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Research Article

Effect of compression ratio and load on performance and emission behavior of VCR-CRDI engine fueled with Moringa oleifera biodiesel

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ABSTRACT

The preliminary objective of the present work is to evaluate the performance and emission characteristics for different CR and engine loads using diesel and Moringa oleifera biodiesel blends as fuel. In the present work mono cylinder, 4-stroke, CRDI-VCR type, CI engine tested using diesel and Moringa oleifera biodiesel blend MB10, MB20, and MB30to investigate the performance and emission behavior of an engine concerning CR at the different loading conditions (0.88, 1.75, 2.66 and 3.5 kW). The experiment was performed at four different CRs 15:1, 16:1, 17:1, and 18:1 at fixed IT 23°bTDCand IP 600 bar. The results of the experiment show that the highest BTE for diesel and biodiesel blend MB30 is reported at 27.26% and 28.26% at the higher CR of the present investigation 18:1 and 100% load condition. The increase in load and CR shows the reduction in the BSFC and BSEC of an engine for all tested fuels and the minimum BSFC and BSEC reported among the entire fuel blend is 0.30 kg/kWh and 12.9 MJ/kWh for MB30 fuel blend at higher CR of present investigation 18:1 and 100% load condition. The minimum emission of CO and HC reported for MB30 fuel at higher CR of present investigation 18:1 and 100% load condition is 0.04 % vol and 8 ppm. In the present investigation, the highest CR of 18:1 and 100% load condition offers the minimum emission of NO_x reported as 522 ppm for the biodiesel blend MB20 among entire fuel blends. The results reveal that the NO_x emission of the MB20 fuel blend is about 11.97% less than recorded for diesel. The emission of smoke is almost zero for all the fuel blends at the higher CR 17:1 and 18:1 up to 50% loading condition. The highest emission of smoke was observed at lower CR 15:1 and 100% loading conditions for all the tested fuel blends. Moringa oleifera biodiesel blend MB30 shows an enhancement in thermal performance by increasing BTE and decreasing BSFC while improving emission characteristics by reducing emissions of pollutants such as CO, HC, smoke, and NO_x.

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INTRODUCTION

The energy demand in India increasing rapidly in the last 20 years because of rapid growth in the industrial sector, population growth, and improvement in the living standard. The transport sector of India contributes about 6.7% to the GDP of the nation. The energy consumption of the transport sector is mainly fulfilled by diesel which is around 73% of total demand [1]. Fossil fuels are available in limited stocks and hence for sustainable development, it is required to identify new sources of energy sources or development of new and effective techniques to utilize existing nonconventional sources of energy.

Moringa oleifera is a fast-growing, drought-resistant tree of the family Moringaceae, native to the Indian subcontinent. The plant starts bearing fruits at the age of 6–8 months if raised from the cuttings. India is the largest producer of Moringa with an annual production of 1.1–1.3 million tons of tender fruits from an area of 38,000 ha. Among the main states of Moringa cultivation, Andhra Pradesh leads in both area and production (156.65 km2) followed by Karnataka (102.80 km2) and Tamil Nadu (74.08 km2) [2].

Anwar [3] used several multi criteria decision analysis approaches to determine the optimal feedstock for biodiesel production. Fifteen distinct criteria were employed in the study to evaluate the sixteen most often used biodiesel. According to the statistics, the top feed stock for the manufacture of biodiesel is coconut, while the second-most popular feed stock is Moringa oleifera. The physical and chemical properties of the Moringa oleifera biodiesel also in-line with the different standards such as ASTM D6751-2, EN 14214, and Australian standard. Rajak et al. [4] carried out an economical assessment for the jatropha and Moringa oleifera biodiesel, considering the seeds cost, seeds peeling cost, cost of the oil extraction, and other expenses such as the cost of methanol, catalyst, labour cost, electricity cost, and electricity cost. They found that the production costs for the jatropha and Moringa oleifera biodiesel were 76 and 68 Rs/liter, respectively.

Balasubramanian and Subramanian [5] tested a mono-cylinder, air-cooled CI engine powered by Karanja oil-based biodiesel by varying CR engine speed at 100% load condition. They found that the highest CR 21:1 offers the highest BTE along with reduced CO and smoke emission meanwhile raising value for NO_x and HC emission. They also investigate that late injection of fuel helps to achieve the reduction of emission of NO_x but also reduces the BTE.H. Raheman and Ghadge [6] tested mahua based biodiesel on a Ricardo E6 engine by varying CR and timing of fuel injection. The results show that an increase in the proportion of mahua biodiesel in the fuel blend raises BSFC and temperature of exhaust gas while a minimal decrement is observed for BTE at all tested CR. Further to this, the improvement in BTE and BSFC was observed with an increase in CR and advancement in injection timing of the fuel. Sayin and Gumus [7] worked on Lombardini make 6-LD-400 engine operated using the blend of diesel and biodiesel to evaluate the effect of CR and parameters of injection. They noted that as the % volume of biodiesel rises in the tested fuel blend improves performance parameters except BTE whereas emission reduces other than NO_x. They also concluded that an increase in CR, IP, and advancement in IT improves performance and emission parameters qualitatively.

Rosha et al. [8] evaluated the effect of CR on Kirloskar make TV1,mono cylinder, CI engine fueled using palm biodiesel. The outcome of the study shows that mean effective pressure, BTE increasing, and fuel ignition delay are reduced with an increase in CR. The result about emission characteristics reveals that the emission of smoke, CO, and HC reduced except for NO_x emission at higher CR.A. Saravanan et al. [9] mixed rapeseed and mahua biodiesel in equal proportion by volume. The outcome of the work shows that fuel blend BL20 (80% diesel, 10% rapeseed biodiesel, and 10% mahua biodiesel) shows thermal performance near to diesel and reduces the emission of CO, HC, and smoke. The result also indicates an increase in the NO_x by3.77%. Bora and Saha [10] used a mixture of rice bran biodiesel and biogas in a CI engine to test the effect of CR operated at a fixed IT of 230 bTDC. The results indicate that a higher CR of 18:1 and at full load condition engine offers the highest BTE of 20.27% under dual fuel mode and reduces the emission of CO and HC by 17.67% and 17.18%. For the same CR and load condition emission of NO_x increased by 42.85%.

Teoh et al. [11] used biodiesel derived from Moringa seed oil in a CI engine using to investigate the impact of engine speed on the performance and emission pattern of an engine. The results imply that as engine speed increases it leads to reduce the BTE and increases BSFC. The results about emission characteristics show that the engine emits less CO, and PM while emitting more NO_x with the increase in speed. Mofijur et al. [12] performed an experiment on a CI engine using biodiesel derived from Moringa oleifera seed oil by changing the operating speed of an engine at the 100 % load condition. They discovered that for the entire speed, the biodiesel blend develops less power and has higher BSFC. The release of pollutants like smoke, CO, and UHC reduces except NO_x for all tested biodiesel blends. Rashed et al. [13] tested multi-cylinder diesel fueled with the palm, jatropha, and Moringa oil methyl ester to study the effect of an engine speed on the performance and emission characteristics of an engine. The result of the experiment shows that palm oil-based methyl ester shows enhancement in both performance and emission behavior compared to Moringa and Jatropha oil methyl ester. It is also concluded that the results of Moringa oil methyl ester closely match with the palm oil.

More et al. [14] conducted an experiment on a single-cylinder, water-cooled CI engine utilizing several fuel mixtures of diesel, diethyl ether, and biodiesel made from used cooking oil. The outcome demonstrates that adding diethyl ether to fuel blends of biodiesel and diesel improves its thermal performance while lowering its emissions of CO, HC, smoke, and NO_x. More et al. [15] carried out an experiment on a mono-cylinder diesel engine using ternary fuel blends of used cooking oil biodiesel, diesel, and diethyl ether at different CR. The result shows that higher CR of 18:1 offers the lowest NO_x emission and lower CR offers minimum emission of CO for all tested fuel blends. They have also identified the optimized CR for each fuel blend which offers lower emission and better thermal performance.

From the above literature, it is derived that enhanced thermal performance and emission characteristics are achieved with an increase in CR for an all-tested engine except NO_x emission. The literature also indicates that the research was conducted by varying CR or speed at fixed load for different blends of biodiesel derived from the Moringa oleifera seed oil or using single fuel blends of Moringa oleifera biodiesel at different CR, speed and load. It is required to perform in-depth experiment work on the CI engine to study the effect of CR on performance and emission behavior by varying load and fuel blends of Moringa oleifera biodiesel.

The main objective of the present study is to investigate the effect of CR and engine load on performance and emission characteristics of diesel engines fueled with diesel and biodiesel blends of MB10, MB20, and MB30 and identify the combination of optimum CR, engine load, and fuel blend having better performance and emission characteristics.

MATERIALS AND METHODS

The primary aim of the present experimental study is to explicate the impact of CR on BTE, BSFC, BSEC, and emission characteristics. The experimentation work was carried out at different loading conditions (0.88, 1.75, 2.66, and 3.5 kW), fixed IT-23^0bTDC, IP-600 bar, and considering four CRs15:1, 16:1, 17:1 and 18:1. The experimental setup consists of mono cylinder, CRDI-VCR type engine fueled with the neat diesel and Moringa oleifera biodiesel blend (MB10, MB20 and MB30).

Moringa Oleifera Biodiesel Production

Moringa oleifera seed oil is the primary feedstock used to produce biodiesel using the trans-esterification reaction (Fig. 1). Moringa seed oil has an FFA content of less than 2% hence single-step trans-esterification process was selected to produce the Moringa oleifera biodiesel. The trans-esterification reaction was carried out in a magnetic stirrer equipped with a three-neck flask and condenser. The

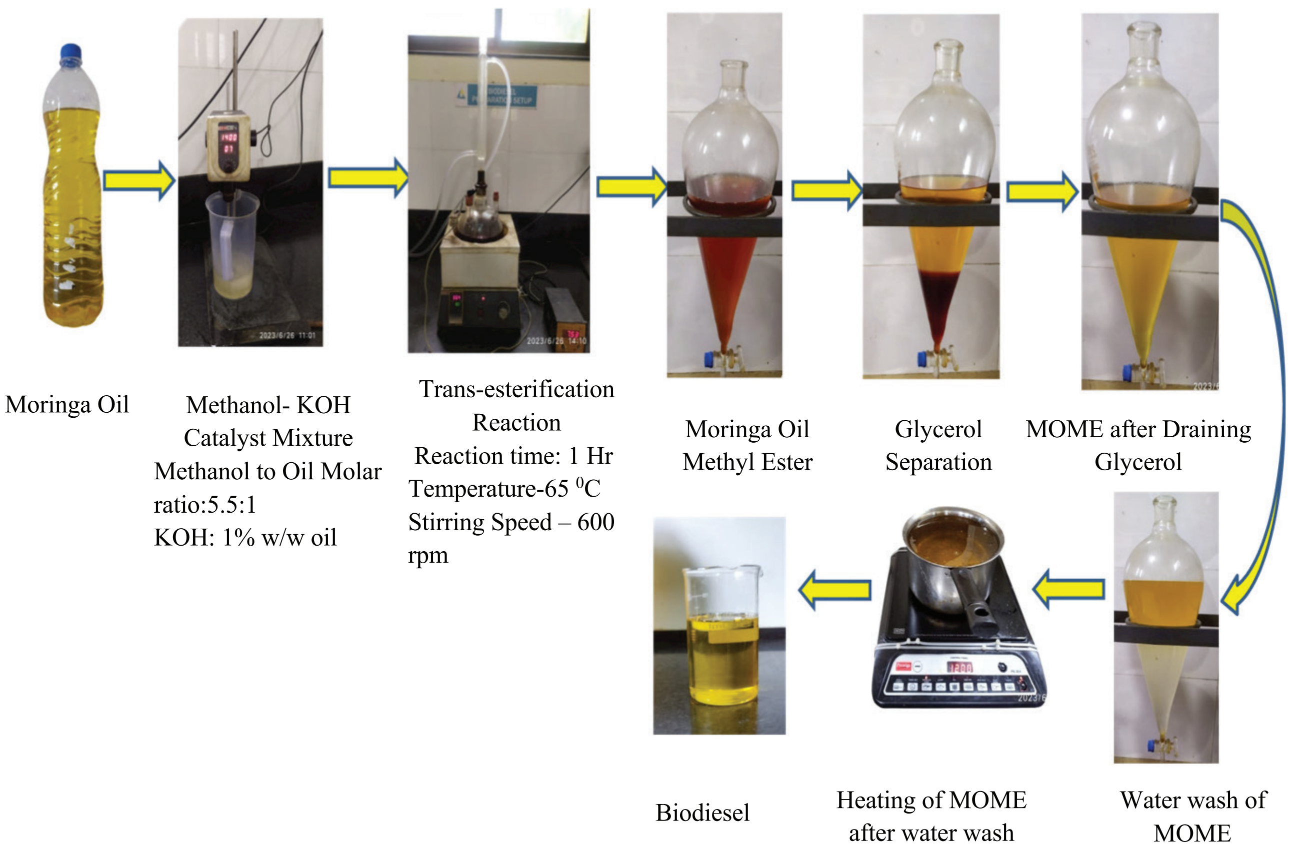


Figure 1. Moringa oleifera biodiesel production.

methanol-to-oil molar ratio is kept at 5.5:1, and the catalyst KOH content is 1% (w/w oil). The mixture of Moringa oleifera oil and methanol with catalyst KOH was kept in three neck flasks in a magnetic stirrer and the reaction was carried out by maintaining a reaction temperature of 60^0C-65^0C and a constant stirring speed of 600 rpm for 1hr [16]. The mixture was settled down for 12 hours to separate the MOME and glycerol. After the separation of glycerol from MOME the water wash of MOME is performed by heating distilled water to remove the residue of the KOH and afterward, the MOME was heated at 110^0C to remove the residue of methanol and water from the MOME. The biodiesel yield achieved using the trans-esterification reaction at the mentioned parameter is about 95 %.

Moringa Oleifera Biodiesel Properties

The apparatus and the test procedure followed in the investigation of significant physical and chemical characteristics are shown in Table 1.

The physico-chemical parameters of the diesel and Moringa oleifera biodiesel blend employed in the experiment work. shown in Table 2. It also shows that the value of different properties fulfills the limit set by the ASTM standards.

Experiment Setup

The test was performed on a mono-cylinder, 4-stroke, CRDI-VCR type, CI engine at IP- 600 bar and IT-23^0bTDC by changing CRs from 15:1 to 18:1 with the neat diesel and biodiesel blend MB10, MB20, and MB30 at different loading condition. The alteration in the CR was achieved by tilting the cylinder block arrangement. It facilitates alteration in CR without halting the engine or varying cylinder geometry. The equipment for measuring the various parameters including gas pressure, shaft angle, the flow rate of air, and fuel and load readings were installed in this arrangement. A data-capturing device is utilized to transfer these signals and link them with computers. The module comprises a separate control panel with an air box, two fuel tanks, a manometer, a fuel measuring device, transmitters to detect air and fuel flow, a process indicator, and a piezo powering unit. Rota meters are given to measure the flow of engine cooling water.

For online performance assessment, the software package "Enginesoft" based on lab views is offered. Engine Soft is a software program for engine performance monitoring systems that is based on Lab view and was created by Apex Innovations Pvt. Ltd. The "Enginesoft" is utilized to perform the different tasks required for the testing of an engine such as monitoring, collection, and reporting of data. The "Enginesoft" software program is used to estimate the power, and efficiency of an engine, usage of fuel and air, and heat release. The photographic view and schematic layout of the test setup are shown in Figure 2. (a) and (b). The details about the arrangement of various sensors and devices mounted on the setup are shown in Table 3.

The main specifications of main parameters of the test setup are mentioned in Table 4.

Uncertainty Analysis

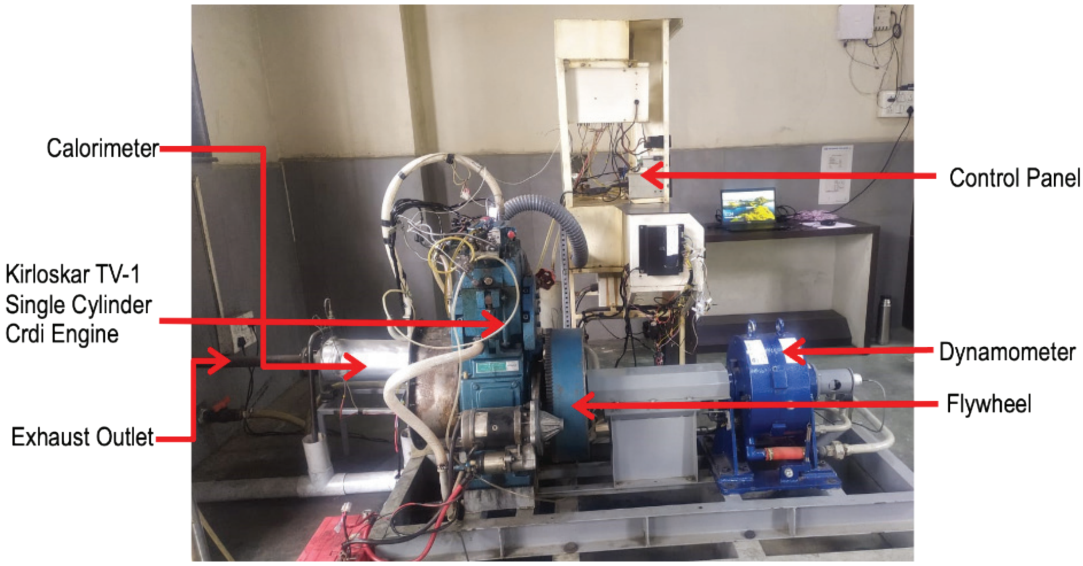
The selection of equipment, its state, calibration, environment, data collection, and preparation of the

Table 1. Equipment list

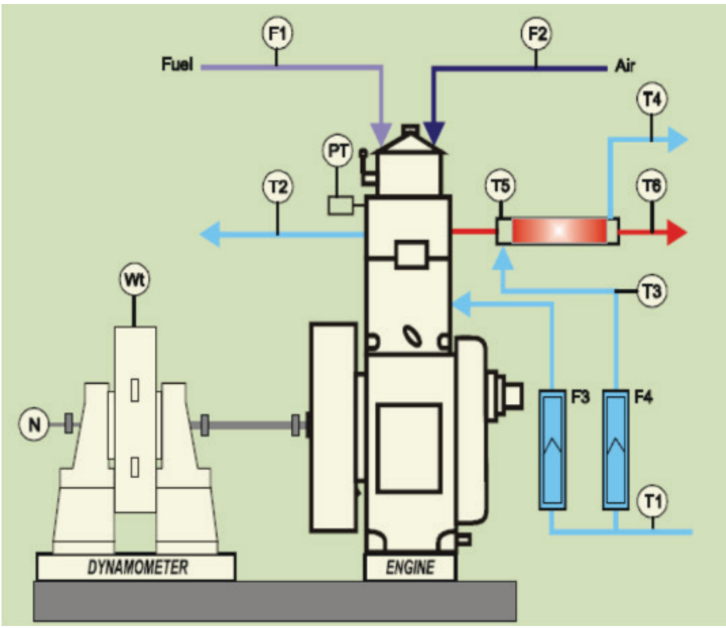
Property	Equipment	Manufacturer	Test method
Calorific value	Semiautomatic digital bomb calorimeter	Hamco	D 4809
Flash point	Pensky marten flash point apparatus (Closed cup)	RICO	D 93-58 T
Density	Hydrometer	Leimco	D 287
Kinematic viscosity	Kinematic viscosity bath	Hamco	D 445

Table 2. Physical and chemical parameters of fuel blends

Property	ASTM Standard	Diesel	MB100	MB10	MB20	MB30	Limits as per ASTM Standard
Acid Value (mg of KOH/gm of oil)	D 6751	0.03	0.41	0.06	0.09	0.15	Max 0.5
FFA (%)	---	0.02	0.21	0.03	0.05	0.08	----
Calorific Value (kJ/kg)	D 4809	42987	40005	42731	42433	42134	----
Flash Point (^{0}C)	D 93-58 T	53	135	62	70	78	Min 130^{0}C
Density (kg/m^3)	D 287	816	874	829	834	838	870-890
Kinematic Viscosity @ 40^{0}C (cSt)	D 445	2.09	4.03	2.31	2.50	2.70	1.9-6
Dynamic Viscosity @ 40^{0}C (cP)	D 445	1.73	3.52	1.93	2.1	2.28	----



(a)



(b)

Figure 2. (a) Experiment setup and (b) Schematic layout of the setup.

experiment should propagate errors and uncertainties in the experiments. The test has been carried out with utmost care still errors will always enter into all experiments. Uncertainty analysis is necessary to ascertain the experiments' reliability. The maximum error in any parameter used to calculate the result is equal to the error in the final result, according to Holman [17]. Using the % uncertainties of different measuring instruments it is possible to estimate the uncertainties of measuring parameters such as BP, BTE, BSEC, and BSFC which are later used to estimate the overall uncertainties [18]. The overall uncertainty of an experiment work can be computed using the values of errors for different measuring parameters presented in Table 5.

Total uncertainty of experiment = Square root of (Uncertainty of BTE)^2 + (Uncertainty of BSFC)^2 + (Uncertainty of BSEC)^2 + (Uncertainty of BP)^2 + (Uncertainty of CO)^2 + (Uncertainty of CO_2)^2 + (Uncertainty of HC)^2 + (Uncertainty of NO)^2 + (Uncertainty of Smoke)^2 = $((1.49)^2 + (1.11)^2 + (1.41)^2 + (0.50)^2 + (0.007)^2 + (0.50)^2 + (0.005)^2 + (0.02)^2 + + (0.1)^2)^{0.5}$ = ±2.44%

Table 3. Arrangement of sensor/device

Sr.no	Number	Description/Location
1	T1	Temperature of coolant at the inlet of an engine.
2	T2	Temperature of coolant at the outlet of an engine.
3	T3	Temperature of coolant at calorimeter inlet.
4	T4	Temperature of coolant at calorimeter outlet.
5	T5	Exhaust gas temperature at the inlet of the calorimeter.
6	T6	Exhaust gas temperature at the outlet of the calorimeter.
7	F1	Fuel Flow Transmitter.
8	F2	Air Flow Transmitter.
9	Wt	Load Cell Sensor.
10	PT	Cylinder Pressure Transducer.
11	N	Engine RPM (CA) Sensor.
12	F3	The mass flow rate of engine jacket cooling water.
13	F4	The mass flow rate of calorimeter cooling water.

Table 4. Engine specification

Parameters	Description
Manufacturer and Model	Kirloskar, TV-1 Model.
Type of test engine	Mono cylinder, VCR-CRDI type, 4 stroke, water-cooled CI engine.
Length of stroke (mm)	110
Bore diameter (mm)	87.5
Range of Compression Ratio	12:1 to 18:1
Power output (kW)	3.5 kW @ 1500 rpm.
Displacement (cc)	661 cc.
Dynamometer type	Eddy current type, Water cooled

Table 5. Accuracy of the measurement

Measurement	Device	Range	Resolution	Uncertainty (%)
CO	AVL make Five gas analyzer, Model: Digas 444N	0-15% Vol	0.001 % Vol	±0.007
CO_2	AVL make Five gas analyzer, Model: Digas 444N	0-20% Vol	0.1 % Vol	±0.50
HC	AVL make Five gas analyzer, Model-Digas 444N	0-20000 ppm (Vol)	1 ppm (0-2000 ppm) 10 ppm (> 2000 ppm)	±0.005
NO_x	AVL make Five gas analyzer, Model: Digas 444N	0-5000 ppm (Vol)	1 ppm Vol	±0.02
Smoke	AVL makes Smoke meter Model: AVL-437	0-100 %	0.1%	±0.10

RESULTS AND DISCUSSION

Brake Thermal Efficiency

The ratio of the engine power available at the crankshaft and energy supplied due to the combustion of fuel is considered a brake-thermal efficiency. This parameter shows how efficiently the thermal energy of the fuel is utilized to generate the brake power output. It is preliminarily relying on the supplied fuel mass and its energy content. Figure 3. (a), (b), (c), (d) shows the alteration in an engine's BTE under varied loading conditions for different CRs and fuel blends. The outcome shows that for all blends, BTE slightly rises

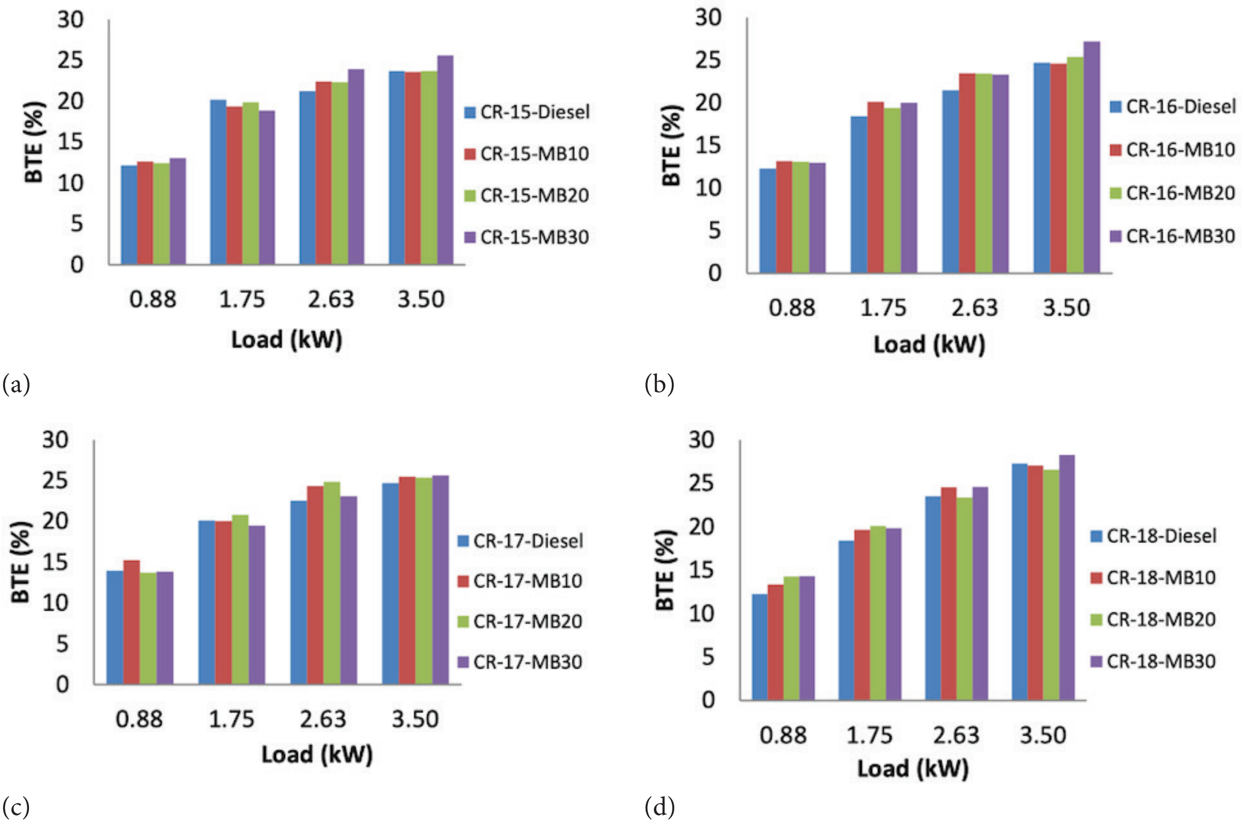


Figure 3. Variation in BTE for different load and fuel bends at (a) CR-15, (b) CR-16, (c) CR-17 and (d) CR-18.

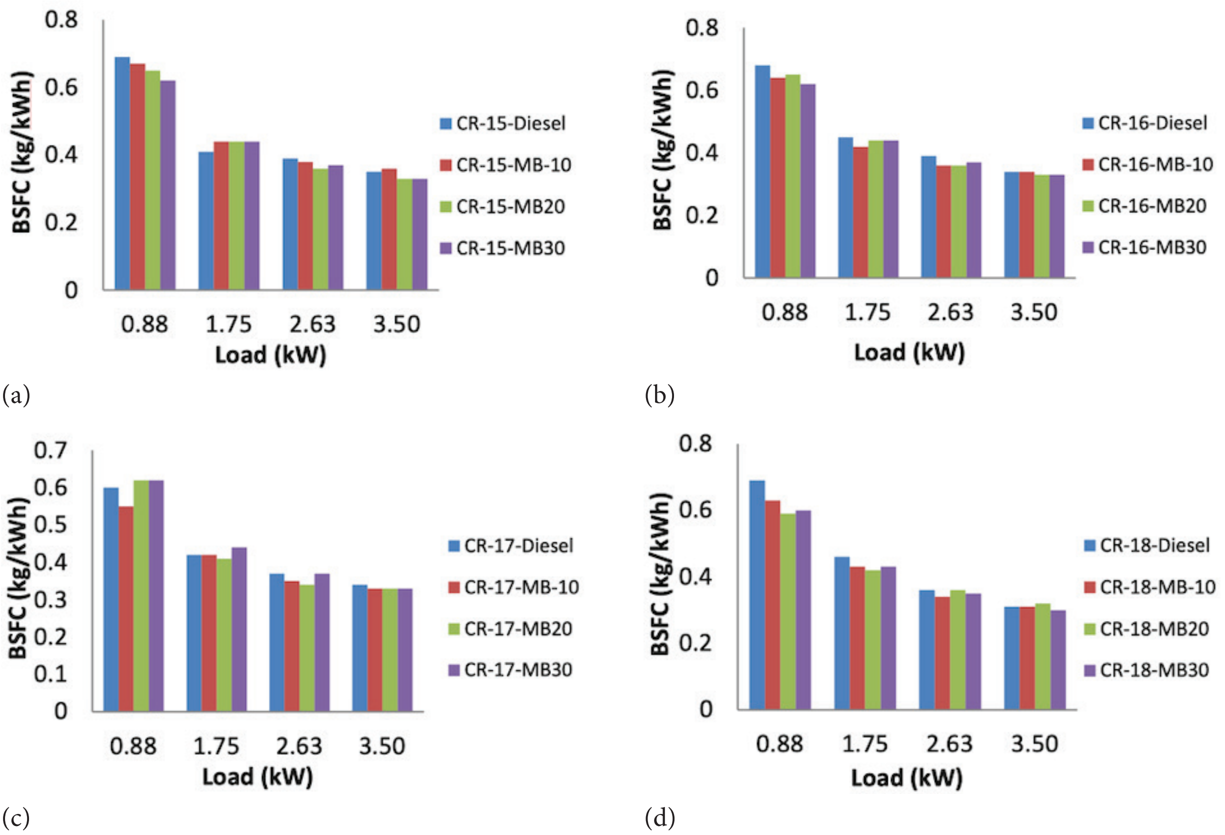


Figure 4. Variation in BSFC for different load and fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18.

with an increase in CR and load. The result indicates that BTE increases marginally with a marginal increase in CR and load for all blends. This could be because an increase in load lowers heat loss and enhances engine power output, whereas higher side CR leads to rises in combustion temperature and pressure, which improves combustion efficiency and minimizes ignition delay [19, 20].

The results show that the highest BTE reported for diesel and biodiesel blend MB30 was 27.27% and 28.26% respectively at the CR of 18 and full loading condition. Also noted that at each CR and for 100% load condition biodiesel blend MB30 offers higher BTE than diesel as it has a higher value of cetane number than diesel and Moringa oleifera is an oxygenated fuel having an oxygen content of about 13% (% Wt) which helps in enhancing complete combustion [21].

Brake-specific Fuel Consumption

It is the ratio of the fuel mass contributed to combustion and power available at the crankshaft of the prime mover. Any engine's BSFC reflects the extent the of fuel being used to obtain the unit power output at the crankshaft. Figure 4. (a), (b), (c), (d) depicts the changes in the BSFC value of an engine at different loading conditions for different CR and fuel blends. The result shows that as the load and CR increase it reduces the BSFC for all tested fuel blends. As previously said, this could be because increasing engine load reduces heat losses, and increasing CR elevates engine temperature and pressure, which improves combustion efficiency and shortens ignition delay [22].

The lowest BSFC recorded for the diesel at 100% load condition and 15:1, 16:1, 17:1, and 18:1 CR is 0.35, 0.34, 0.34 and 0.31 kg/kWh. Biodiesel blend MB30 offers minimum BSFC at 100% load condition and for CR 15:1, 16:1, and 17:1 is 0.33 kg/kWh, and for CR 18:1 is 0.30 kg/kWh. The minimum BSFC reported for diesel and among biodiesel blend MB30 is 0.31 kg/kWh and 0.3 kg/kWh at full loading condition and higher CR of 18:1. It was also observed from the result that at each CR and full load condition biodiesel blend MB30 offers lower BSFC than diesel. The reason behind this might be that biodiesel has more oxygen than diesel which enables complete combustion [23] and higher lubricity of the engine.

Brake-Specific Energy Consumption

The experiment performed in this study is by using different blends of biodiesel with various calorific values. In such cases, BSFC is an arguably inappropriate measure to assess the diesel cycle-based engine's performance when the engine is operated using fuel blends of different calorific values and densities. To demonstrate how effectively

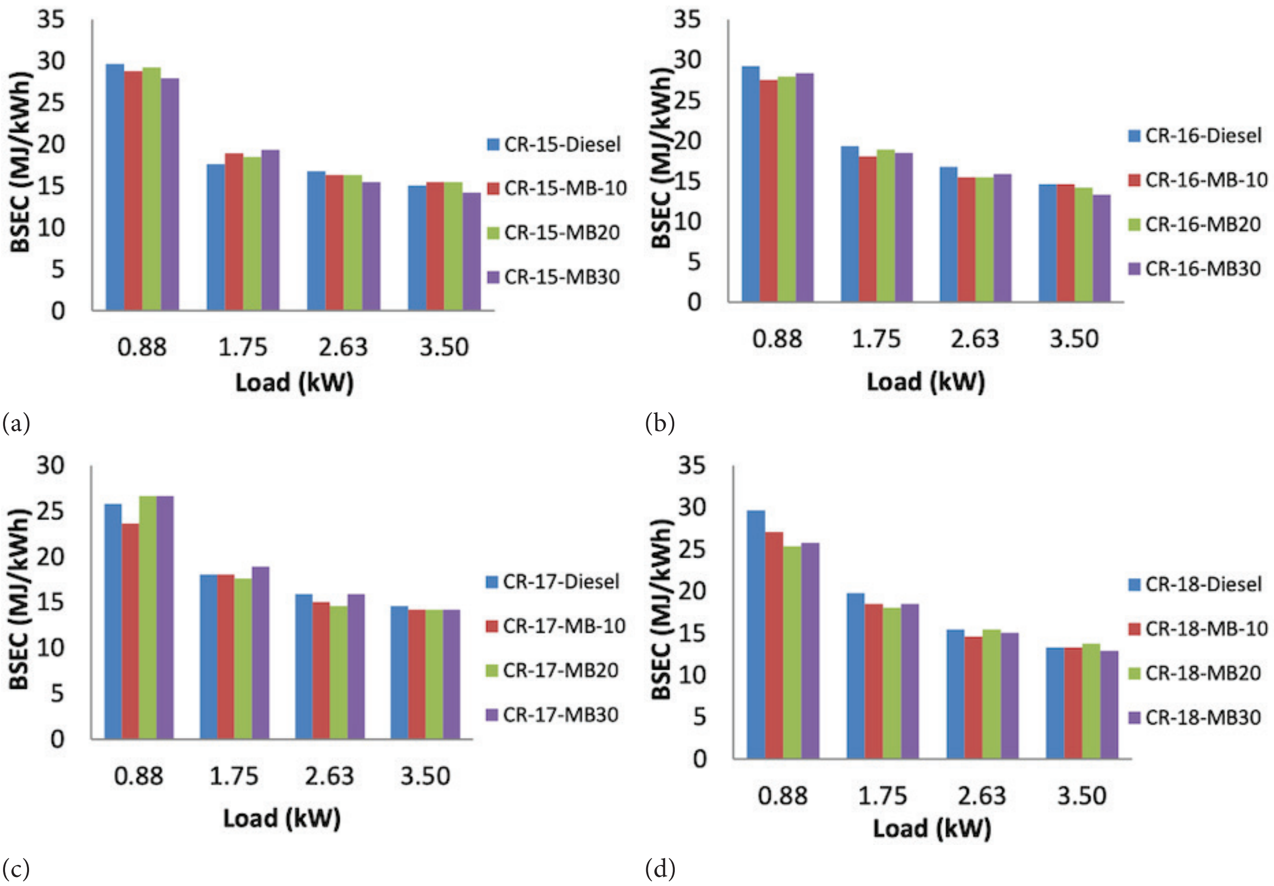


Figure 5. Variation in BSEC for different load and fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18.

energy from supplied fuel is retrieved, BSEC seems more impactful. The use of the energy available in fuel to produce valuable work is less effective as BSEC increases. Figure 5. (a), (b), (c), and (d) displays the change in BSEC for various operating load at different CR and fuel blends. The outcome depicts that BSEC reduces at higher load and CR for all tested fuel blends.

The lowest BSEC offered by the diesel and biodiesel blend MB30 is 13.33 and 12.90 MJ/kWh at full load and higher CR 18:1. The more oxygen molecules in biodiesel allows complete combustion and efficient energy use from the fuel, which is the fundamental cause for the biodiesel blend having lower BSEC than diesel at each CR and load. These results also support the reason behind the higher BTE of biodiesel blend MB30 than diesel as observed before in BTE [11].

Analysis of Exhaust Gas Emission

CO emission

The CO in the flue gas is primarily due to a shortage of oxygen that is required to convert all the carbon into CO_2. Figure 6. (a), (b), (c), (d) presents the CO emission at all tested loading conditions and CR for different fuel blend. The findings show that CO emission reduces as the set load and CR increases for the entire fuel blend because as load and CR increase, the combustion temperature rises, improving the rate at which carbon and oxygen combine to generate CO_2 and lowering CO emissions [24].

The lowest CO emission observed for the diesel and among biodiesel blend for MB30 is 0.04 % vol at full load condition and higher CR of 18:1.It is also observed from the results that at each CR and full load condition biodiesel blend offers less emission of CO than diesel because the biodiesel's ingrained oxygen content improves the process of combustion and supports to lower down CO emissions [19, 21].

HC emission

An unburned or partially burnt fuel particles that develop as an outcome of low temperature near the combustion walls and an accumulation of fuel particles in the combustion's crevice volumes is the main cause of HC emissions. Figure 7. (a), (b), (c), (d) displays the behavior of HC emission value at various loading conditions for the different CR and fuel blends. The outcome depicts that the

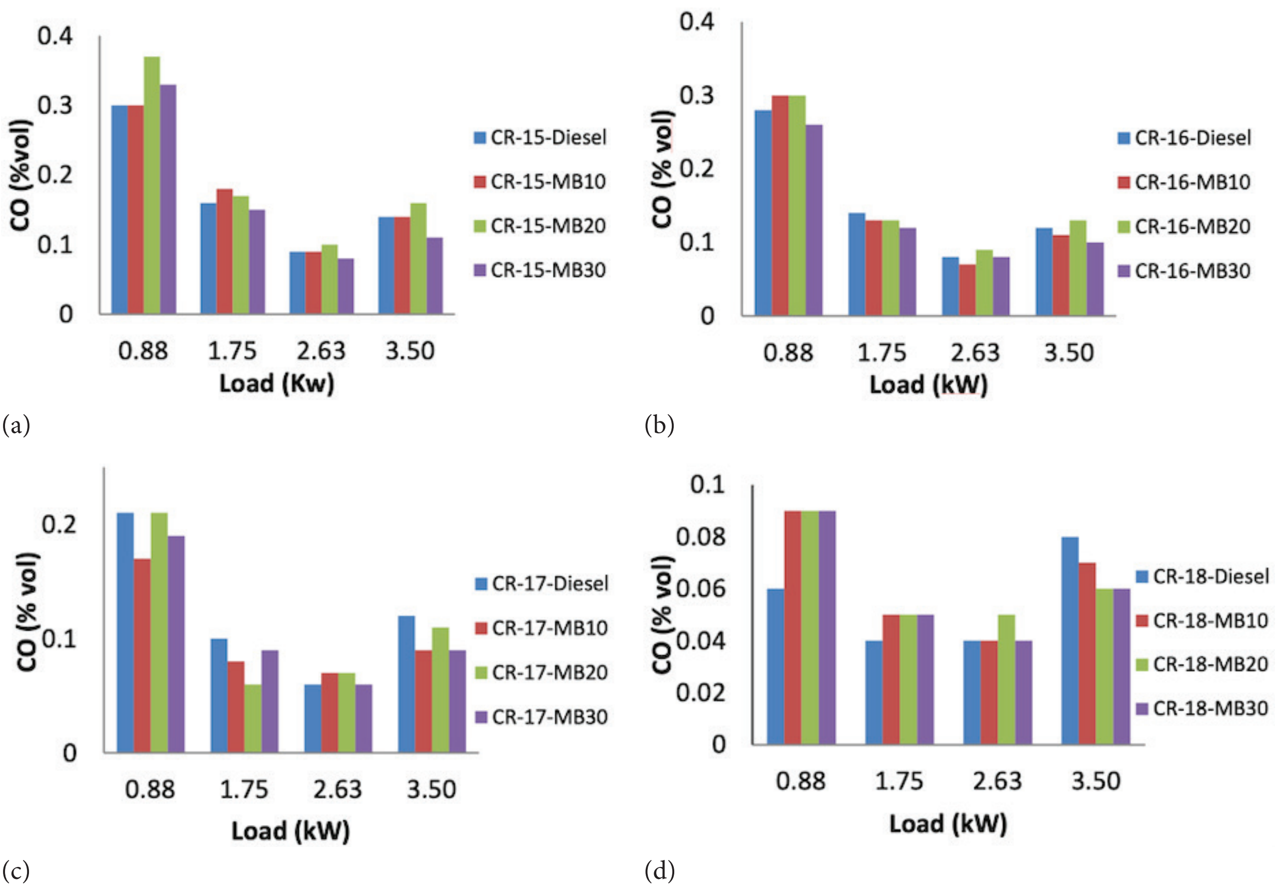


Figure 6. Variation in the emission of CO at different loads and fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18.

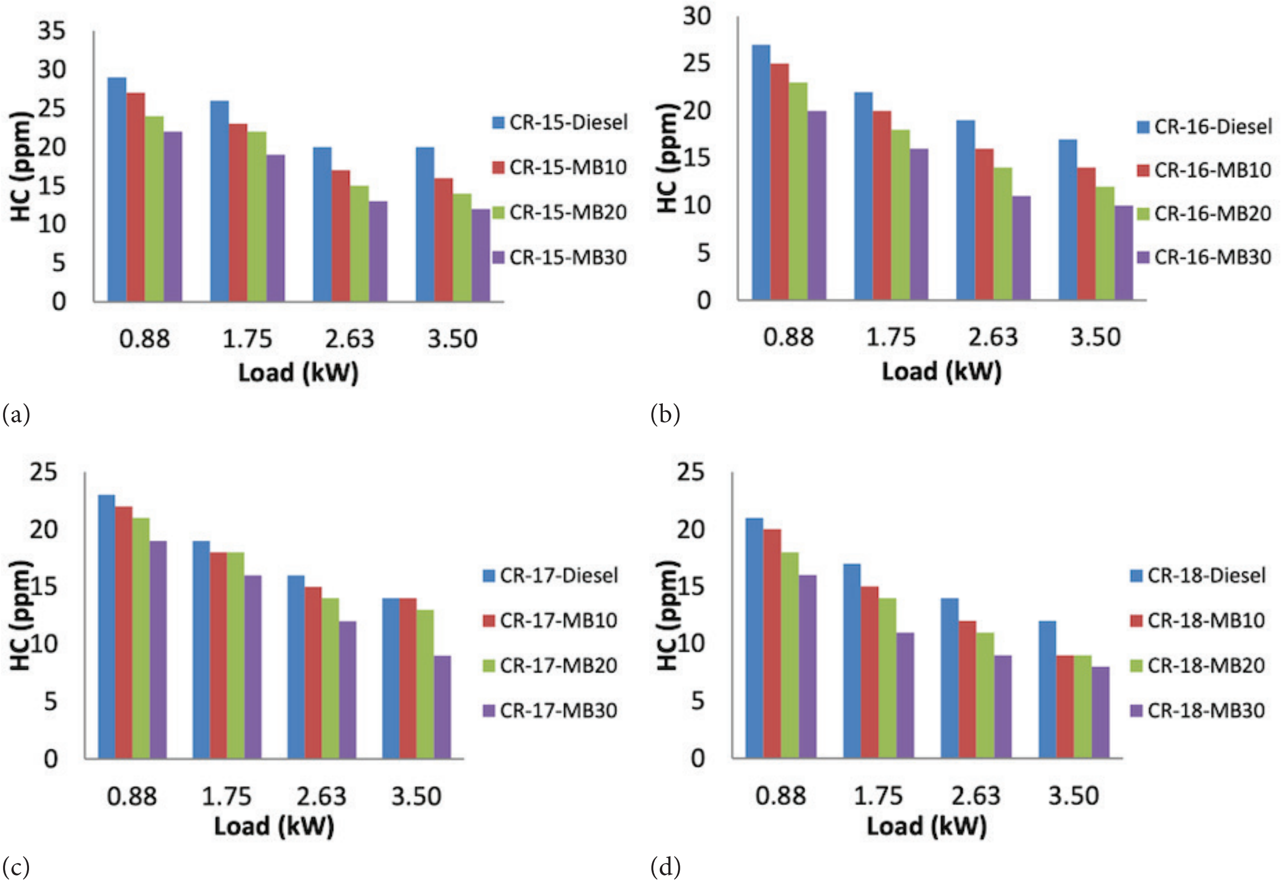


Figure 7. Variation in the emission of HC for different load and fuel bends at t (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18.

emission of HC reduces with a rise in load and CR conditions for the entire fuel blend. The cause for the lower HC emission value with the rise in load and CR is due to improvements in combustion temperature and pressure, which results in improved fuel combustion [6, 18].

The minimum emission of HC observed for diesel and biodiesel blend MB30 is 12 and 8 ppm respectively at full load and higher CR of 18:1.Due to the presence of oxygen in the biodiesel and having less carbon than diesel which results in a higher carbon to oxygen ratio hence biodiesel mix had lower HC emissions than diesel at each CR and load condition [25].

NO_x emission

NO_x is an undesirable and harmful pollutant emitted during the combustion of fossil fuels. NO and NO_2 constitute the two primary elements of NOx. When compared to NO_2, which makes up a small portion of exhaust emissions, NO occupies a higher fraction. Figure 8. (a), (b), (c), (d) depicts the increase in NO_x with the rise in CR and test load for each fuel blend. Higher NO_x emissions are frequently noticed when load and CR rise. As a result, the temperature of the combustion increases, resulting in increased NO emissions [26].

At higher CR 18:1 and full load conditions diesel offers a NO_x emission of 593 ppm and among the biodiesel blend MB20 offers minimum NO_x emission of 522 ppm. It is also noticed that each CR and full load biodiesel blend offers less emission of NO than diesel as a biodiesel blend has higher viscosity compared to the diesel which increases their latent heat and specific heat and reduces the peak temperature and pressure inside the engine cylinder [27].

Smoke

The presence of particulate carbon particles in exhaust emissions was commonly referred to as smoke emissions. The lack of air molecules and the atomization quality of fuel inside the cylinder are crucial variables influencing smoke emissions from diesel engines. Figure 9. (a), (b), (c), (d) displays the variation in opacity of smoke at various load conditions for varieties of fuel blends and at different CRs. It was observed that the emission of smoke increases with rising load conditions for each CR and fuel blend. This may be due to the increase in load lowering the pressure and temperature of the engine cylinder due to a rise in fuel

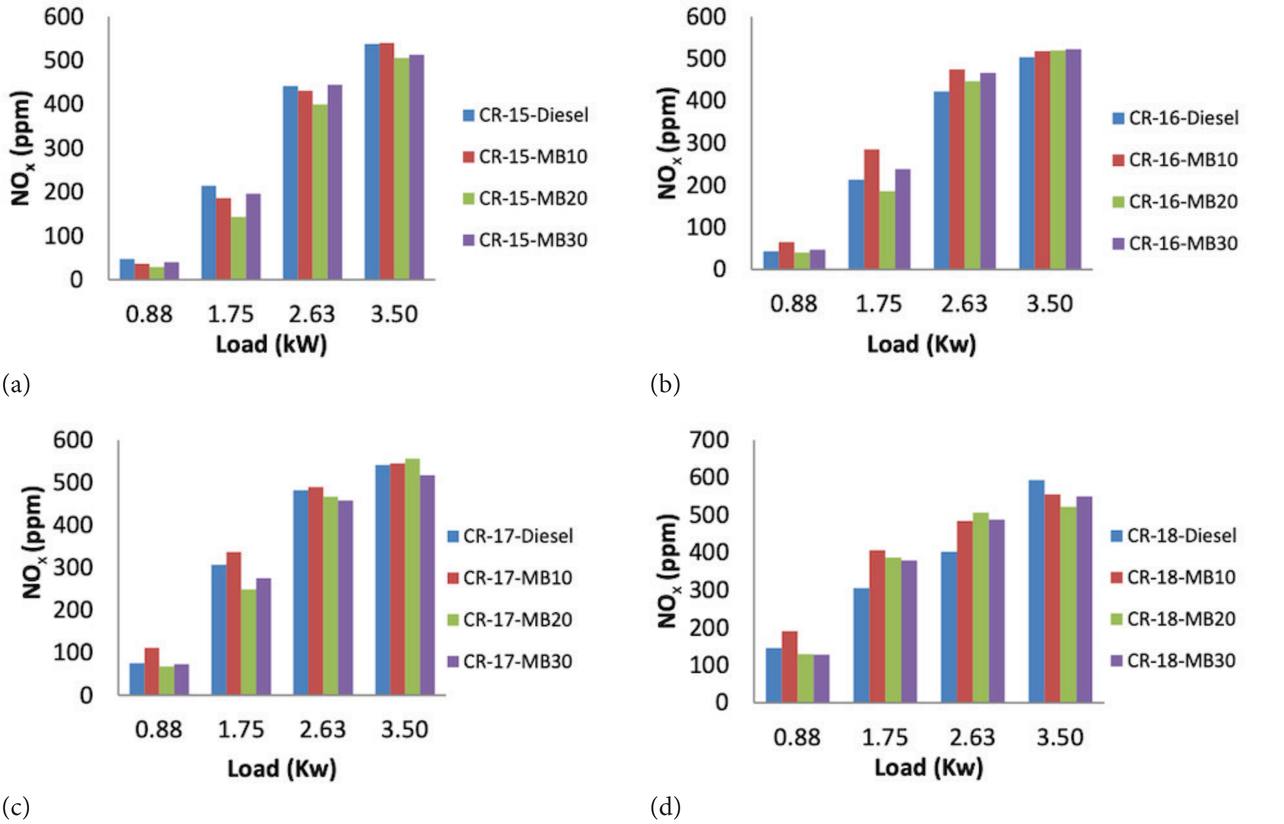


Figure 8. Variation in the emission of NO_x for different load and fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18.

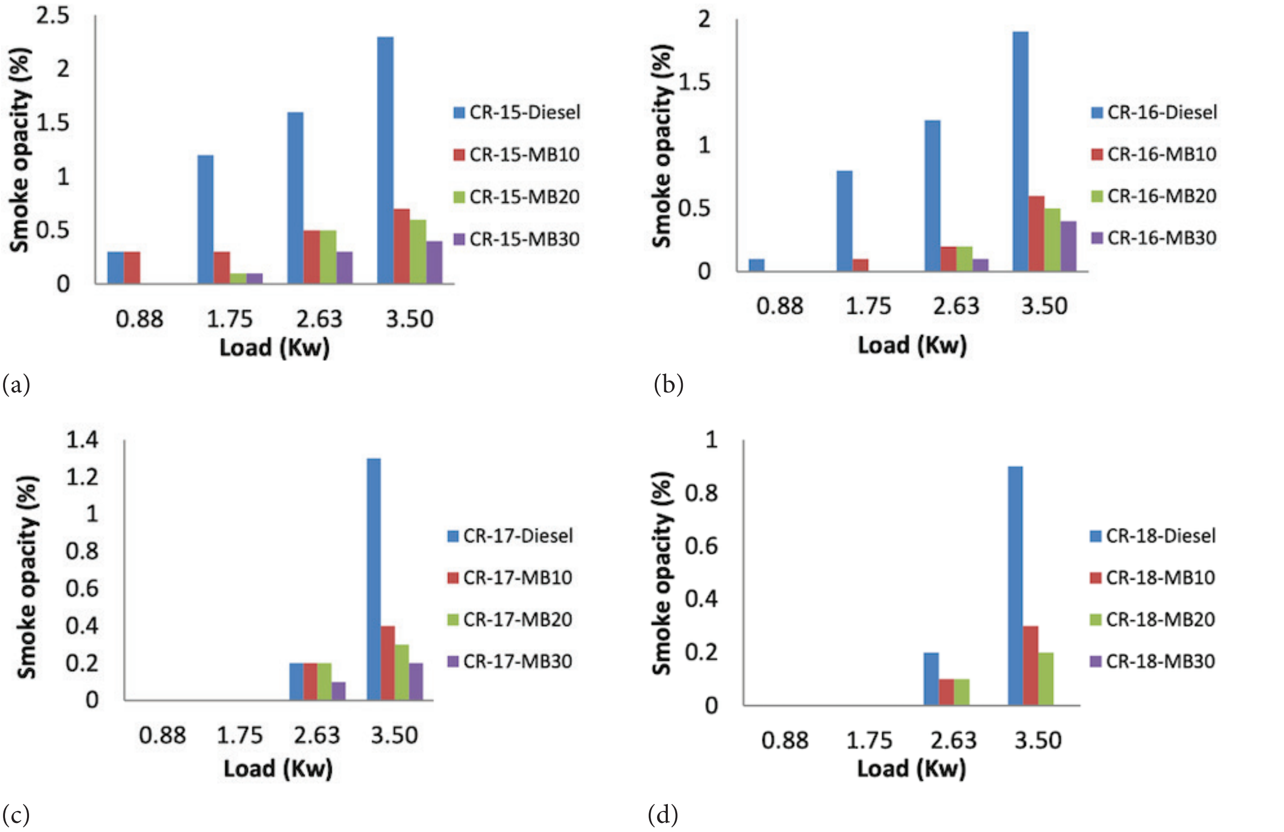


Figure 9. Variation in the emission of smoke for different load and fuel bends at (a) CR-15, (b) CR-16, (c) CR-17, and (d) CR-18.

demand and a short delay period leads to improper combustion. The emission of smoke due to an increase in the temperature, pressure, and oxygen content of the fuel accelerates the process towards complete combustion [20].

The result indicates that at higher CRs of 17:1 and 18:1 and up to 50% loading condition smoke emission is almost zero for each tested fuel. The maximum smoke emission observed for the diesel and MB10 fuel was 2.3 and 0.7 at CR 15:1 and 100% load condition. The presence of oxygen resulted in a lower value of smoke for the biodiesel blend compared to diesel.

CONCLUSION

The highest recorded biodiesel extraction of 94.5% was reported for the following operating conditions: methanol to oil molar ratio 5.5:1, reaction temperature around 60^0C-65^0C, KOH as stimulus with 1wt %, time duration of chemical reaction 60 minutes and maintaining agitator speed 600 rpm.

The biodiesel blend MB30 run achieved the highest BTE around 28.26% at CR 18:1 and the full load which is 3.63% higher than baseline fuel diesel. The ingrained oxygen in biodiesel improves the efficiency of combustion and the higher value cetane number of the Moringa oleifera biodiesel shortens the delay in ignition which results in increases in the BTE of Moringa oleifera biodiesel blend compared to diesel.

Biodiesel blend MB30 had the lowest reported BSFC and BSEC value around 0.3 kg/kWh and 12.9 MJ/kWh for higher CR 18:1 with 100% loading condition. BSFC value is around 3.23 % below pure diesel results. This slight decrease observed in the value for BSFC and BSEC of the biodiesel blend than diesel may indicate improvement in the combustion reaction because of additional oxygen molecules present in biodiesel and the higher value of cetane number of Moringa oleifera biodiesel.

A minimum 0.04 % vol. of CO is released by both diesel and biodiesel blend MB30 at higher operating CR of 18:1 and load condition of 100% while biodiesel blend MB30 shows the minimum emission of HC is 8 ppm for the same operating conditions which is around 33.34% below diesel fuel performance.

At the highest operating CR of 18:1 and 100% load condition, the biodiesel blend MB20 emits the lowest NO_x which is 522 ppm compared to other tested fuel blends. It is almost 11.97% less than diesel. The lowest emission of smoke is reported for diesel and biodiesel blend MB30 is zero for the higher CR 18:1 and up to 50% loading condition while the highest emission of smoke is reported for diesel and biodiesel blend MB10 is 2.3 and 0.7 at lower CR 15:1 and full load condition.

According to the above-mentioned statement, Moringa oleifera biodiesel blend MB30 exhibits improvement in thermal performance by enhancing BTE and lowering BSFC while reducing the emissions of pollutants such as CO, HC, smoke, and NO_x at full load and higher CR conditions.

NOMENCLATURE

MB10	90% Diesel+ 10% Moringa oleifera methyl ester by volume
MB20	80% Diesel+ 20% Moringa oleifera methyl ester by volume
MB30	70% Diesel+ 30% Moringa oleifera methyl ester by volume
MB100	100% Moringa oleifera biodiesel
BSFC	Brake-specific fuel consumption
CR	Compression ratio
BTE	Brake thermal efficiency
IP	Injection pressure
BSEC	Brake-specific energy consumption
bTDC	Before top dead center
CO	Carbon mono oxide
IT	Injection timing
CO_2	Carbon dioxide
VCR	Variable compression ratio
HC	Hydro carbon
CRDI	Common rail direct injection
NO_x	Nitrogen oxides
GDP	Gross domestic produce
FFA	Free fatty acid
MOME	Moringa oil methyl ester

DECLARATIONS

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

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirmed that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

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

ETHICS

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

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