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

Supriya B. Chavan,[†] Rajendra Rayappa Kumbhar,[‡] Ashutosh Kumar,[§] and Yogesh C. Sharma*[,§]

[†]Department of Chemistry, Bhagwant University, Ajmer 305004, Rajasthan, India

[‡]Rajarshi Chhatrapati Sahu College, Kolhapur 416002, Maharashtra, India

[§]Department of Chemistry, Indian Institute of Technology (BHU) Varanasi, Varanasi 221005, Uttar Pradesh, India

**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 stabilizer[9] 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 ethanol[12] 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* gars[23] 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 $CO_2$ emissions. The emissions of CO, HC, and $NO_x$ depend upon the aromatic content of diesel fuel,[24] and the increase in $CO_2$ 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 |

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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* oil[32] 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* 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.

**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 | *cis*-10-heptodeconic acid | 0.038 |
| 9 | oleic acid | 37.279 |
| 10 | *cis*-11-eicosenoic acid | 0.230 |
| 11 | linoleic acid | 35.00 |
| 12 | $\alpha$-linolenic acid | 0.086 |
| 13 | $\gamma$-linolenic acid | 0.238 |
| 14 | eicosadienoic acid | 4.871 |
| 15 | *cis*-11,14,17-eicosatrienoc acid | 0.086 |
| 16 | arachidonic acid | 0.153 |
| 17 | *cis*-13′,16-docosadienoic acid | 0.202 |

**Experimentation Based on Engine Trial.** In this study, a diesel engine was used manufactured from Kirlosker (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 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.

**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 |

## 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/cm$^3$, while those of JB10, JB20, JB30, and JB100 were 0.832, 0.836, 0.840, and 0.867 gm/cm$^3$. 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


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**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 |

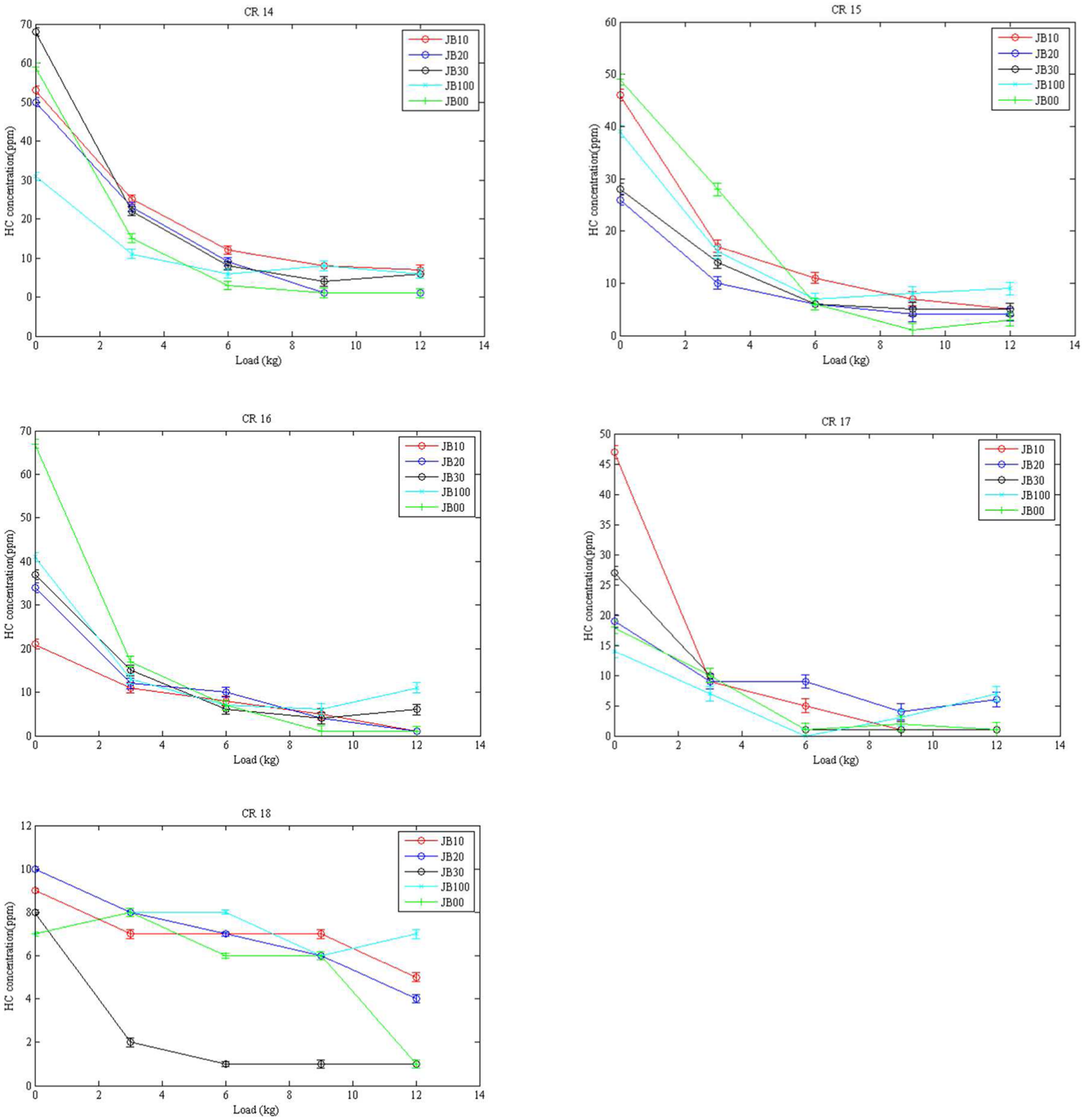


**Figure 1.** Concentration of HC emission (ppm) versus load (kg) plots at CR of 14, 15, 16, 17, and 18.

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



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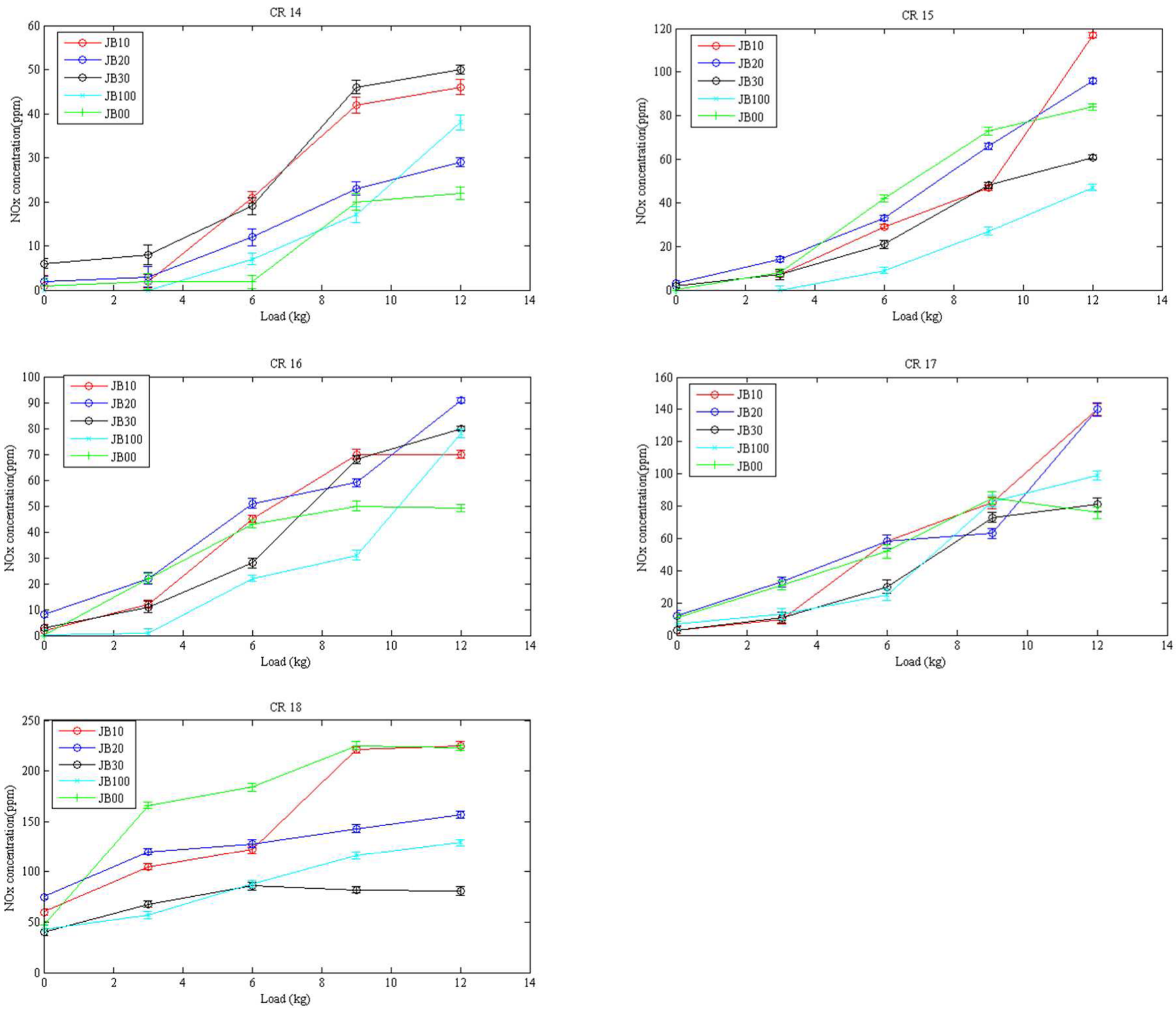


**Figure 2.** Concentration of $NO_x$ emission (ppm) versus load (kg) plots at CR of 14, 15, 16, 17, and 18.

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 work[36] 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 be 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


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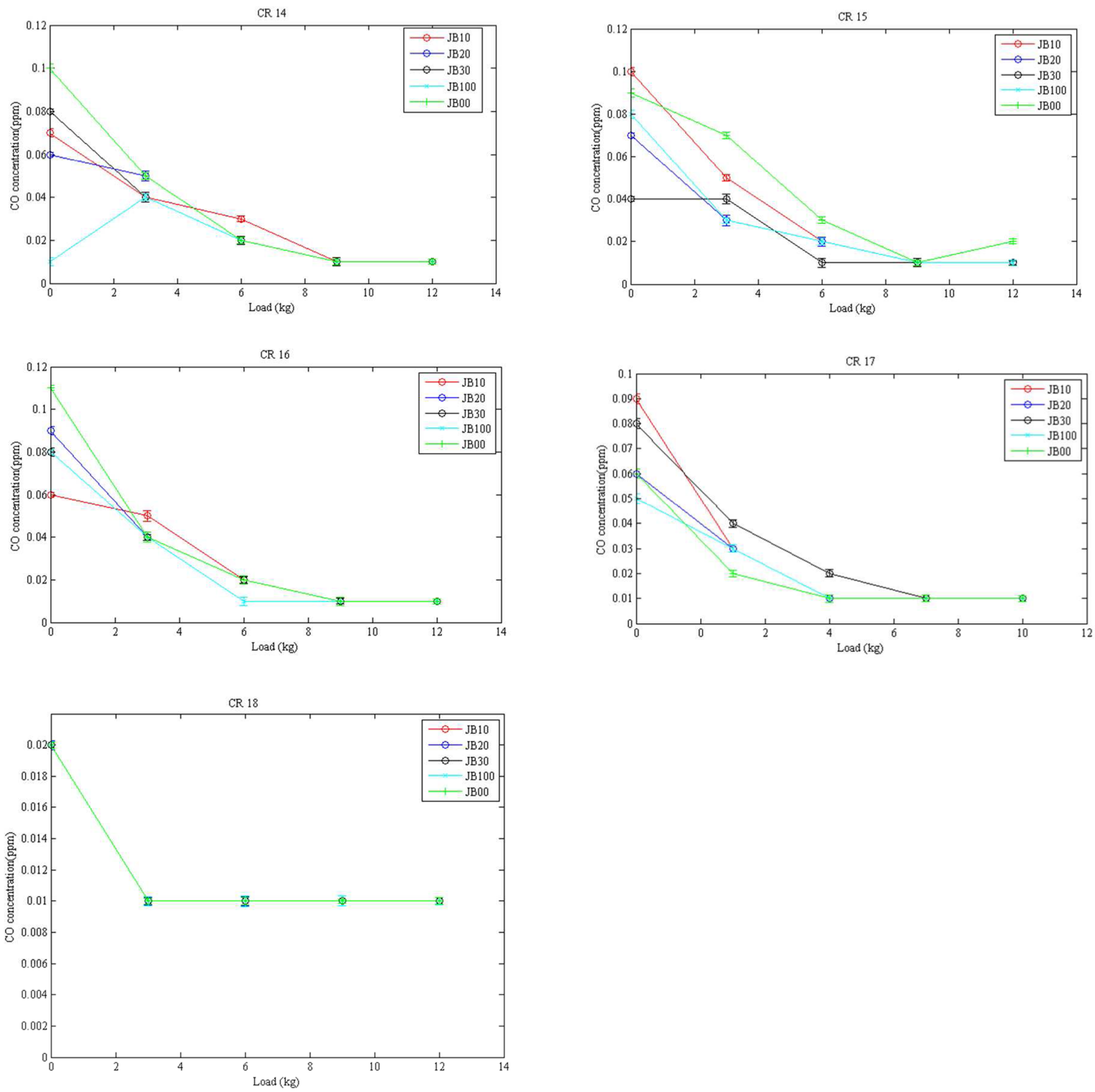


**Figure 3.** Concentration of CO emission (ppm) against load (kg) plots at CR of 14, 15, 16, 17, and 18.

(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


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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 $NO_x$.

## ■ AUTHOR INFORMATION


### Corresponding Author

*Telephone: +91-542-6702865. Fax: +91-542-6702876. E-mail: ysharma.apc@itbhu.ac.in.


### Notes

The authors declare no competing financial interest.

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