

Study of Biodiesel Blends on Emission and Performance Characterization of a Variable Compression Ratio Engine

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ABSTRACT: This study explores the emission of different pollutants using different blends in a variable compression ratio (VCR) engine. Biodiesel synthesized from *Jatropha* oil using a heterogeneous catalyst was investigated for emission analysis on a single-cylinder VCR engine with various blending ratios as well as load. Blends (biodiesel + diesel) of JB00, JB10, JB20, JB30, and JB100 were prepared at 40 °C. The emission parameters, such as nitrogen oxides (NO_x), carbon monoxide (CO), and hydrocarbon (HC), were studied and compared to diesel fuel. Results showed that, among the blends prepared from methyl ester of *Jatropha*, JB30 shows reduction in emissions of CO and HC up to 43 and 50%, respectively, with an increment of NO_x emission up to 20% at the lowest load and compression ratio (CR) of 15. The optimum parameter for the lowest pollutant emission for JB30 was found with a load of 6 kg at CR of 15.

■ INTRODUCTION

The fossil fuels, such as diesel, gasoline, liquefied petroleum gas (LPG), etc., are diminishing sources of energy, but the demand for energy is increasing day by day. In this regard, biodiesel is a sustainable option^{1,2} because it is a nontoxic, biodegradable, renewable, oxygenated, and sulfur-free fuel^{3,4} and can be obtained by treating various kinds of vegetable oils and fats.^{5,6} Biodiesel production is 82% of the total biofuel production in the European Union, and its global production is estimated to be over 35 billion liters.⁷ The comparative higher heating values of biodiesel (39–41 MJ/kg) make it competitive to gasoline (46 MJ/kg), petrodiesel (43 MJ/kg), petroleum (42 MJ/kg), and coal (32–37 MJ/kg) for use in transportation fuel.⁸ Therefore, it can be used as a blend or stabilizer⁹ at a particular proportion with diesel fuel without any modification to the diesel engine.^{10,11} Diesel engines produce a large amount of polluting gases, such as carbon monoxide (CO), unburnt hydrocarbons (HCs), and nitrogen oxides (NO_x), which pose a threat to the environment and, hence, living beings. Emissions of these harmful gases and particles, also result in the greenhouse effect. These gases and particles if inhaled by the humans and animals can cause various detrimental diseases. Hence, to prolong the air excellence, the European emission standard restricted the pollutant emissions for light-duty vehicles as well as heavy-duty vehicles, as mentioned in Table 1.

Therefore, the study of blending of a renewable source of fuel, such as ethanol¹² or biodiesel,¹³ with diesel on the emissions of polluting gases is very significant for many

purposes, such as transportation, pollution, energy generation, etc. Several studies^{3,14–17} have explored performance and emission features of biodiesel engines at various engine speeds, loads, and biodiesel ratios. These results showed that the engine performance is affected by the percentage of biodiesel present in the fuel.^{18–20} The numerous works on blending of diesel with soybean,²¹ *Ceiba pentandra*,²² and *Eruca sativa* gars²³ derived biodiesel were reported for direct-injection diesel engine performance and emission. All of these studies agreed with the decrease in CO and HC emissions but increase in NO_x and CO₂ emissions. The emissions of CO, HC, and NO_x depend upon the aromatic content of diesel fuel,²⁴ and the increase in CO₂ and NO_x indicates more oxidation because of the presence of constituent composition of biodiesel. The amount of this constituent oxygen varies with feedstock used for biodiesel production. Hence, the importance of different feedstocks cannot be ignored at pollution prospects.

Vallinayagam et al.²⁵ had studied the pine biodiesel blended with diesel at 25, 50, and 75%. The study showed reduction in emissions of HC, CO, and smoke up to 30, 65, and 70%, respectively, but NO_x emission was higher than diesel fuel at the highest load (12 kg). Therefore, the major pollutant emissions decrease using biodiesel as a blend in a diesel engine. Abedin et al.²⁶ studied palm and *Jatropha* biodiesel blends for performance, emission, and heat loss. The experiment revealed reduction in emission of CO up to 30.7% and HC up to 25.8% for 20% blends. Emissions of NO_x reduced by 3.3% upon applying 10 and 20% blends of palm biodiesel, whereas they increased by 3.0% for 10 and 20% blends of *Jatropha* biodiesel. Baste et al.²⁷ have reported that blending of diesel with 20% *Pongamia pinnata* oil methyl ester can be used safely in a conventional compression ignition (CI) engine without

Table 1. Emission Limits for Vehicles as Per Euro VI

pollutants	light-duty vehicles (g/km)	heavy-duty vehicles (g/kWh)
CO	0.5	1.5
NO _x	0.17	0.13
HC	0.08	0.4

Received: April 8, 2015

Revised: May 27, 2015

Published: May 28, 2015

modifications to the engine. The effect of injection pressure in a direct-injection diesel engine was studied by Nagarhali et al.²⁸ In this study, the blended fuel used two different feedstock-derived biodiesels with comparison to diesel. The study reveals that emissions, such as HC and CO, were lower at 200 bar, while NO_x emission was higher at 200 bar for mixtures of *Jatropha* (80%) and karanja (20%) biodiesel.

Raheman et al.²⁹ and Agarwal et al.³⁰ worked with common karanja-derived biodiesel. Both commonly agreed on reduction of HC emission, with contradictory results reported for NO_x and CO emissions. However, Raheman et al. used the blending of biodiesel at 20, 40, 60, and 80% with diesel and performed the experiment for a direct-injection diesel engine. The blending used by Agarwal et al.³⁰ was 10, 20, 50, and 100%, and a direct-injection CI diesel engine was used to perform the experiment. The blending of waste cooking oil biodiesel with diesel was used by Singh et al.³¹ at 10% (B10), 20% (B20), and 30% (B30) loading. At various compression ratios (CRs) (12, 14, and 16), the emissions of HC and NO_x got reduced for every biodiesel-blended fuel. Overall, a literature survey suggests that there may be a possibility to reduce pollutant emissions, especially NO_x, using different resource-derived biodiesels and different CRs. Mostly virgin oil is used for biodiesel production in the industry. The higher cost of virgin oil enhances the overall cost of biodiesel. Therefore, the non-edible *Jatropha* oil³² is the best possible option for biodiesel production. The study of the CR effect on pollutant emissions for *Jatropha*-oil-derived biodiesel may be an option as a blended fuel for a diesel engine. Hence, non-edible *Jatropha* oil was used in this study to obtain biodiesel by using a heterogeneous eggshell-derived catalyst preceded for emission analysis, such as NO_x, CO, HC, etc., compared to diesel fuel on variable compression ratios (VCRs) for a VCR diesel engine.

EXPERIMENTAL SECTION

Preparation of Blends. The synthesized methyl ester of *Jatropha* oil was used to study emission analysis in a VCR engine. The composition (%) of *Jatropha* oil was determined with the help of gas chromatography (Table 2).

For a comparative study with diesel fuel (JB00), the blending of biodiesel has been prepared with the diesel fuel by volume as JB10 (i.e., 10% *Jatropha* biodiesel and 90% diesel fuel), JB20 (20% *Jatropha*

Table 2. Composition of *Jatropha* Oil

number	component	composition (wt %)
1	caprylic acid	0.036
2	myristic acid	0.066
3	pentadecanoic acid	0.009
4	palmitic acid	14.240
5	heptadecanoic acid	0.085
6	stearic acid	6.585
7	palmitoleic acid	0.796
8	<i>cis</i> -10-heptadecanoic acid	0.038
9	oleic acid	37.279
10	<i>cis</i> -11-eicosenoic acid	0.230
11	linoleic acid	35.00
12	α -linolenic acid	0.086
13	γ -linolenic acid	0.238
14	eicosadienoic acid	4.871
15	<i>cis</i> -11,14,17-eicosatrienoic acid	0.086
16	arachidonic acid	0.153
17	<i>cis</i> -13',16'-docosadienoic acid	0.202

biodiesel and 80% diesel fuel), JB30 (30% *Jatropha* biodiesel and 70% diesel fuel), and JB100 (100% *Jatropha* biodiesel). Density, flash point, fire point, and calorific value were found as per ASTM standard methods.

Experimentation Based on Engine Trial. In this study, a diesel engine was used manufactured from Kirloskar (model TV1). The major technical specifications of the engine were mentioned in Table 3. It is a water-cooled, four-stroke, internal combustion (IC) diesel

Table 3. Technical Specification of the Engine

model	TV1 (Kirloskar)
type	water-cooled, four-stroke, IC diesel engine
number of strokes	4
number of cylinders	1
CR	12–18
rated power (kW)	3.5
dynamometer arm length (mm)	145
rated speed (rpm)	1500
cylinder diameter (mm)	87.5
stroke length (mm)	110
crank angle (deg)	resolution 1
connecting rod length (mm)	234

engine. It can be operated at a maximum power of 3.5 kW at 1500 rpm. Primitively, the required biodiesel blend is filled in the fuel tank and ensured the cooling water circulation for an eddy current dynamometer and engine. The necessary CR was adjusted; the engine started without loading for 10 min; and the emissions of different pollutants were analyzed (HC, NO_x, and CO) with the help of an exhaust gas analyzer (Neptune Opax2000). Three replicates of data were recorded to calculate the mean value and lower the error during the experiment. By increment in loading with the help of a rotating dynamometer loading unit, emissions were observed after every 3 min run with respected loads. Then, the load was diminished to zero. The experiment was repeated at CR of 14–18 for each blend of JB10, JB20, JB30, and JB100 at different loads of 0, 3, 6, 9, 12 kg. After completion of all trials, the engine was run on diesel fuel (i.e., JB00) for elucidation of the result at different loads.

RESULTS AND DISCUSSION

Physical and Thermal Properties of *Jatropha* Methyl Ester and Blends. The *Jatropha* methyl ester was blended with diesel fuel at 40 °C, and its major chemical properties were studied. The density of fuel is a significant parameter in terms of exhaust emission.³³ The density determined for diesel fuel was 0.830 gm/cm³, while those of JB10, JB20, JB30, and JB100 were 0.832, 0.836, 0.840, and 0.867 gm/cm³. Because biodiesel is denser than diesel fuel, the density gets increased with increment in blend. The flash point and fire point of diesel fuel were 64 and 69 °C, respectively, while those of JB10, JB20, JB30 and JB100 were 68, 74, 79, and 178 °C and 76, 82, 88, and 189 °C, respectively. The flash point and fire point also got increased upon blending and are, therefore, considered as safe factors in storage and transportation. The calorific value of diesel fuel was 42.50 MJ/kg, while those of JB10, JB20, JB30, and JB100 were 41.5, 41.0, 39.7, and 39.5 MJ/kg. Properties of diesel and biodiesel blends are mentioned in Table 4.

Emission Tests. HC Emission. The emission of HC at various CRs and with different loads of blended fuel was studied. The observed results were plotted at respected CR with HC emission against load. It can be observed from Figure 1 that, with an increase in load and CR, the emission of HC becomes lowered. The blend content enhancement decreases the HC emission, especially at lower load (0–6 kg) at CRs of

Table 4. Properties of Diesel and Biodiesel Blends

properties	ASTM 6751 standard ²⁷	JB00	JB10	JB20	JB30	JB100
density (gm/cm ³)	D1448-1972	0.830	0.832	0.836	0.840	0.867
flash point (°C)	D93	64	68	74	79	178
fire point (°C)	D93	69	76	82	88	189
calorific value (MJ/kg)	D6751	42.50	41.5	41.00	39.7	39.5

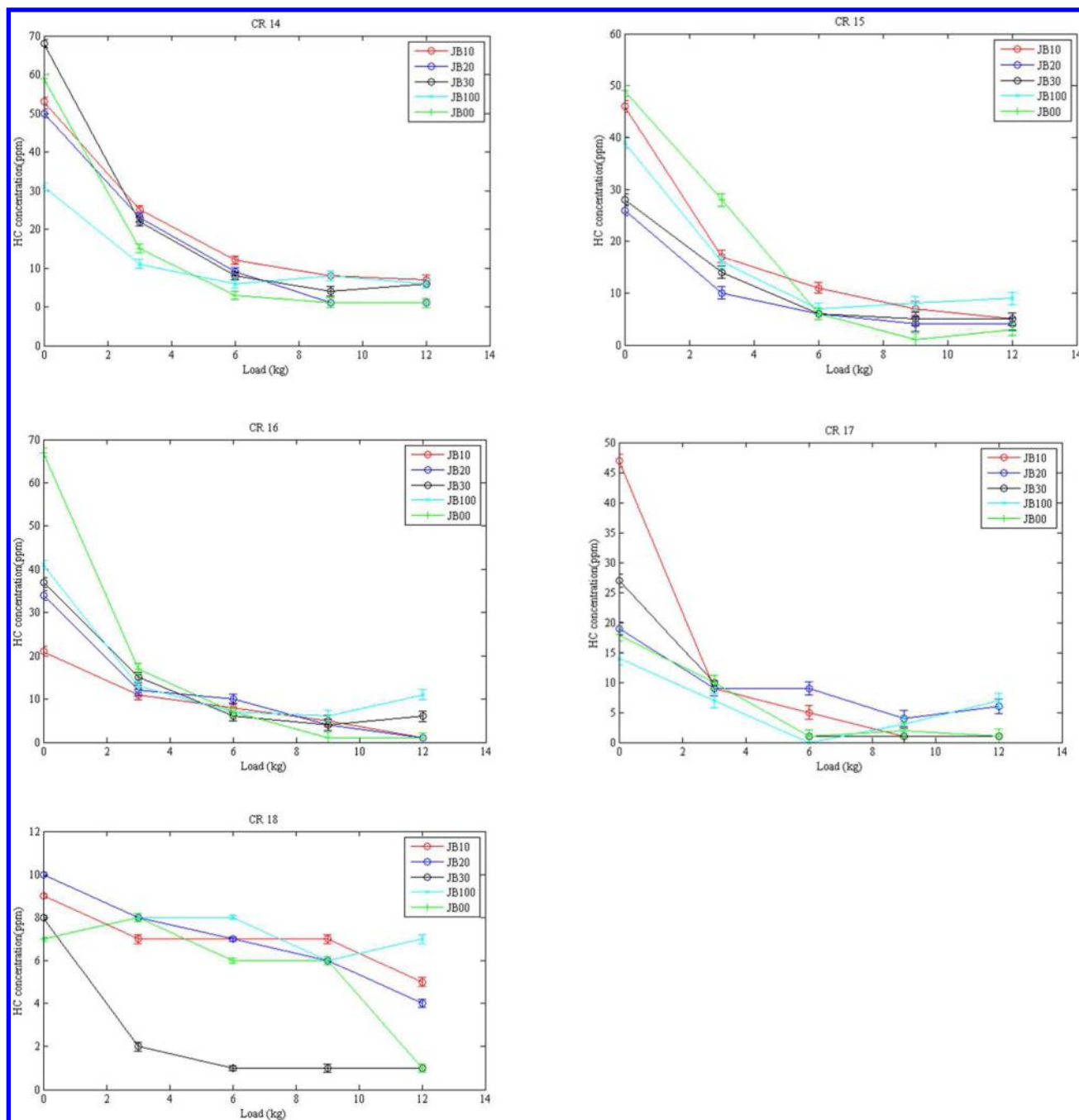


Figure 1. Concentration of HC emission (ppm) versus load (kg) plots at CR of 14, 15, 16, 17, and 18.

15 and 16. It is also quite interesting that the CR has a diverse effect for different blended fuels on HC emission. At a higher load, diesel fuel showed comparatively lower HC emission with respect to other blended fuels at CRs of 14–16. At CR of 17, JB30 competed with diesel, and at CR of 18, it showed the lowest frequent HC emission with load of 6–12 kg. Lowering of the HC emission may be due to a high cetane number of

biodiesel blends. A higher cetane number lowers the combustion delay, which enhances the combustion. Another reason for the low HC emission with an increase in the blend content was due to more oxygen content (11.68%) than diesel fuel. JB30 emission of HC was found comparable to JB20 at CR of 15. The plots of HC emissions for different blends and diesel

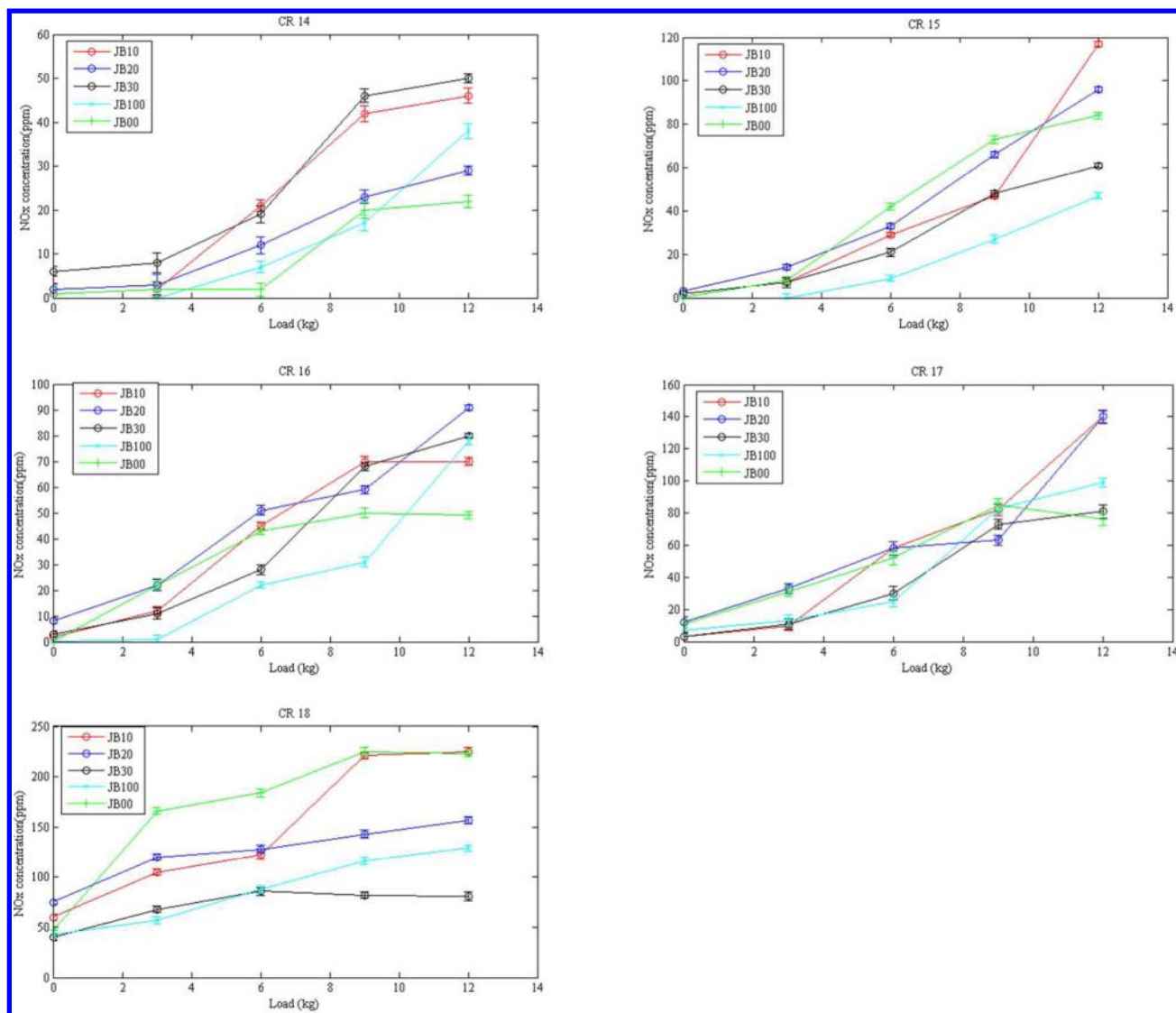


Figure 2. Concentration of NO_x emission (ppm) versus load (kg) plots at CR of 14, 15, 16, 17, and 18.

fuel with load at CR of 14, 15, 16, 17, and 18 were illustrated in Figure 1.

NO_x Emission. NO_x emission is temperature-dependent. To suppress the NO_x emission, Palash et al.³⁴ worked on the effect of the antioxidant (*N,N'*-diphenyl-1,4-phenylenediamine) over NO_x emission and blended fuel with *Jatropha* biodiesel by volume of 5, 10, 15, and 20%. The presence of the antioxidant was able to reduce the free radicals formed as a result of fuel combustion and, therefore, reduces the NO_x formation. In this study, the effect of CR of 14–18 during NO_x emission for JB00, JB10, JB20, JB30, and JB100 with different load shows interesting performance. The NO_x emission generally increased with an increase of the biodiesel content in the blend with the biodiesel blend prepared with either kerosene or diesel.³⁵ It has been supported by the work³⁶ over *Jatropha* biodiesel that the constituent oxygen in biodiesel contributes a little bit higher emission of NO_x compared to pure diesel, but the emissions of all other pollutants (HC, CO, and CO_2) get reduced. It may be also because the biodiesel usually contains comparatively more double-bonded molecules than diesel fuel. These double-bonded molecules have slightly higher adiabatic flame temperatures, which deals with increase in NO_x emission. This type of

behavior can occur as a result of reduction in soot formation with biodiesel. Radiation from the soot produced in the flame zone is a major source of heat transfer away from the flame and can lower the bulk flame temperatures, depending upon the amount of soot produced at the engine operation conditions.

The NO_x emissions for JB00, JB10, JB20, JB30, and JB100 was illustrated in Figure 2 at different CRs (14, 15, 16, 17, and 18). The NO_x emissions were found increasing with the increase in load and CR. It may be due to increase in the temperature inside the combustion chamber at a high load. Nitrogen from air easily mixes with oxygen and produces NO_x . This activity of NO_x emission with CR may also be because of the lower ignition delay, which increases the peak pressure and temperature. The emission of NO_x for diesel (JB00) was found lowest at every CR, except at CR of 18 and 15. The blends JB100 and JB30 have shown lower emissions compared to diesel and other blends at CR of 15 and 18 for the lowest and highest loads.

CO Emission. The CO emission for JB00, JB10, JB20, JB30, and JB100 with load is compared at different CRs (14, 15, 16, 17, and 18) has been shown in Figure 3. The load has shown an antagonistic effect over CO emission. The lowest CO emission

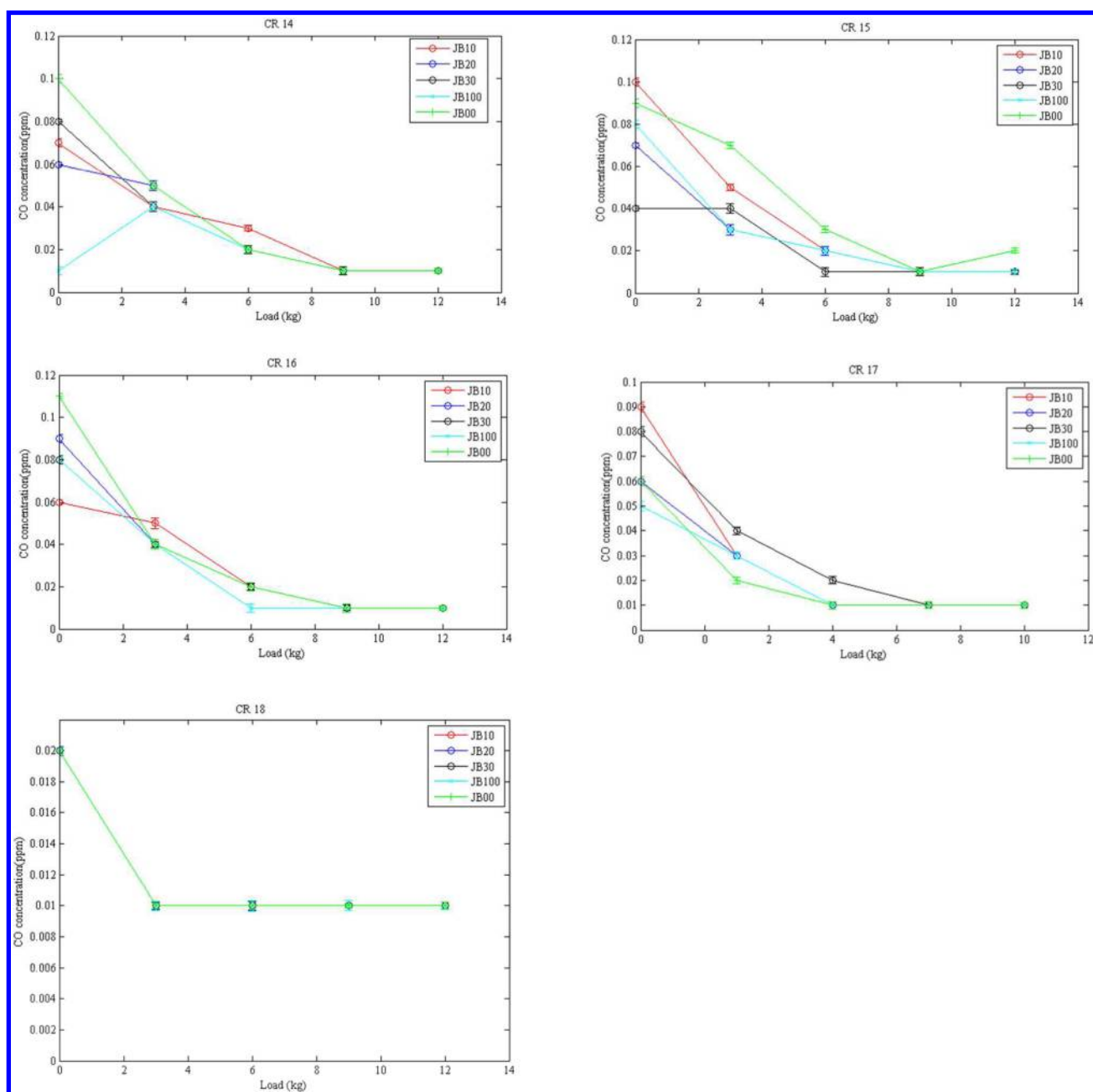


Figure 3. Concentration of CO emission (ppm) against load (kg) plots at CR of 14, 15, 16, 17, and 18.

(0.01 ppm) was achieved at every CR but at higher load (9 and 12 kg), whereas the highest emission (0.11 ppm) was obtained for diesel fuel at CR of 16. The biodiesel and blended fuel have shown lower emission of CO, especially at lower CR and load. At loads of 9 and 12 kg, CO emission of diesel fuel was found almost similar to other blends at every CR. Moreover, in the study at the highest CR (18), diesel and blended fuel show a common CO emission pattern. Therefore, at the higher CR, the effect of load and blend can be neglected. It indicates that, to control CO emission, blending up to 30% can be nullified upon increasing CR up to 18. However, at CR < 18, the blending amount of biodiesel has a significant role in the lowering of the CO emission. This may be due to the presence of oxygen in biodiesel, which leads to complete combustion. The blend JB30 has shown almost the least CO emission at CR of 14, 15, and

16. Upon increasing CR of 14–17, the CO emission for the JB30 blend becomes lowered at a higher load.

CONCLUSION

The experimental analysis suggests that HC and CO emissions decrease with an increase in load and CR, whereas NO_x emission increases with an increase in load and CR. The optimum blend and CR was observed as JB30 and CR of 15, respectively. The HC and CO emissions were decreased by 43 and 50%, respectively, whereas NO_x emission was increased by 20% at the lowest load (0) for JB30, as compared to diesel fuel. However, with the increase of load, NO_x emission got decreased up to 50% for JB30 at a load of 6 kg. The study reveals that, at CR of 15 and load of 6 kg for JB30, CO and NO_x emissions decrease up to 50% and the HC emission remains constant. Therefore, the JB30 blend with a load of 6 kg

at CR of 15 was found as the optimum parameters to operate a VCR diesel engine for the lowest emissions of HC, NO_x and CO gases. Moreover, at the highest CR (18) and load (6–12 kg), JB30 shows the lowest emission for each pollutant. The overall results affirm that JB30 is the best possible blend to be used for the lowest emissions of HC, CO, and NO_x.

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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The authors are thankful to the Council of Scientific and Industrial Research (CSIR) for financial assistance (P 25/330). The authors are thankful to IBDC, Baramati, Maharashtra, for help in experiments.

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