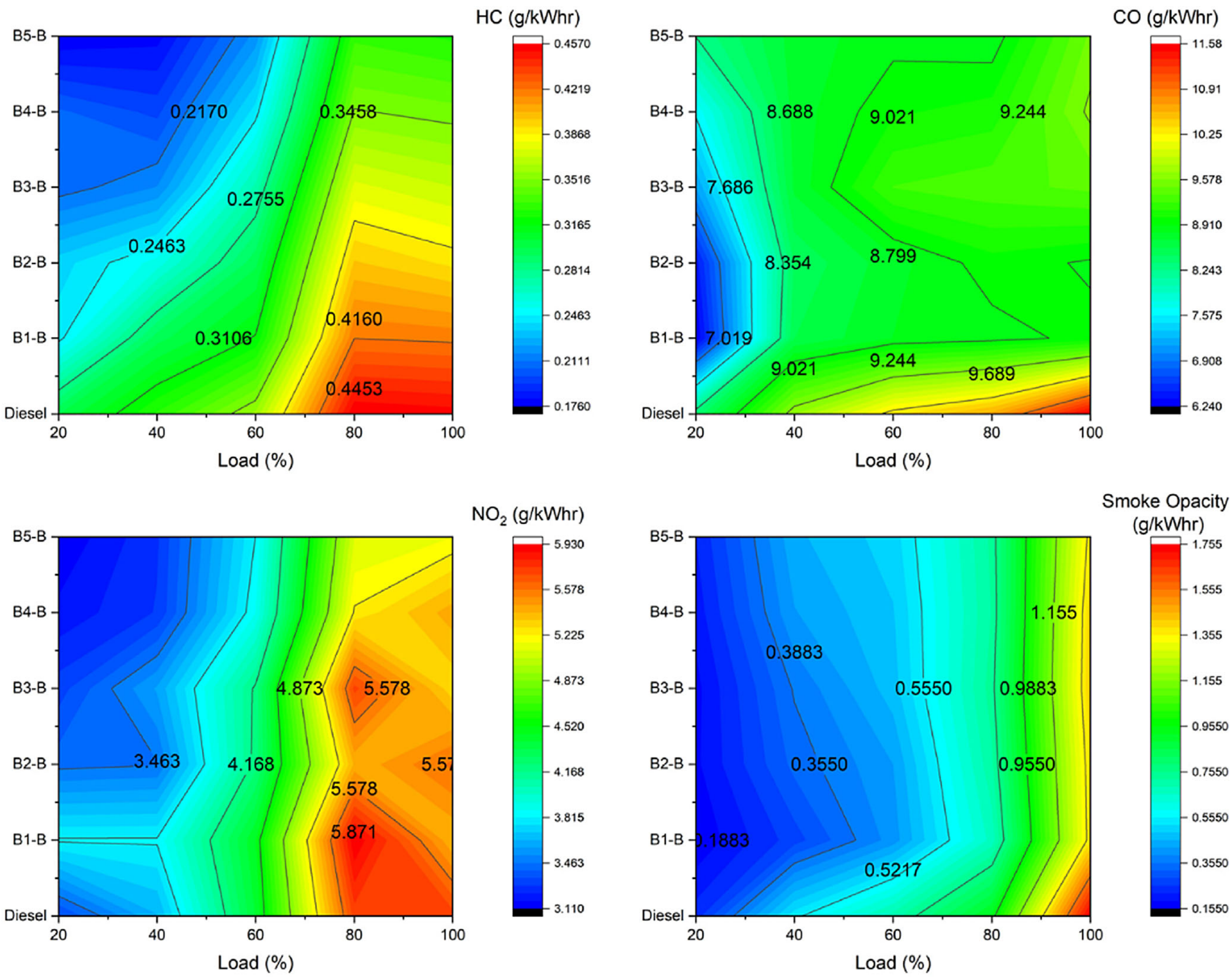

FIGURE 20 Variation of HC, NO_2, CO, and smoke opacity in terms of g/kW h

TABLE 6 Comparison of the present study with previous research

Name of researcher	Triple blends	Brake thermal efficiency 5%–10% Blend	Brake thermal efficiency 20%–25% Blend	CO	NOx
Yesilyurt et al.[42]	Diesel + safflower + pentanol	6% lower	13.9% lower	Lower compare diesel	Higher than diesel
Karthick et al.[49]	Diesel + *Linum usitatissimum* + *Hevea brasiliensis*	2.8% lower	5.8% lower	Lower compare diesel	Lower compare diesel
Ramakrishnan et al.[60]	Diesel + *Calophyllum inophyllum* + pentanol	4.2% higher	10.6% higher	Lower compare diesel	Higher than diesel
Kumar et al.[61]	Diesel + Pongamia + waste cooking	0.9% lower	14% lower	Lower compare diesel	Higher compare diesel
Shrivastava et al.[62]	Diesel + karanja + roselle	1.4% lower	3.4% lower	-	Lower compare diesel
Srithar et al.[63]	Diesel + *Pongamia pinnata* oil + mustard oil	0.6% lower	7% lower	Blend 5%–10% – Lower	Higher compare diesel
Present study	Diesel + *Brassica napus* + *Linum usitatissimum*	0.8% lower	4.2% lower	Lower compare diesel	Higher than diesel

biodiesel blends, because of their oxygen concentration. The smoke opacity levels of B1-B, B2-B, B3-B, B4-B, and B5-B are reduced by 17%, 13%, 9%, 7%, and 5%, when compared to diesel at maximum load.

HC, NO_2, CO, and smoke opacity (g/kW h) emissions characteristics with respect to brake power of triple blend biodiesel were shown in Figure 20. B1-B has high oxygen availability also raises temperature and emissions. Similarly, increasing the load which increases emissions. This behavior in the combustion chamber was caused by poor air quality. The total emissions of each blend and diesel at full load were 1045, 1005, 981, 958, 916, and 1097 g/kW h, respectively. The HC emission were lower for B3-B, B4-B, and B5-B compared to B1-B and B2-B at maximum break power. The HC emissions of B1-B, B2-B, B3-B, B4-B, and B5-B were 7.5%, 13.9%, 18.6%, 23.3%, and 28% lower than diesel at higher break power. The combustion process requires fuel atomization to complete burning of fuel. The oxygen content of the blends improves the fuel atomization. The CO emission of B1-B and B2-B was 22% and 23% lower than diesel at maximum load. The rich fuel ratio of B1-B and B2-B at maximum load decreases the CO emission. The NO_2 emission of triple blends were decreases with respect to the proportion of BN-B and LU-B in the biodiesel blend. The NO_2 formation of triple blends was 2%, 2.2%, 4%, 5%, and 9.7% lower than the diesel at higher loads. The smoke opacity of diesel and triple blends was increases with increasing load. The smoke opacity was higher in the diesel compared to triple blends. The triple blends have smoke opacity of 21%, 20%, 19.4%, 19.2%, and 19.1% lower than diesel.

Table 6 shows a comparison of triple blend biodiesel. The BTE, CO emission, and NOx emission values of various triple blend biodiesels show that they are compatible with all SCDE engines.

5 | CONCLUSION

The use of alternative, renewable, and sustainable resources has been encouraged through the development of triple biodiesel blends of BN-B, LU-B, and diesel. The current investigation was conducted with this goal in view. The performance and exhaust emissions of a SCDE running on conventional diesel fuel and five different triple biodiesel blends of BN-B–LU-B–diesel fuel was tested and discussed in this study. Both triple B1-B (90% diesel, 5% BN-B, and 5% LU-B) and B2-B (80% diesel, 10% BN-B, and 10% LU-B) produce specific comparable output properties that are similar to diesel. The following were summarized based on the test results:

- The percentage of methyl ester conversation in BN-B and LU-B were 97% and 96%.
- The calorific value of B1-B and B2-B were 42 and 41 MJ/kg making them suitable for use in SCDEs under higher load conditions.
- The CN value of the B1-B and B2-B has improved the ignition process.
- The highest CN in the B3-B, B4-B, and B5-B has the shortest ignition delay due to high temperature and pressure inside the chamber.
- The oxygen content in each blends improves the combustion process and reduces the emission.
- B1-B and B2-B can be used in the SCDE without requiring any engine modifications because of the triple blends of BN-B, LU-B, and diesel.

NOMENCLATURE

B	fuel burette reading in ml
BN-B	biological diesel from *Brassica napus*
BP	brake power in kW
BTE	brake thermal efficiency in %
B1-B	blend 1 biodiesel (90% diesel, 5% BN-B, and 5% LU-B)
B2-B	blend 1 biodiesel (80% diesel, 10% BN-B, and 10% LU-B)
B3-B	blend 1 biodiesel (70% diesel, 15% BN-B, and 15% LU-B)
B4-B	blend 1 biodiesel (60% diesel, 20% BN-B, and 20% LU-B)
B5-B	blend 1 biodiesel (50% diesel, 25% BN-B, and 25% LU-B)
CO	carbon monoxide
CO_2	carbon dioxide
CV	calorific value of fuel in kJ/kg
d	diameter of bore in m
EX_g	exhaust flow rate in kg/h
FC	fuel consumption in kg/h
HC	hydrocarbon
I	current in A
I_a	intake air in kg/h
IMEP	indicated mean effective pressure
l	stroke length in m
LU-B	biological diesel from *Linum usitatissimum*
M	measured quantity
MW	molecular weight in g/mol
NO	nitric oxide
NO_2	nitrogen dioxide
p	cylinder pressure in N/m^2
SCDE	single cylinder diesel engine
SFC	specific fuel consumption in kg/h
t	is the fuel consumption time in seconds
TFC	total fuel consumption in kg/h
U_M	represent the uncertainty in the measured quantity
V	voltage in V
V	volume in m^3
ρ	density of fuel used in g/ml
φ	power factor

AUTHOR CONTRIBUTIONS

Elango Murugesan: Conceptualization (lead); data curation (lead); methodology (lead); writing – original draft (lead). **G. Radhakrishnan Kannan:** Project administration (lead); supervision (lead); writing – review and editing (lead).

ACKNOWLEDGMENT

The authors would like to thank the Principal and management of RVS Technical Campus Coimbatore for their assistance in completing this research project.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

All data are given in the manuscript.

ORCID

Elango Murugesan https://orcid.org/0000-0002-2547-6561

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How to cite this article: Murugesan E, Kannan GR. An experimental study on synthesis of ternary biodiesel through potassium hydroxide catalyst transesterification. *Environ Prog Sustainable Energy*. 2022;e13958. doi:10.1002/ep.13958