Taylor & Francis
Taylor & Francis Group

Australian Journal of Mechanical Engineering

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tmec20

Combined effect of DEE and Jatropha biodiesel–diesel fuel blends on the enhancement of VCR diesel engine parameters at varying loads and compression ratios

B. R. Varpe & Y. R. Kharde

To cite this article: B. R. Varpe & Y. R. Kharde (2022): Combined effect of DEE and Jatropha biodiesel–diesel fuel blends on the enhancement of VCR diesel engine parameters at varying loads and compression ratios, Australian Journal of Mechanical Engineering, DOI: 10.1080/14484846.2022.2038405

To link to this article: https://doi.org/10.1080/14484846.2022.2038405

Published online: 23 Feb 2022.

AUSTRALIAN JOURNAL OF MECHANICAL ENGINEERING
https://doi.org/10.1080/14484846.2022.2038405

Combined effect of DEE and Jatropha biodiesel–diesel fuel blends on the enhancement of VCR diesel engine parameters at varying loads and compression ratios

B. R. Varpe [a] and Y. R. Kharde [b]

[a]Department of Mechanical Engineering, Amrutvahini College of Engineering, Sangamner, Ahmednagar- 422 608, Savitribai Phule Pune University, Pune, India; [b]Department of Mechanical Engineering, Sir Visvesvaraya Institute of Technology, Nashik - 422 102, Savitribai Phule Pune University, Pune, India

ABSTRACT

In the field of biodiesel, the oxygenised alternatives, dimethyl ether (DME) and diethyl ether (DEE), are the promising alternative due to high Cetane number and oxygen content. In this research, experimental analysis is done for different fuel blends of Jatropha oil and DEE as additives. Biodiesel of 10, 15, and 20% with 10% DEE is used by mixing with diesel named as A1, A2 and A3. For 20% of DEE with same % of biodiesel, second batch of blends is prepared as B1, B2 and B3. These blends are prepared, and their physicochemical properties are tested. The compression ratio (CR) at 16, 17 and 18 is used as input for engine performance and emission analysis. Load on the engine is increased from 3 kg to 12 kg as full load for all blends and diesel. Results shows that engine gives better performance at higher load and higher CR. A3 blend shows the highest value of BTE than other fuel blends and diesel at all CR and loads. A3 blend shows the lowest value of BSFC compared to other fuel blends at CR 16 and CR 18. Performance of A3 and B2 fuel blends is better than all other fuel blends.

ARTICLE HISTORY
Received 16 July 2020
Accepted 2 February 2022

KEYWORDS
Jatropha biodiesel; Diethyl ether; VCR engine; diesel engine performance; diesel engine emissions

1. Introduction

The diesel engines have become the main source of transportation and the diesel fuel is used in wide ranging applications ranging from industries to automobiles (Demirbas 2009). The diesel fuel is well-known to deliver better performance and lower emissions in vehicles (Demirbas 2007). However, rapid and excessive usage of diesel and other fossil fuels has led to exhaustion of these valuable resources (Atabani et al., 2012). Also, the excessive use of fossil fuels has increased the greenhouse gas (GHG) emissions, which in return have increased the global temperature leading to depletion of ozone layer thus enabling UV rays to enter the earth. The drastic use of fossil fuels has also resulted in many health issues due to emission of many noxious emissions such as SOx, HC, CO, NOx, PM and smoke. Moreover, the excessive use has increased the price of crude oil in global market, and stringent governmental regulation and emissions norms have led to an increase in the demand of non-conventional sources of energy. Biodiesel is one such renowned renewable energy source, and it is produced from edible and non-edible oils (Basha, Gopal, and Jebaraj 2009). India has a vast forest area and the vegetations are covered with numerous oil-bearing edible and non-edible plants and trees. The well-known non-edible feedstocks in India are Honge, cottonseed, mahua, Jatropha, neem, castor, etc. (Atabani et al., 2012). The potential of Jatropha as a biodiesel feedstock is explored in the current research. Many preceding literatures have reported that Jatropha oil delivers comparable diesel properties; however, the density and viscosity of Jatropha are higher than diesel fuel; thus, sometimes it causes blocking of fuel filters, clogging of fuel lies and cold starting problems (Soudagar, Nik-Ghazali, and Abul Kalam et al. 2018). Hence, to reduce the viscosity of Jatropha in diesel fuel, the authors have successfully added diethyl ether (DEE). Thus, the viscosity and density of the base fuel is reduced, thus making the fuel cleaner resulting in rapid combustion.

A thorough literature has been reviewed in the subsequent paragraphs on the effect of biodiesel and alcohols on diesel engines. Venu et al. (2016) used ethanol-based biodiesel additive with titanium oxide, DEE, and zirconium oxide as extra ternary additives to analyse CI engine behaviour. Oxidation rate increased, light-off temperature dropped and base area was increased with the fuel causing emission enhancement with the addition of nanoparticles. Imdadul et al. (2016) added 5–15% of pentanol to Calophyllum inophyllum oil and engine properties were in detail analysed. BSFC reduced and BTE increased for the added alcohol than the B20 blend without additive. In his similar work (Imdadul et al. 2016), they used n-butanol and pentanol as alcohols to add them with petroleum-based biodiesel. HC and CO emission reduced but NOx and CO_2 increased.

CONTACT B. R. Varpe varpebhausahebr@gmail.com Department of Mechanical Engineering, Amrutvahini College of Engineering, Sangamner, Ahmednagar- 422 608, Savitribai Phule Pune University, Pune, India

Devarajan et al. (2017) used cyclo-octanol with palm oil with 20% and 30% as additive. The emissions were found to reduce due to better atomisation. Sathiyamoorthi and Sankaranarayanan (2017) used ethanol for lemongrass biodiesel at lower concentrations. Combustion pressure was higher and more heat release with BSFC and BTE adding to improved performance. Emission increased with the increase in ethanol % in the biodiesel. The ignition delay period was also found to increase with ethanol addition. Xingcai et al. (2004) reported an enhancement of diesel engine characteristics when ethanol is used as a fuel additive with diesel in a 1S DI CI engine. The results illustrated an enhancement in BSFC due to lean mixture, but the BTE enhanced by 1–2.3% with addition of 10 to 15%E vol. in diesel fuel. Also, E-D blended fuels results in lower CO, NOx and smoke emissions. The authors also reported that with the addition of ethanol in the diesel fuel increased the cetane value and encouraging results relate to NOx and CO, while the HC emissions slightly increased. Dogan et al. (2011) investigated the effect of five fuel blends, B5 with 95%D and 5% vol. of n-butanol, B10 with 95%D and 10% vol. of n-butanol, similarly, B15, B20 and D100 (neat diesel fuel) on CI engine characteristics. The results illustrated an increase in the engine characteristics, the BTE and reaction in the BSFC, while all the emissions, CO, HC, NOx and smoke reduced for the fuel blends with n-butanol additive. De Caro et al. (2001) studied the effect of organic additives on physicochemical properties of diesel and ethanol fuel blends. The authors added two percent of additives and varied the percentage of ethanol from 10 to 20% vol. The blends with and without the organic fuel additives were used in the CI engine with direct and indirect injection. The authors reported an increase in the performance and reduction in emissions with the addition of fuel additives. Ajav et al. (1999) investigated the effect of ethanol-diesel fuel blend in diesel engine. The authors used 5, 10, 15 and 20% of E-D fuel blends. The authors reported no loss in power, 5% of E in diesel fuel increased the power output, while 20%E reduced the power due to reduction in Cv of the fuel. For 20%E in diesel, fuel increased the BSFC by 9% compared to neat diesel. The EGT, temperature of lubricating oil and CO and NOx reduced for diesel-ethanol fuel blends as compared to neat diesel. Li et al. (Li et al. 2005) investigated the effect of different percentage levels of ethanol additive in diesel fuel on the performance and emissions characteristics of diesel engine, the blends used in their investigation are E5-D (5% ethanol), E10-D, E15-D E20-D and D100, respectively. The authors reported in an enhancement in the BTE and reduction in BTE, and smoke decreased for E10–D and E15–D fuel blend, also the NOx and CO reduced for higher percentage of ethanol in diesel. While, the HC emissions increased with an increase in the percentage of ethanol in diesel. Rakopoulos et al. (2012) reported that the addition of DEE (8, 16 and 24% vol.) to diesel fuel increases the performance characteristics and reduces the noxious emissions of a high-speed DI CI engine operating at a speed of 2000 rpm at three loads. The authors reported the engine operation was smooth up till 24% vol. of DEE in diesel fuel. Iranmanesh et al. (2008) investigated the effect of DEE and biodiesel-diesel blend on Kirloskar TAF1, 4-S, AC, 1-cylinder diesel engine. The diesel–biodiesel was blended with 5%, 10%, 15% and 20% vol. of DEE. For the fuel blends with DEE, (5–15%) was found desirable, improved the performance and decreased the emissions were observed. While, for the DEE, percentage above 15% lead to instability in engine speed and fluctuations in the engine power output affecting the fuel pump rack. This was due to an inconsistent combustion process owing to the high volatility of DEE. Mohanan et al. (2003) investigated the effect of DEE (5%, 10%, 15%, 20% and 25% (by vol.)) and diesel fuel blend on Kirloskar (AV1), 4-S, 1-cylinder diesel engine. The lowest fuel blend (5%) showed an overall improvement in the engine performance and emitted lower levels of smoke and CO due to an increase in the BTE. On the contrary, the higher fuel blends (20% and 25%) reduced the BTE and thick smoke was observed due to cavitation's in the nozzle of the fuel injector credited to phase separation of the fuel blends leading to large droplet size thus improper fuel injection.

To overcome difficulties of biodiesel blends, Cetane number enhancers and co-solvent additives have wide scope as a diesel fuel blend for diesel engines (Lapuerta, Armas, and García-Contreras 2007). An additive is used to keep the blends homogeneous and stable and used as an ignition improver. Additives are used to compensate for a cetane number, improve the viscosity and stabilise the fuel blend mixture (De Caro P, Mouloungui, and Vaitilingom et al. 2001). The lower percentages of biodiesel blends increase the BTE, reduced emission and BSFC (Jindal et al. 2010).

DEE can be used as a good alternative to diesel fuel because it has good thermal efficiency and lowers exhaust emissions. DEE has no stability problems in diesel, having a higher Cetane number and good solubility in the diesel fuel (Rakopoulos et al. 2012). Varpe et al. performed experimentation on DEE/Jatropha blended Variable Compression Ratio (VCR) diesel engine with varying loads. They obtained at full load and at higher CR the engine parameter BTE increases and the BSFC decreases for DEE-Jatropha biodiesel–diesel fuel blends. The fuel blend with 10% DEE + 20% JME + 70% diesel is the best fuel to improve the engine performance parameters and reduce emission characteristics compared with other blends and diesel fuel (Varpe et al. 2020). Single-cylinder, four-stroke VCR engine with waste cooking oil methyl ester and its 20%, 40%, 60% and 80% blends with diesel shows reduction of CO, HC and an increase in NOx emissions (Muralidharan and Vasudevan 2011).

The premixed HCCI-DI engine using different DEE percentages varying from 0% to 40% indicates audible knocking at 40% DEE premixed fuel ratio. NOx and soot emissions decreased up to 19.4% and 76.1%, respectively, and CO and HC emissions increased (Cinar et al. 2010). The diesel fuel blends with 8%, 16%, and 24% DEE, in single-cylinder diesel engine revealed that bio-DEE is a very promising fuel for diesel engines (Rakopoulos et al. 2012). Jindal et al. found that the combined increase of C.R. & IP increases the BTE and reduces BSFC while having lower emissions and for small-sized DI constant speed engines used for agricultural applications (3.5 kW), the optimum combination was found as CR of 18 with IP of 250 bar (Jindal et al. 2010). The NO_x and CO emissions increase with B100 compared to D100 at all loads. Also increase in NO_x emission with B80E20 fuel compared with all fuels blends but biodiesel 76%-ethanol 19%-DEE 5% bled shows reduction of NO_x and CO emissions and increase in THC emissions (Carvalho et al. 2020). SFC increases with improvement in BTE for 10% and 20% DEE in Jatropha biodiesel. Addition of DEE is an effective technique improve the results of Jatropha biodiesels (Raja et al. 2019). Diesel engine with 5% DEE and biodiesel mixture increase diesel engine performance considerably for all engine loads compared with all fuels (Ibrahim 2018). DEE fuel blends with 5% DEE and 20% ethanol show lower NOx and PM emissions compared with D100 and B20 fuels for medium and high loads also improvement in BTE at the high load (de Carvalho Mas et al. 2020). Smigins and Zakis (2020) found that engine power reduced by 6.2%–17.3% for all DEE blends gives better results for low level blends compared with pure rapeseed oil. Different DEE blends showing large decrease of NOx emissions 20% DEE and 30% DEE fuel blend shows better performance comparison to with pure rapeseed oil.

Hence, the preceding literature suggests the use of alcoholic fuel additives in biodiesel and diesel fuel increases the cetane number, reduces the viscosity, enhances lubrication, stabilise the mixture and ensures fuel homogeneity. Limited studies are available on the effect of DEE and biodiesel on the diesel engine performance and emission characteristics by varying the CR of diesel engine at four different loads. Hence, the authors have attempted to investigate the effect of DEE-Jatropha-diesel fuel blends by varying the compression ratios (16, 17, 18) at different loading conditions (25%, 50%, 75% and 100%) on 4-S, 1-cylinder VCR engine's performance and emission characteristics. Six different fuel mixtures were studied, DEE-10% + Jatropha-10% + Diesel-80% (A1), DEE-10% + Jatropha-15% + Diesel-75% (A2), DEE-10% + Jatropha-20% + Diesel-70% (A3), and DEE-20% + Jatropha-10% + Diesel-70% (B1), DEE-20% + Jatropha-15% + Diesel-65% (B2) and DEE-20% + Jatropha-20% + Diesel-60% (B3).

2. Material and methods

2.1. Jatropha biodiesel preparation

Jatropha curcas belongs to a family of plant species known as Euphorbiaceae. It is resistant to strong winds and droughts. It is cultivated in Africa (Ghana, Tanzania, Mozambique, etc.), South east Asia (Malaysia, Indonesia, Myanmar, Vietnam, Brunei, East of India, etc.) and central and south America (Mexico, Chile, Costa Rica, Brazil, Argentina, etc.) (Achten et al. 2007). Figure 1 illustrates the pictorial view of Jatropha plant with fruits and dried Jatropha seeds.

It can be grown in sandy, saline or gravelly soils and any landscape is suitable for its growth. The oil content of *J. curcas* seeds is around 37% and the tree can grow seeds for a duration of 50 years. The oil has many beneficial properties for its applications as biodiesel such as low acidity and viscosity, good stability in base oils and superior cold properties compared to other biodiesel feedstocks. Also, *J. curcas* has high cetane number compared to diesel fuel, which makes it the best option fuel with

Figure 1. (a) Jatropha plant with fruits and (b) dried Jatropha seeds (Persistent start-up uses jatropha seeds to make profitable fuel 2013).

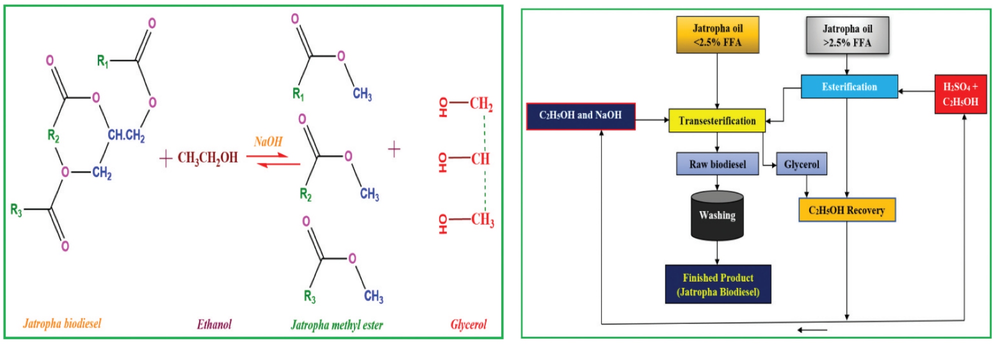

Figure 2. The equation for transesterification reaction of Jatropha oil.

minor engine modifications (Moniruzzaman, Yaakob, and Shahinuzzaman 2017; Silitonga et al. 2011; Mofijur et al. 2013).

The vegetable oil comprised triglycerides; in the transesterification method, ethanol is deprotonated with a Jatropha oil to produce a stronger nucleophile (Parawira 2010; Chauhan, Kumar, and Cho 2012; Imtenan et al. 2014; Soudagar et al. 2019, 2020). In the present investigation, sodium hydroxide and sulphuric acids are used as catalysts. The oil yields 98% of biodiesel, provided the oil contains low moisture and FFA. The process of transesterification reaction is illustrated in detail in Figure 2.

The DEE is completely miscible in diesel and biodiesel fuel blend. The initial valuation tests reveal that the solubility of DEE in the fuel blends with blending ratio of 10% was conducted and found to be miscible and no phase separation as observed for a period of 20 weeks, hence no emulsifying agents were added to the fuel blends. The results obtained in the current investigation are in good agreement with similar research on DEE and biodiesel.

The preparation of DEE is derived from the articles by Patil and Thipse (2015) and Nigam et al. (2011). The DEE is manufactured in lab through distillation of ethanol mixing with sulphuric acid. Initially, ethyl alcohol (CH_3CH_2OH) is mixed with concentrated H_2SO_4. The sulphuric acid dissociates into hydronium ions, H_3O^+. The H ion traverses the electronegative O atom of the ethanol, producing a positive charge illustrated in Eq. (1).

$$CH_3CH_2OH + H_3O^+ \rightarrow CH_3CH_2OH_2^+ + H_2O \quad (1)$$

Later, a nucleophilic O atom of unprotonated ethanol molecule dislocates a water molecule from the transverse (electrophilic) ethyl alcohol producing DEE, H ion and water shown in Eq. (2). Figure 3 shows the structure of a DEE molecule.

$$\begin{aligned} &CH_3CH_2OH_2^+ + CH_3CH_2OH \\ &\quad \rightarrow H_2O + H^+ + CH_3CH_2OCH_3CH_2 \end{aligned} \quad (2)$$

2.2. Uncertainty analysis

The errors of an engine are calculated using uncertainty analysis, while estimating the errors, it is assumed that the information gathered under ideal conditions and complete understanding and information of all the equipment's and system used are available (Soudagar et al. 2019, 2020). Table 2 illustrates the uncertainty percentage of measured parameters. The numerous unknown uncertainties are determined by mathematical equation, which is shown in Eq. (3).

$$\frac{U_y}{y} = \sqrt{\left[\sum_{i=1}^{n}\left(\frac{1}{y}\frac{\partial y}{\partial x_i}U_{xi}\right)^2\right]} \quad (3)$$

In the equation, 'y' is a parameter, which is dependent on the factors 'xi' and 'Uy' signifies the deviation/uncertainties in parameter 'y'. At various engine operations, the observations and readings are noted, and the uncertainty is ascertained by repeated experimentations. The uncertainty percentage of the parameters involved in the investigations is estimated as follows:

Overall uncertainty =

$$\pm\sqrt{(BTE^2 + BSFC^2 + HC^2 + CO^2 + NOx^2 + Smoke^2)}$$

$$\pm\sqrt{((0.38)^2 + (0.40)^2 + (0.25)^2 + (0.62)^2 + (0.28)^2 + (0.66)^2)}$$

$$\pm 1.124856$$

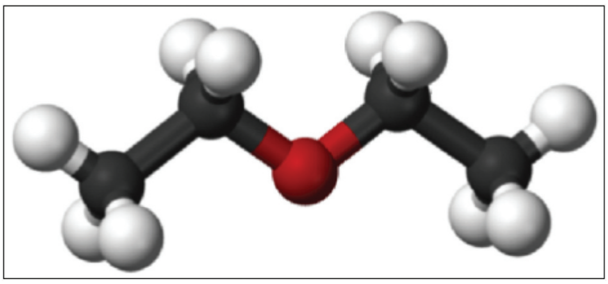

Figure 3. Structure of DEE molecule (adopted from (Patil and Thipse 2015) with permission).

Table 1. The agronomic traits and limitations of Jatropha plantations (Moniruzzaman, Yaakob, and Shahinuzzaman 2017; Becker and Makkar 2008; Jones and Miller 1992).

Good agronomic traits
(1) Needs less nutrients (nitrogen).
(2) Robust tree which can spread in semi-arid and dry regions and poor soil conditions.
(3) Involves minimal workforce and laborious efforts.
(4) Intercropping can be performed with many precious crops such as sugar cane, fruits and vegetables to protect the crops from insects, pathogens and cattle grazing.
(5) It is used as an insecticide, nematicide and fungicide in tribal medicines.
(6) It relatively grows rapidly compared with other biodiesel feedstocks.
(7) The yield of seeds per hectare is four tones without much maintenance and very little water.
(8) The Jatropha oil is non-edible; hence, the food vs fuel debate does not arise as in the case of edible feedstocks.

The drawbacks of Jatropha
(1) The kernels and leaves are poisonous to animals and humans.
(2) The phorbol esters, trypsin inhibitors and others chemical present in Jatropha make the entire detoxification a complex process.
(3) The agricultural land used leads to competition with edible feedstocks.

Table 2. Uncertainty percentage of measured parameters.

Measurement	Range	Accuracy	Uncertainty
CO	0–12% vol	±0.03%	0.62
HC	0–15,000 ppm	±10 ppm	0.25
NOx	0–3000 ppm	±50 ppm	0.28
Smoke	0–99.9	±1%	0.66
BTE	-	-	0.38
BSFC	-	-	0.40

Table 3. Composition of fuel blends.

No.	Blend composition	Abbreviation
1.	DEE-10% +Jatropha-10% +Diesel –80%	A1
2.	DEE-10% +Jatropha-15% +Diesel –75%	A2
3.	DEE-10% +Jatropha-20% +Diesel –70%	A3
4.	DEE-20% +Jatropha-10% +Diesel –70%	B1
5.	DEE-20% +Jatropha-15% +Diesel –65%	B2
6.	DEE-20% +Jatropha-20% +Diesel –60%	B3
7.	100% Diesel (Reference)	D100

Different blends of DEE + biodiesel (BD) + diesel (D) were prepared for the conduction of the trial on 4-Stroke, single cylinder, VCR diesel engine. Table 3 illustrates the composition of fuel blends.

The properties of diesel, A1, A2, A3 and B1, B2, B3 were determined according to ASTM D6751-15 and EN standards. All the properties were measured in Indian Biodiesel Corporation (IDC), Baramati, India. Table 4 illustrates the properties of neat diesel, Ethanol, Jatropha biodiesel, DEE, A1, A2 and A3 blends and B1, B2 and B3. Figure 4 illustrates the fuel blends used in the current investigation.

2.3. Experimental setup

The engine used in the current investigation is a VCR, Kirloskar make, 1-cylinder, WC, diesel engine, as illustrated in Table 1. The engine is coupled to a five-gas analyser and smoke metre and the readings were derived from Enginesoft software. The combustion chamber used in the current investigation is hemispherical and CR is varied without stopping the VCR engine. DAQ and LabVIEW softwares are used as an interface between the computer and the engine sensors (air and fuel flow, temperatures and load measurement sensors). Table 5 illustrates the specification of VCR test engine used in the current investigation. The engine parameters employed in current investigation are illustrated in the Table 6. Figure 5 illustrates the schematic diagram of the test engine used in the current investigation.

3. Results and discussion

The experimentation process was performed on DEE/biodiesel blend (A1, A2, A3, B1, B2 and B3) in diesel fuel at three CRs (16, 17 and 18) and four loads (3 kg, 6 kg, 9 kg and 12 kg). Performance and emission parameters are measured by using gas analyser and eddy current dynamometer. Table 6 illustrate the parameters employed in the current investigation and Table 7 illustrates experimentation chart for conducting tests.

3.1. Effect of load and blends on engine performance at three CRs

The BTE and BSFC for diesel and blends A1, A2, A3, B1, B2 and B3 are shown in Figures 6–11 for CR 16–18, respectively. From Figure 6, it is clear that BTE

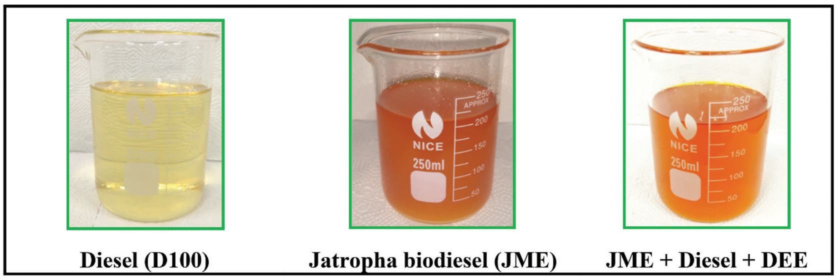

Figure 4. The fuel blends used in the current investigation. Diesel (D100) Jatropha biodiesel (JME) JME + diesel + DEE.

Table 4. Physiochemical properties of fuel blends.

Properties	Standard	Diesel	Ethanol	Biodiesel	DEE	A1	A2	A3	B1	B2	B3
Density (kg/m^3 at 20°C)	ASTM D4052	840	789	880	710	865	869	874	860	866	870
Calorific value (MJ/kg)	ASTM D5865	42.5	27	39.9	34	37.5	34	31.5	36.5	33.5	33.5
Liquid viscosity (CP at 20°C)	ASTM D445	3.03	1.2	3-4	0.23	3.1	3.3	3.7	2.9	3.1	3.2
Cetane number	ASTM D613	45–50	5–8	40–50	125	44	49	55	47	56	59
Flash point (°C)	ASTM D93	235	423	-	160	244	249	259	242	245	248
Oxygen content (wt%)	EN 14112	0	34.3	10	21.6	-	-	-	-	-	-

Table 5. Test engine specifications.

Number of strokes	Four
Fuel type	Diesel
Cylinder	Single
Rated power	3.5 kW
Speed	1500 rpm
Cylinder diameter	87.5 mm
Stroke	110 mm
Connecting rod length	234 mm
Compression ratio	12 to 18:1
Load indicator	Digital, range 0–50 Kg, supply 230VAC
Fuel tank	Capacity 15 L with glass fuel metering column
EGR	Water cooled, SS, range 0–15%
Piezo sensor	Range 5000 PSI, with low noise cable
Temperature sensor	Type RTD, PT100 and thermocouple, Type K
Load indicator	Digital, range 0–50 kg, supply 230VAC
Load sensor	Load cell, type strain gauge, range 0–50 kg
Data acquisition device	NI USB-6210, 16-bit, 250kS/s
Rotameter	Engine cooling 40–400 LPH; calorimeter 25–250 LPH
Dynamometer	
Model	AG10
Make	Saj test plant rig
End flanges both sides	Cardon shaft model 1260 type
Air gap	0.77 mm
Torque	11.5 Nm
Hot coil voltage	60 V
Continuous current (amp)	5
Cold resistance ohm	9.8

Table 6. The parameters employed in the current investigation.

Factors considered	Parameters employed
Engine	VCR
Combustion chamber (CC)	Hemispherical (HCC)
Injection pressure (IP)	220 bar
Fuel injector (FI) holes	3 holes, 0.3 mm dia.
Speed	1500 rpm (constant)
CR	16,17,18
Fuel	Diesel, A1, A2, A3, B1, B2, B

increases with the increase in load for all the blends with load due to the increase in combustion temperature. Also, with the increase in biodiesel and DEE percentages in diesel, BTE increases due to oxygen percentage. The oxygen content increases with the addition of biodiesel and DEE in diesel. BTE is highest for blend A3 at maximum load than pure diesel, which is 41.2%. In Figure 7, the respective BSFC is depicted for increasing load and blends. BSFC decreases with the increase in load due to more utilisation of fuel during combustion at higher load and CR. For CR 16, diesel fuel and B1 blend showed the lowest value of BSFC compared to other blends, which is about 0.28 kg/kWh at full load condition.

In Figure 8, the BTE and respective BSFC in Figure 9 at CR 17 is provided at all blends compared to diesel with increasing load. From Figure 8 it is seen that with the increase in load BTE also increases. Also, with the increase in biodiesel, percentages in diesel BTE increase. Here too, the same fact of increase in oxygen content and rise in combustion chamber temperature with increasing load is the main driving force for BTE improvement for blends. Maximum BTE is observed at maximum load for A3 and B2 blends. The range of BTE for A3 blend is 20.37% to 39.37%, which is higher than diesel fuel. Figure 9 shows BSFC for B1 and B2 is almost same as that of diesel fuel and at all the loads. B3 shows higher value of BSFC compared to other fuels at CR 17. BSFC decreases with the increase in load. Lowest value of BSFC is observed for B1, B2 and diesel, which is 0.28 kg/kWh.

The BTE and BSFC at CR 18 are shown in Figures 10 and Figure 11, respectively, with increasing load. The increase in BTE and reduction in BSFC with load are clearly seen. Figure 10 shows that BTE increases with the increase in load. With the increase in Jatropha percentage, BTE also increases as oxygen percentage increases in fuel blend. As compared with diesel, all the blends show higher values of BTE at all the loads. A3 blend shows highest values of BTE for the entire load. Highest value of BTE is for A3 at maximum load, which is about 42.54%. In Figure 11, it is shown that BSFC is almost same for all the fuel blends at each load. For diesel fuel, the value of BSFC is lowest at maximum load of 12 kg. Fuel blends A3 and B3 show lower values of BSFC (0.27 and 0.28 kg/kWh) compared with other fuel blends, which is close to the value of pure diesel (0.25 kg/kWh).

From the comparison of Figures 6–11 having CR 16, 17 and 18, the effect of load on BTE for DEE/Jatropha and biodiesel blend can be made. From comparison, it can be said that CR has very little effect on the BTE of the engine almost at all loading range on the engine. Maximum BTE is observed at full load condition with CR value of 18 which is 42.57%. The effect of load and CR on BSFC can also be made. At lower and at higher loads, BSFC is affected by CR. BSFC values are lower at CR of 18 compared to CR 17 and 18. Minimum value is 0.27kg/kWh for A3 blend.

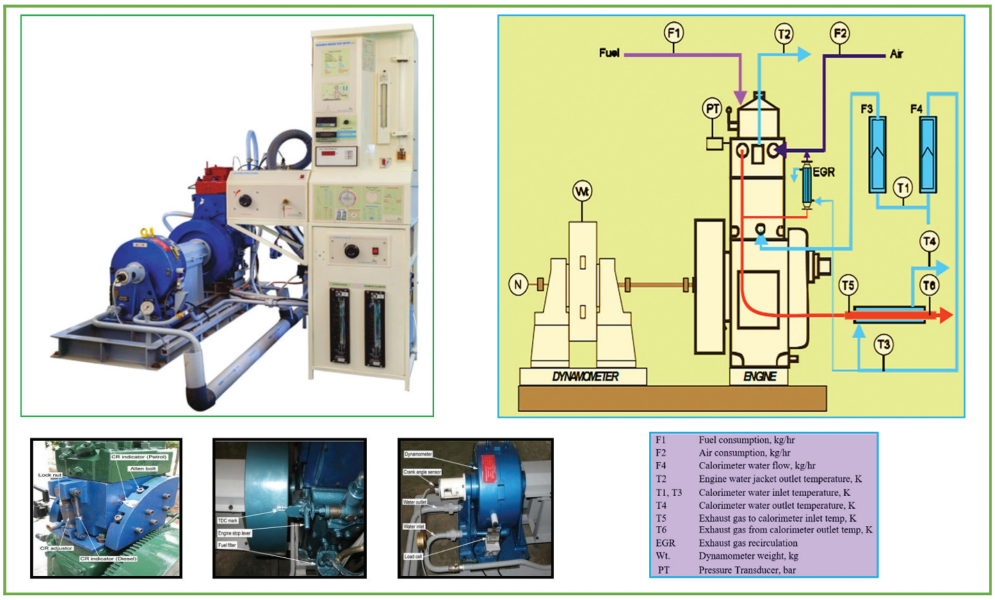

Figure 5. Pictorial representation of the Kirloskar-make VCR diesel engine.

Table 7. Experimentation chart for conducting tests.

CR	Inputs (Blend A)		Inputs (Blend B)		Load (%)	Load (kg)	Equivalent BP (kW)	Output
16	DEE (10%)	Biodiesel-10% (A1)	DEE (20%)	Biodiesel-10% (B1)	25%	3	0.9	BTE, BSFC
17	Diesel	Biodiesel-15% (A2)	Diesel	Biodiesel-15% (B2)	50%	6	1.7	CO, HC, Smoke, NOx
18		Biodiesel-20% (A3)		Biodiesel-20% (B3)	75%	9	2.5	
					100%	12	3.4	

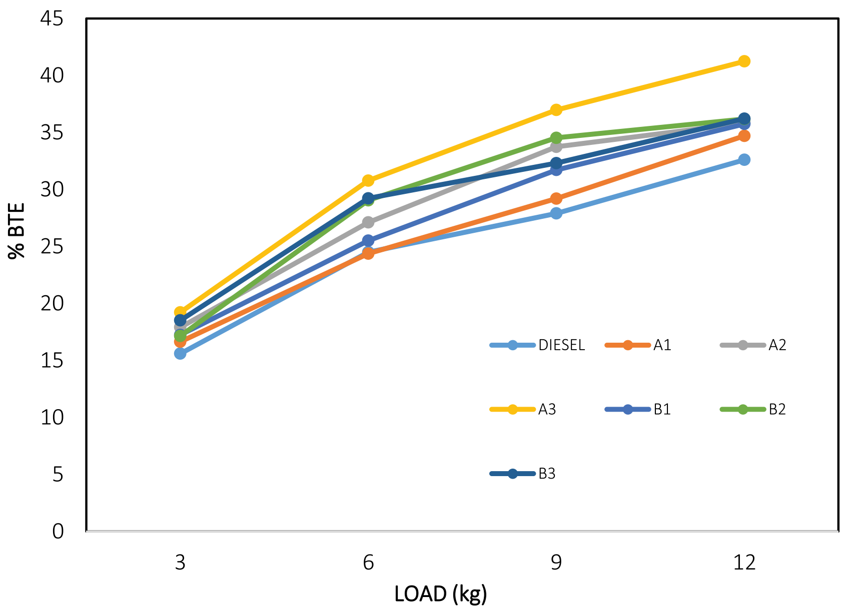

Figure 6. BTE vs Load at CR 16.

3.2. Effect of load and blends on emission characters at three CRs

Figures 12–14 show the effect of load on CO emissions for DEE/biodiesel blends A1, A2, A3, B1, B2 and B3 relative to diesel for CR 16–18, respectively. From figures, it is seen that CO emissions decrease with the increase in load for all fuels. At CR 16 for higher loads, B1 and B2 show lowest CO emissions than all other fuel blends and diesel fuel.The main reasons of the lower CO in B1, B3 and B2 are the availability of more oxygen in the blend due to the presence of DEE

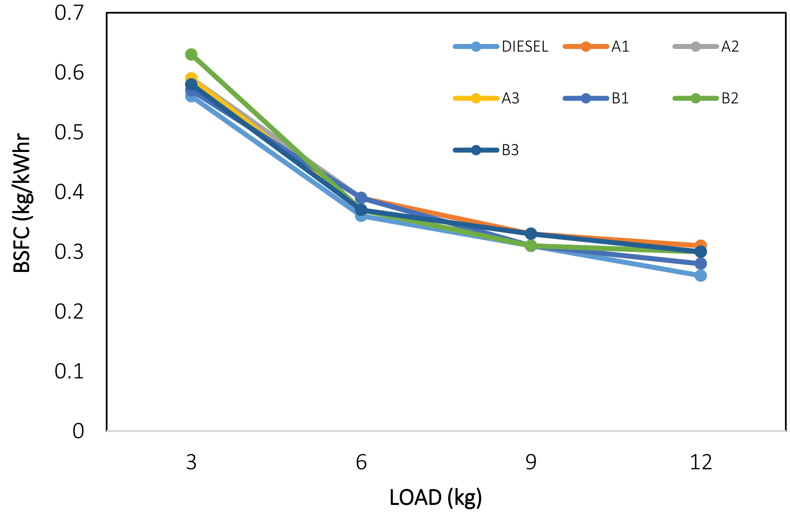

Figure 7. BSFC vs Load at CR 16.

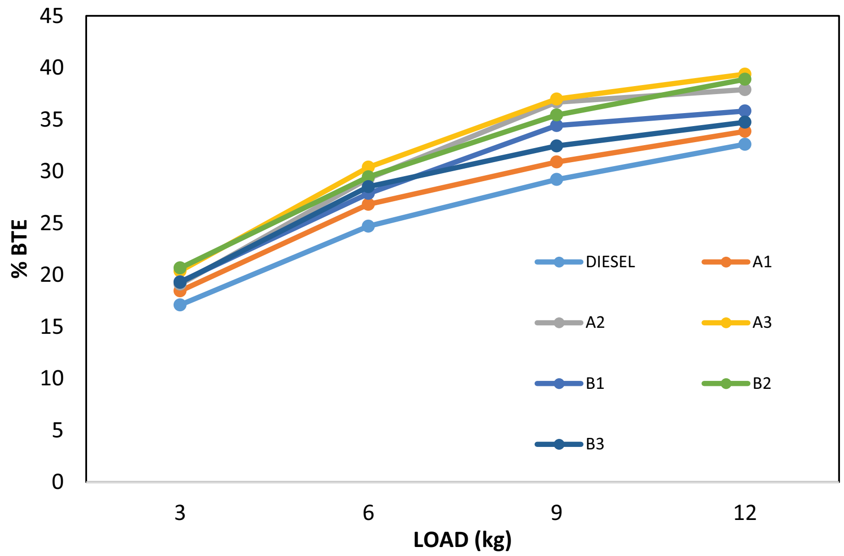

Figure 8. BTE vs Load at CR 17.

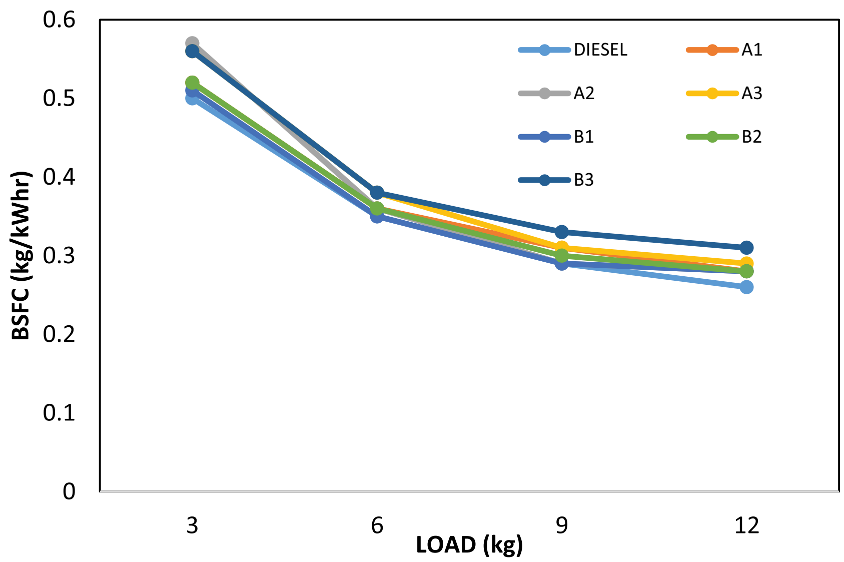

Figure 9. BSFC vs load at CR 17.

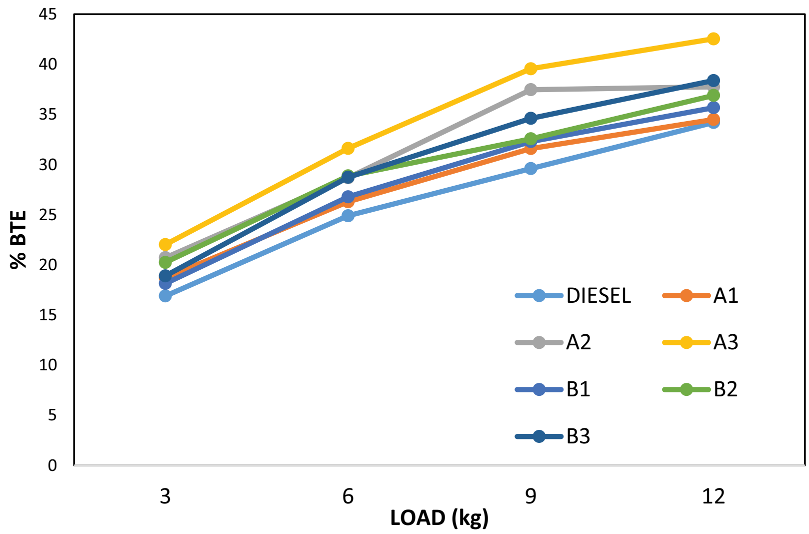

Figure 10. BTE vs load at CR 18.

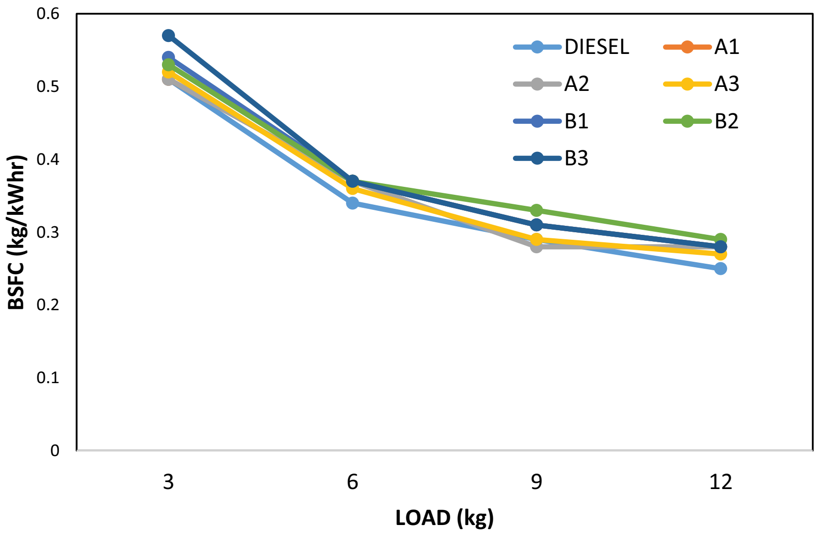

Figure 11. BSFC vs load at CR 18.

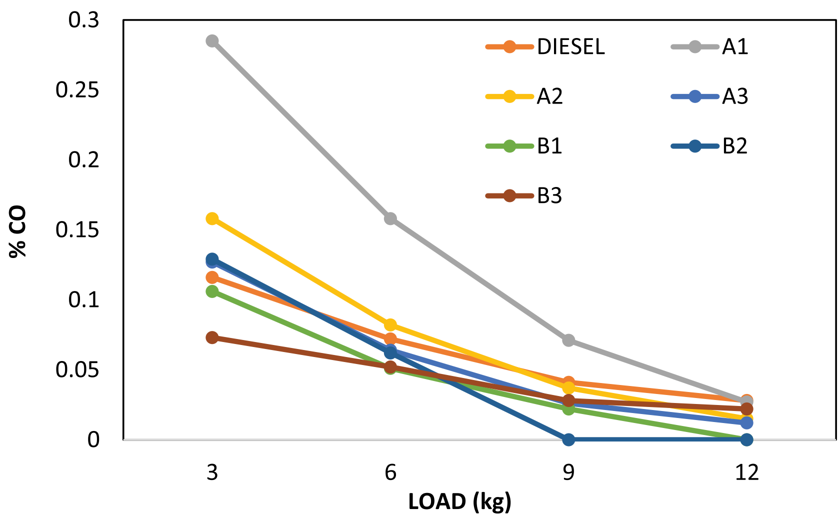

Figure 12. CO vs load for CR 16.

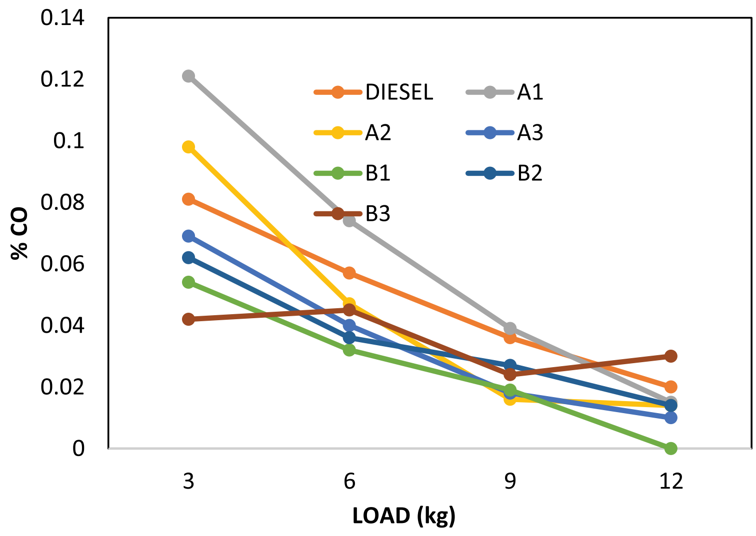

Figure 13. CO vs load for CR 17.

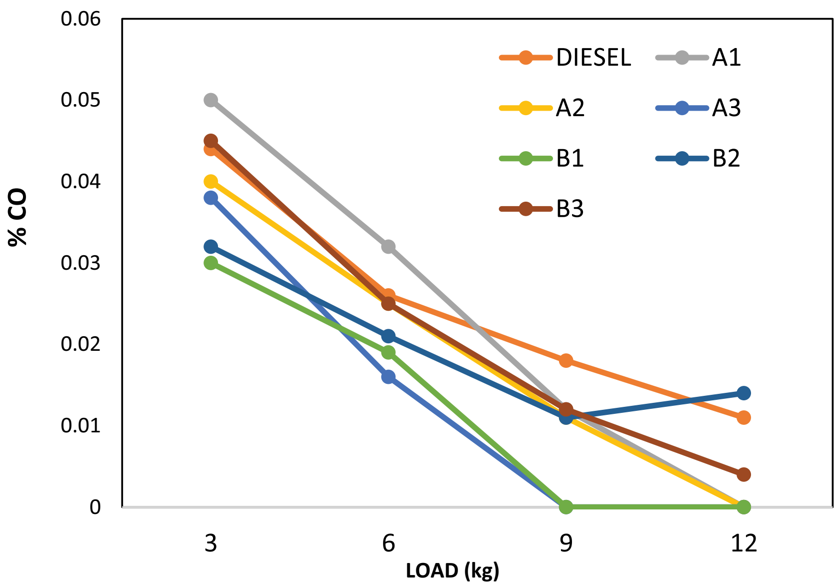

Figure 14. CO vs load for CR 18.

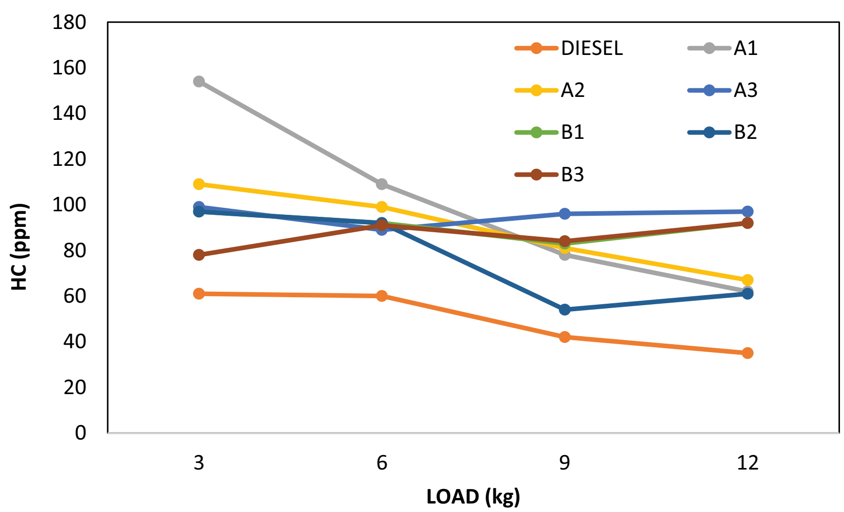

Figure 15. HC vs load for CR 16.

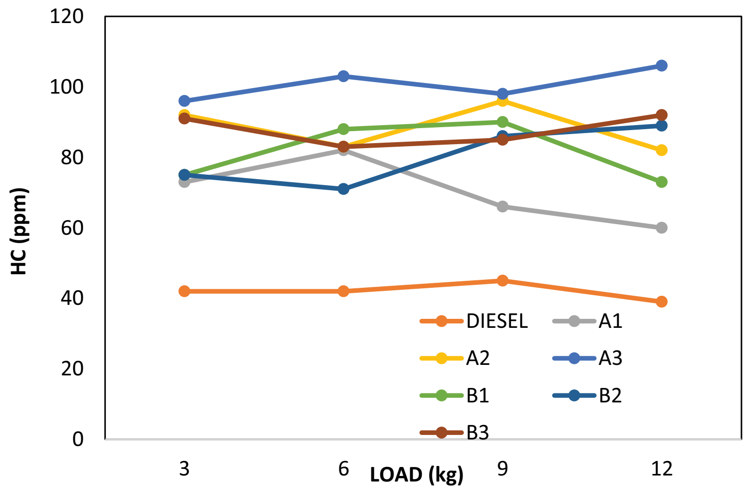

Figure 16. HC vs load for CR 17.

and biodiesel. Also, DEE having higher volatility and Cetane number is responsible for improving combustion efficiency. Fuel blends B1 and B2 show 0% CO at higher load, which are the best performance at CR 16. At CR 17, fuel blend B1 shows lowest value of CO emissions than all other blends including diesel fuel. The range of CO emissions for blend B1 is 0% at full load (12 kg) to 0.055% at low load (3 kg). Fuel blends B2 and B3 have CO emission range of 0.03% at full load to 0.06% at low load. At CR 18, fuel blends A3 and B1 show lowest value of CO emissions than all other blends including diesel fuel. The range of CO emissions for blends A3 and B1 is 0% at full loads (9 kg and 12 kg) to 0.035% at low load (3 kg), which is less

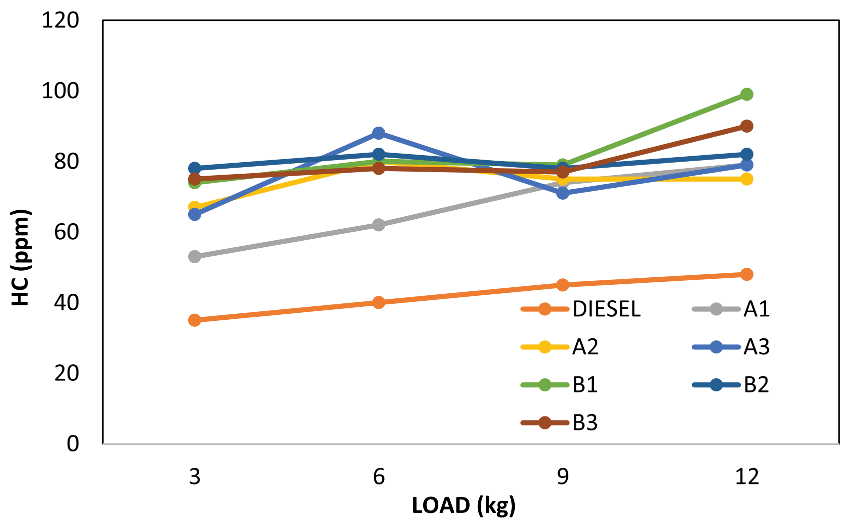

Figure 17. HC vs load for CR 18.

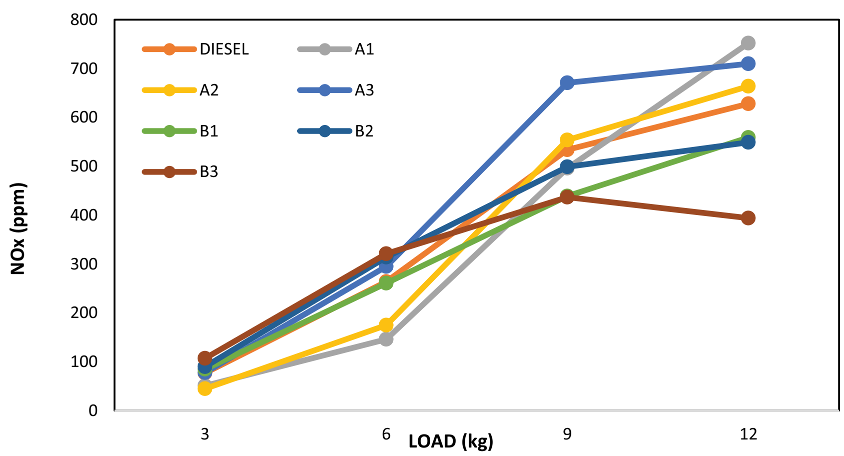

Figure 18. NOx vs load for CR 16.

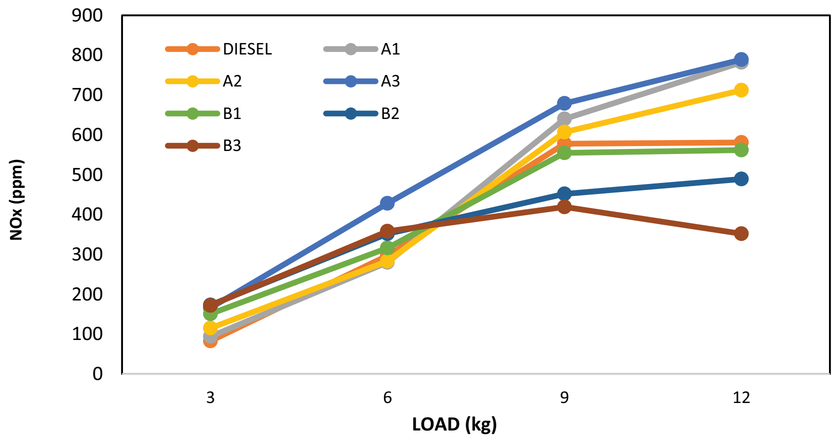

Figure 19. NOx vslLoad for CR 17.

than other fuel blends and diesel fuel. This may be due to higher oxygen contents in B1 and A3 fuels. B1 and A3 contents 30% DEE and biodiesel, which give best performance in CO emissions. As blending percentage increases, ignition delay is prolonged. Due to higher latent heat of evaporation of DEE (460 kJ/kg), slow vaporisations occur; hence, incomplete combustion takes place in cylinder, which leads to more CO emissions.

Figures 15–17 show the effect of load on HC emissions for DEE/biodiesel blends at CR 16–18 respectively. From figures, it is seen that CO emissions decrease with the increase in load for all fuels. For CR 16, diesel fuel shows lowest HC emissions than all DEE/biodiesel blends. DEE having the higher latent heat of evaporation causes lower combustion temperature, especially the temperature near the cylinder walls during the mixture formation. In this case more HC is produced from the cylinder boundary. Second, due to DEE/biodiesel blending, calorific value of blend decreases which is also responsible for the increase in HC emissions. Range of HC emissions for B1 and B3 blends is 79 ppm at low load to 95 ppm at full load, which is higher than diesel fuel. For diesel, HC range is 38 ppm to 60 ppm. Blend B2 has lower HC emissions than other fuel blends. For B2, the range of HC emission is 60 ppm to 98 ppm. At CR 17, the range of HC emissions for diesel fuel blends is 40 ppm to 45 ppm, which is much lower than fuel blends. Fuel blend A1 shows lower HC emissions than all other blends, which contains 10% DEE and 10% BD. For A1 fuel blend, the range of HC emission is 60 ppm to 80 ppm. As biodiesel percentage increases, viscosity of fuel blend increases, which tends to have incomplete combustion causing higher HC emissions. Therefore, A1 blend is best blend for CR 17. At CR 18, range of HC emissions for diesel fuel blends is 37 ppm to 48 ppm, which is much lower than fuel blends. Fuel blend A1 shows lower HC emissions than all other blends, which contains 10% DEE and 10% BD. For A1 fuel blend, the range of HC emission is 55 ppm to 77 ppm. Therefore, fuel blend A1 gives best performance for HC emissions at CR 18.

Figures 18–20 illustrate the effect of load on NOx emissions on diesel and biodiesel blends at C 16, 17 and 18, respectively. NOx emissions mainly depend

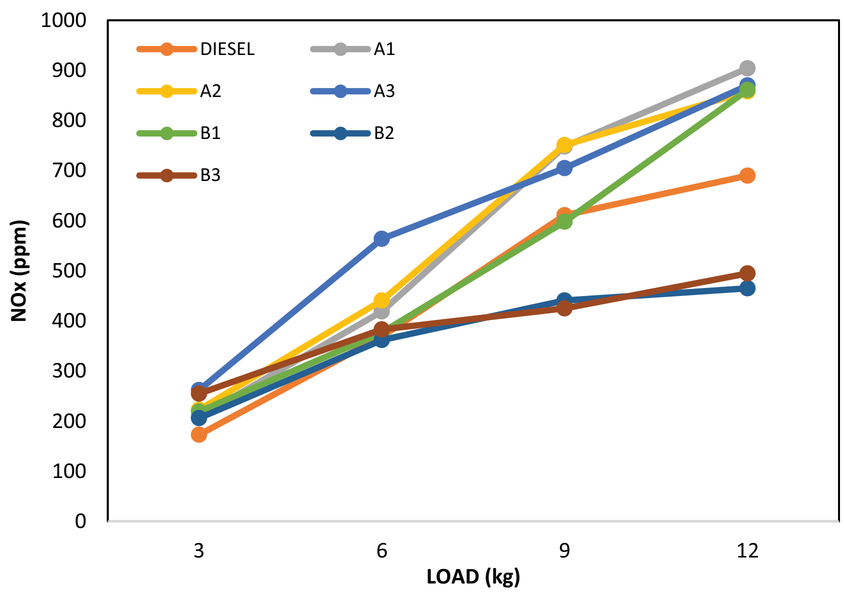

Figure 20. NOx vs load for CR 18.

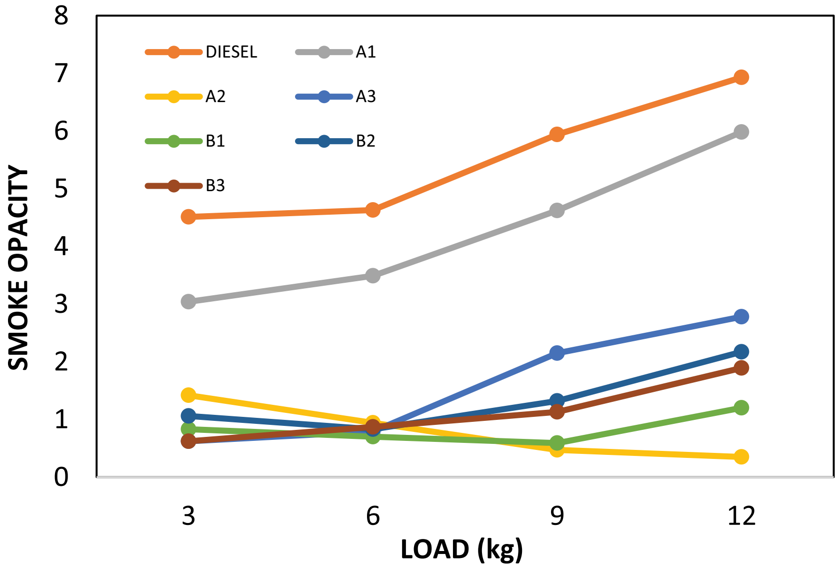

Figure 21. Smoke opacity vs load for CR 16.

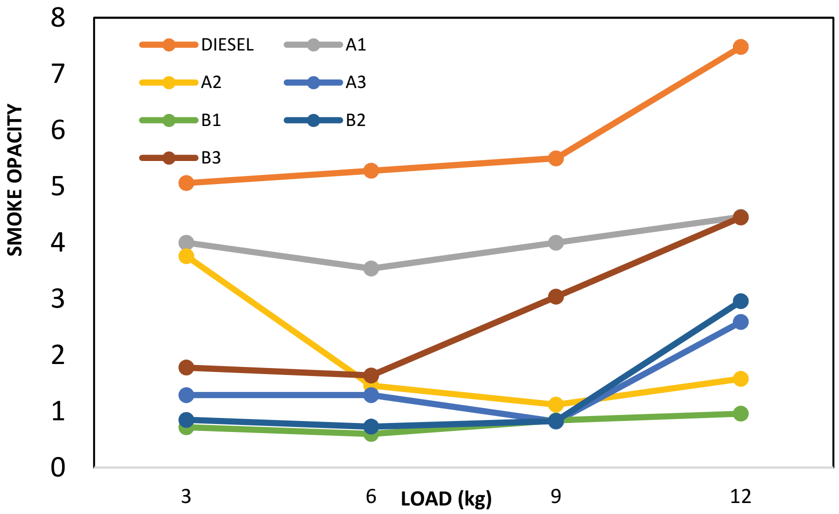

Figure 22. Smoke opacity vs load for CR 17.

upon peak cylinder temperature, spray pattern, atomisation and ignition delay. From figures, it is seen that NOx emissions increases with the increase in load for all fuels. This is due to increase in peak temperature and BMEP (brake mean effective pressure) with increase in load. At higher loads (9 kg and 12 kg), fuel blends B1, B2 and B3 show lower NOx emissions than diesel fuel. This is because of the presence of higher DEE percentage than other fuel blends. As DEE increases, Cetane number of fuel blend increases and hence ignition delay of combustion is reduced. As a result of reduced ignition delay period, peak cylinder temperature decreases, hence NOx emissions are lower due to the increase in DEE blends. Higher inherent oxygen present in DEE blends also helps for proper oxidation of hydrocarbons, which is also another cause of reduced NOx compared to diesel fuel. Fuel blend B3 gives best performance for NOx emissions for CR 16 at higher loads. For B3 blend, the range of NOx emission is 100 ppm to 394 ppm, which is lower than diesel. For diesel, NOx emission is 98 ppm at low load to 625 ppm at full load condition. At CR 17 fuel, blends B1, B2 and B3 show lower NOx emissions than diesel fuel and A1, A2 and A3 show higher NOx emissions than diesel. Fuel blend B3 gives best performance for NOx emissions for CR 17 at higher loads. For B3, blend range of NOx emission is 180 ppm to 352 ppm, which is lower than HSD (diesel). For HSD, NOx emission is 98 ppm at low load to 570 ppm at full load condition. When CR is 18, fuel blends A1, A2 and A3 show higher NOx emissions than pure diesel at higher loads (9 kg and 12 kg). Fuel blends B2 and B3 give best performance for NOx emissions for CR 18 at higher loads. For B2 and B3 blends, NOx emissions are nearly same for all loading conditions.

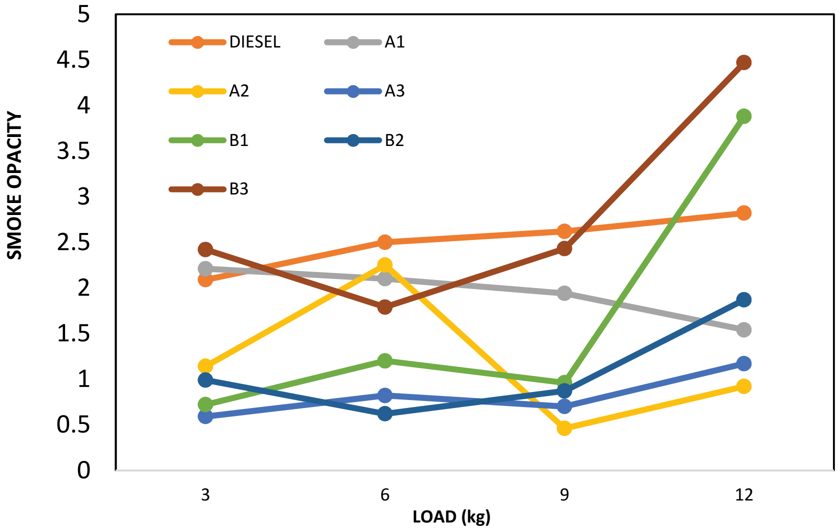

Figure 23. Smoke opacity vs load for CR 18.

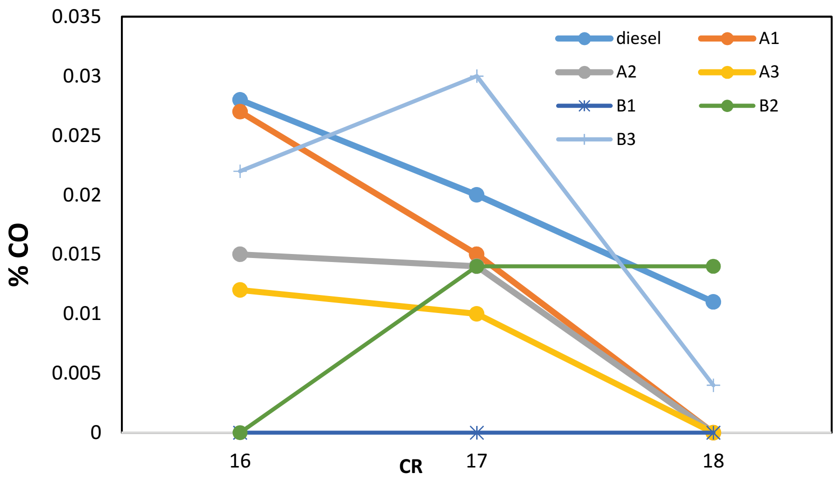

Figure 24. CO vs CR at full load (12 kg /3.4 kW).

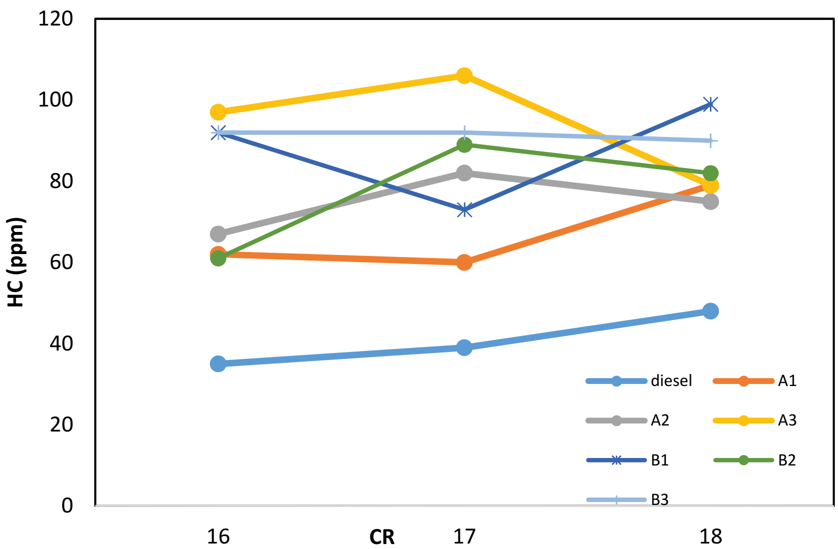

Figure 25. HC vs CR at full load (12 kg/3.4 kW).

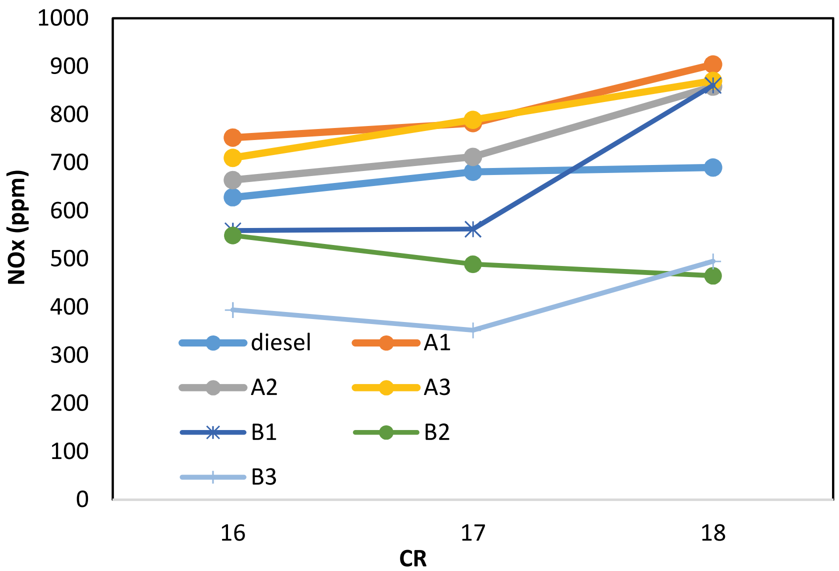

Figure 26. NOx vs CR at full load (12 kg/3.4 kW).

NOx emissions for fuel blends B2 are 250 ppm at lower load to 465 ppm at full load, which is lower than HSD. For HSD, NOx emission is 170 ppm at low load to 700 ppm at full load condition.

The smoke opacity varying with the load and CR for biodiesel blends with additive and pure diesel is shown in Figure 21–23, respectively. From the figures, it is visible that smoke opacity increases with the increase in load. At all loads, all fuel blends show lower value of smoke opacity than diesel fuel. The extra content of oxygen in the biodiesel is the cause for reduction in smoke compared to diesel. Fuel blends B1 and A2 show lower smoke opacity than all other fuel blends. B2 and B3 show higher smoke opacity than B1. Increase in DEE reduces the smoke opacity due to its higher volatility and higher oxygen percentage in blends. But if biodiesel is increased more than 15% in the fuel blends (fuel blends A3 and B3), viscosity of the fuel blend increases. Higher viscosity of fuel blend reduces the atomisation and reduces mixing of air and fuel, which increases the ignition delay. Also, higher fuel viscosity increases C/H ratio in the combustion chamber. Hence smoke opacity increases with higher percentages of biodiesel. Fuel blend A2 shows lowest smoke opacity at higher loads (9 kg and 12 kg). Smoke opacity is 0.35 to 1.5 for blend A2, which is lower than diesel. For diesel, the smoke opacity is 4.5 to 7, which is far greater than all fuel blends. For CR 17, the fuel blends B1 and A2 show lower smoke opacity than all other fuel blends. B1 and B2 show higher smoke opacity than B1. Increase in DEE reduces the smoke opacity due to its higher volatility and higher oxygen percentage in blends. But higher percentage of biodiesel increases the smoke opacity beyond 15% biodiesel. Lowest smoke emissions are observed for Fuel blend B1 at full load. Smoke opacity is 0.77 to 0.96 for blend B1 at CR 17, which is lower than diesel. For diesel, the smoke opacity is 4.5 to 7, which far greater than all fuel blends.

At CR 18, fuel blend A2 shows lower smoke opacity than all other fuel blends. Fuel blend A2 shows lowest smoke opacity at higher loads. Smoke opacity is 0.4 to 0.9 for blend A2 for higher load, which is lower than diesel. For diesel, the smoke opacity is 1.75 to 2.8. Blend B3 shows the highest smoke than diesel fuel at full load. This is because of rich mixture due to reduction in A-F ratio at higher load. B3 fuel contains high percentage of DEE (20%) and biodiesel (20%) than all other fuel blends. Due to higher percentage of DEE and biodiesel in fuel blend, viscosity of the blend increases. Higher viscosity causes poor atomisation and poor mixing of air and fuel, hence smoke opacity increases.

3.3. Effect of CRs on emission characters at full load

In Figures 24–27, the emissions like CO, HC, NOx and smoke opacity with respect to CR variations at full load is shown. CO emissions are lowest at CR 18 compared to CR 16 and CR 17. At higher CR, spray pattern and atomisation are good that cause good mixing of air and fuel. Due to good atomisation and mixing, combustion efficiency increases causing complete combustion, hence reduces CO emissions at higher CR. All the fuel blends show lower CO emissions than diesel fuel. Diesel fuel shows 0.011% and 0.028% CO emission. B1 blend shows 0% CO emission at all CR values. Also fuel blends A1, A2 and A3 show 0% CO emission at CR 18. But, if biodiesel and DEE percentage are higher, viscosity of the blend increases that causes increase in delay period and hence CO%

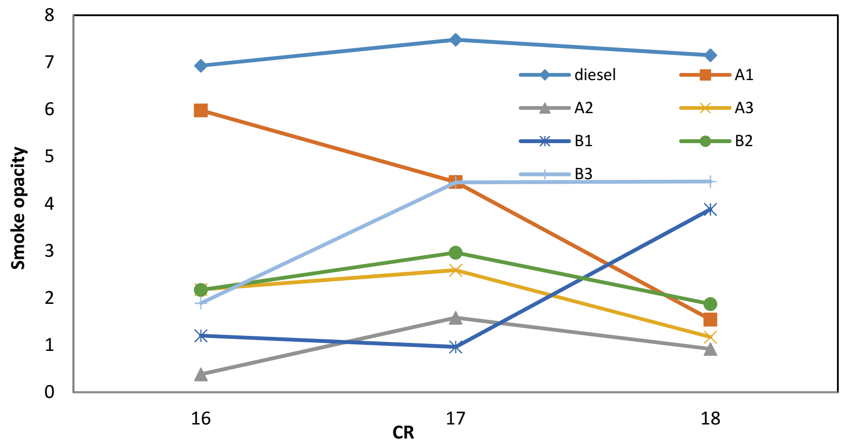

Figure 27. Smoke opacity vs CR at full load (12 kg /3.4 kW).

increases. Figure 27 shows the variation of HC emissions with respect to CR at constant load (full load) for fuel blends. HC emissions slightly increase with the increase in CR. At higher CR, A-F ratio decreases, which cause more rich mixture during combustion, hence increases the HC emissions. All the fuel blends show higher HC emissions than diesel fuel. The main reasons of the higher HC emission are prolonged delay period due to slow vaporisation of DEE and biodiesel blends. Prolonged delay period is responsible for incomplete combustion, which is the main cause of more HC emissions in fuel blends than HSD. A1 shows lower value of HC emissions (62 ppm to 78 ppm) than all other fuel blends. DEE having the higher latent heat of evaporation causing lower combustion temperature, especially the temperature near the cylinder walls during the mixture formation. Diesel fuel shows 35 ppm to 48 ppm HC emission at all CR values. Fuel blends A1, A2, A3 and B2 show almost same value of HC emissions at CR 18, which is about 80 ppm.

In Figure 26, the NOx emissions are found to increase with the increase in CR due to the increase in peak cylinder temperature. Fuel blends B2 and B3 show the lower NOx emissions than diesel. Blends A, A2 and A3 show more NOx emissions than diesel fuel. Fuel blend B3 is the best fuel blend for NOx emission. NOx emissions for B3 are 352 ppm to 495 ppm and for diesel it is 640 ppm to 700 pmm. Smoke opacity decreases with CR for most of the fuels as shown in Figure 27Also, for all CR, fuel blends show lower value of smoke opacity than diesel fuel. Fuel blends B1, A2 and A3 show lower smoke opacity than all other fuel blends. B2 and B3 show higher smoke opacity than B1. Increase in DEE reduces the smoke opacity due to its higher volatility and higher oxygen percentage in blends. But if biodiesel is increased more than 15% in the fuel blends (fuel blends A3 and B3), viscosity of the fuel blend increases. A1, A2, A3 and B2 show almost same smoke emissions at CR 18. Fuel blend A2 shows least smoke opacity which is 0.35 ppm to 1.58 ppm. For diesel, smoke opacity is 7 to 7.5%.

4. Conclusions

The effect of compression ratio and Jatropha with DEE blends is performed in this research. Characters of engine performance mainly BTE and BSFC were analysed. An emission characteristic of the engine is also tested. Following conclusions can be drawn from the experimentation for Jatropha /DEE blends at different values of CR and loads.

For better engine performance, it is better to run the engine at higher load and with higher CR as BTE is enhanced and BFSC is lower due to higher combustion temperature.

BTE increases with the increase in biodiesel and DEE percentage in diesel blend due to increase in oxygen percentage in blends.

A3 blend shows the highest value of BTE (42.57%) compared to other blends and diesel at all CR and loads. Diesel fuel shows lowest value of BSFC (0.25 kg/kWh) than all fuel blends due to higher heating value. While A3 blend shows lower value of BSFC (0.27 kg/kWh) compared other blends at CR 16 and CR 18.

Emission reduces/improves depending upon the load and CR of engine. CO emissions decrease with the increase in CR and load. Fuel blend B1 shows lowest value of CO emissions than all other blends.

Fuel blends B2 having lower HC emissions than other fuel blends at CR 16. Fuel blend A1 shows lower HC emissions than all other blends at CR 17 and fuel blend A1 shows lower HC emissions than all other blends at CR 18.

B1, B2 and B3 show lower NOx emissions than diesel fuel at CR 16 and CR 17. Fuel blends B2 and B3 show lower NOx emissions than diesel fuel at CR 18. This is due to higher percentage of DEE in fuel blend.

Smoke opacity increases with the increase in load. Fuel blends B1 and A2 show lower smoke opacity than all other fuel blends and diesel fuels at CR 16, 17 and 18.

CR 18 gives lower CO emissions and smoke opacity for all fuel blends and CR 16 gives lower HC and NOx emissions. CR 17 gives intermediate emissions for all fuel blends. Overall, fuel blends B1 and B2 gives good emission performance.

Nomenclature

CI	Compression ignition	DI	Direct injection
ATDC	After top dead centre	BTDC	Before top dead centre
CR	Compression ratio	IP	Injection pressure
BTE	Brake thermal efficiency	BSFC	Break specific fuel consumption
BP	Brake power	CC	Combustion chamber
Cv	Calorific value	η_{th}	Thermal efficiency
UBHC	Unburnt hydrocarbon	CO	Carbon monoxide
CO_2	Carbon dioxide	NO_X	Oxides of nitrogen
HC	Hydrocarbon	PM	Particulate matter
ID	Ignition delay	ppm	Parts per million
DEE	Diethyl ether	D100	Pure diesel (100%)
JME	Jatropha biodiesel	D	Diesel
A1	(10% DEE + 10% JME + 90% D)	A2	(10% DEE + 15% JME + 75% D)
A3	(10% DEE + 20% JME + 70% D)	B1	(20% DEE + 10% JME + 75% D)
B2	(20% DEE + 15% JME + 75% D)	B3	(20% DEE + 20% JME + 75% D)

Acknowledgments

The first author would like to express his deep thanks and appreciation to the board of college and university development (BCUD), Savitribai Phule Pune University, Pune, for providing financial support under the research project (Project no. 13ENG000382/2013-15).

Disclosure statement

No potential conflict of interest was reported by the author (s).

Funding

This work was supported by the Board of College and University Development, Savitribai Phule Pune University [13ENG000382/2013-15].

ORCID

B. R. Varpe http://orcid.org/0000-0002-1513-7494

References

Achten, WMJ, E Mathijs, L Verchot, V P. Singh, R. Aerts, B. Muys. 2007. "Jatropha Biodiesel Fueling Sustainability?". *Biofuels, Bioprod Biorefining* 1: 283–291. 10.1002/bbb.39.

Ajav, EA, B Singh, and TK. Bhattacharya. 1999. "Experimental Study of Some Performance Parameters of a Constant Speed Stationary Diesel Engine Using Ethanol-diesel Blends as Fuel." *Biomass & Bioenergy* 17: 357–365. doi:10.1016/S0961-9534(99)00048-3.

Atabani, AE, AS Silitonga, IA Badruddin, T.M.I. Mahlia, H. H. Masjuki, S. Mekhilef. 2012. "A Comprehensive Review on Biodiesel as an Alternative Energy Resource and Its Characteristics". *Renewable and Sustainable Energy Reviews* 16: 2070–2093. 10.1016/j.rser.2012.01.003.

Basha, SA, KR Gopal, and S. Jebaraj. 2009. "A Review on Biodiesel Production, Combustion, Emissions and Performance." *Renewable and Sustainable Energy Reviews* 13: 1628–1634. doi:10.1016/j.rser.2008.09.031.

Becker, K, and HPS. Makkar. 2008. "Jatropha Curcas: A Potential Source for Tomorrow' S Oil and Biodiesel." *Lipid Technology* 20: 104–107. doi:10.1002/lite.200800023.

Carvalho, M, F Torres, V Ferreira, J. Silva, J. Martins, E. Torres. 2020. "Effects of Diethyl Ether Introduction in Emissions and Performance of a Diesel Engine Fueled with Biodiesel-Ethanol Blends". *Energies* 13: 3787. 10.3390/en13153787.

Chauhan, BS, N Kumar, and HM. Cho. 2012. "A Study on the Performance and Emission of A Diesel Engine Fueled with Jatropha Biodiesel Oil and Its Blends." *Energy* 37: 616–622. doi:10.1016/j.energy.2011.10.043.

Cinar, C, Ö Can, F Sahin, H S. Yucesu. 2010. "Effects of Premixed Diethyl Ether (DEE) on Combustion and Exhaust Emissions in a HCCI-DI Diesel Engine". *Applied Thermal Engineering* 30: 360–365. 10.1016/j.applthermaleng.2009.09.016.

De Caro P, Satgé, Z Mouloungui, G Vaitilingom. 2001. "Interest of Combining an Additive with Diesel-ethanol Blends for Use in Diesel Engines". *Fuel* 80: 565–574. 10.1016/S0016-2361(00)00117-4.

de Carvalho Mas, Acbal R. A. Achy, ARA Junior, Junior Lcss, V P. Ferreira, Julio A. M. da Silva, I M. Pepe, et al. 2020. "Mechanical and Emissions Performance of a Diesel Engine Fueled with Biodiesel, Ethanol and Diethyl Ether Blends". *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 42: 182. 10.1007/s40430-020-2269-7.

Demirbas, A. 2007. "Importance of Biodiesel as Transportation Fuel." *Energy Policy* 35: 4661–4670. doi:10.1016/j.enpol.2007.04.003.

Demirbas, A. 2009. "Progress and Recent Trends in Biodiesel Fuels." *Energy Conversvation Management* 50: 14–34. doi:10.1016/j.enconman.2008.09.001.

Devarajan, Y, DB Munuswamy, A Mahalingam, B. Nagappan. 2017. "Performance, Combustion, and Emission Analysis of Neat Palm Oil Biodiesel and Higher Alcohol Blends in a Diesel Engine". *Energy & Fuels* 31: 13796–13801. 10.1021/acs.energyfuels.7b02939.

Doğan, O. 2011. "The Influence of N-butanol/diesel Fuel Blends Utilization on a Small Diesel Engine Performance and Emissions." *Fuel* 90: 2467–2472. doi:10.1016/j.fuel.2011.02.033.

Ibrahim, A. 2018. "An Experimental Study on Using Diethyl Ether in a Diesel Engine Operated with Diesel-biodiesel Fuel Blend." *International Journal of Engineering Science Technologies* 21: 1024–1033. doi:10.1016/j.jestch.2018.07.004.

Imdadul, HK, HH Masjuki, MA Kalam. 2016. "Higher Alcohol–biodiesel–diesel Blends: An Approach for Improving the Performance, Emission, and Combustion of a Light-duty Diesel Engine". *Energy Conversvation Management* 111: 174–185. 10.1016/j.enconman.2015.12.066.

Imdadul, HK, HH Masjuki, MA Kalam, N.W.M. Zulkifli, A. Alabdulkarem, M. Kamruzzaman, M.M. Rashed, et al. 2016. "A Comparative Study of C4 and C5 Alcohol Treated Diesel–biodiesel Blends in Terms of Diesel Engine Performance and Exhaust Emission". *Fuel* 179: 281–288. 10.1016/j.fuel.2016.04.003.

Imtenan, S, HH Masjuki, M Varman, M.A. Kalam, M.I. Arbab, H. Sajjad, S.M. Ashrafur Rahman, et al. 2014. "Impact of Oxygenated Additives to Palm and Jatropha Biodiesel Blends in the Context of Performance and Emissions Characteristics of a Light-duty Diesel Engine". *Energy Conversvation Management* 83: 149–158. 10.1016/j.enconman.2014.03.052.

Iranmanesh, M, JP Subrahmanyam, and MKG. Babu. 2008. "Potential of Diethyl Ether as a Blended Supplementary Oxygenated Fuel with Biodiesel to Improve Combustion and Emission Characteristics of Diesel Engines." *SAE Technical Papers*. doi:10.4271/2008-01-1805.

Jindal, S, BP Nandwana, NS Rathore, V. Vashistha. 2010. "Experimental Investigation of the Effect of Compression Ratio and Injection Pressure in a Direct Injection Diesel Engine Running on Jatropha Methyl Ester". *Applied Thermal Engineering* 30: 442–448. 10.1016/j.applthermaleng.2009.10.004.

Jones, N, and JH. Miller. 1992. "Jatropha Curcas: A Multipurpose Species for Problematic Sites." *L Resource Ser* 1: 40.

Lapuerta, M, O Armas, and R. García-Contreras. 2007. "Stability of Diesel-bioethanol Blends for Use in Diesel Engines." *Fuel* 86: 1351–1357. doi:10.1016/j.fuel.2006.11.042.

Li, DG, H Zhen, L Xingcai, Z. Wu-gao, Y. Jian-guang. 2005. "Physico-chemical Properties of Ethanol-diesel Blend Fuel and Its Effect on Performance and Emissions of Diesel Engines". *Renew Energy* 30: 967–976. 10.1016/j.renene.2004.07.010.

Mofijur, M, HH Masjuki, MA Kalam, A.E. Atabani. 2013. "Evaluation of Biodiesel Blending, Engine Performance and Emissions Characteristics of Jatropha Curcas Methyl Ester: Malaysian Perspective". *Energy* 55: 879–887. 10.1016/j.energy.2013.02.059.

Mohanan, P, N Kapilan, and RP. Reddy. 2003. "Effect of Diethyl Ether on the Performance and Emission of A4 - SDI Diesel Engine." *SAE Technical Papers*. doi:10.4271/2003-01-0760.

Moniruzzaman, M, Z Yaakob, and M Shahinuzzaman. 2017. "Jatropha Biofuel Industry: The Challenges." In *Front Bioenergy Biofuels. IntechOpen*, edited by E Jacob-Lopes, and LQ Zepka, et al. doi:10.5772/64979.

Muralidharan, K, and D. Vasudevan. 2011. "Performance, Emission and Combustion Characteristics of a Variable Compression Ratio Engine Using Methyl Esters of Waste Cooking Oil and Diesel Blends." *Applied Energy* 88: 3959–3968. doi:10.1016/j.apenergy.2011.04.014.

Nigam, PS, and A. Singh. 2011. "Production of Liquid Biofuels from Renewable Resources." *Progress in Energy and Combustion Science* 37: 52–68. doi:10.1016/j.pecs.2010.01.003.

Parawira, W. 2010. "Biodiesel Production from Jatropha Curcas: A Review." *Scientific Research and Essay* 5: 1796–1808.

Patil, KR, and SS. Thipse. 2015. "Experimental Investigation of CI Engine Combustion, Performance and Emissions in DEE–kerosene–diesel Blends of High DEE Concentration." *Energy Conversion and Management* 89: 396–408. doi:10.1016/j.enconman.2014.10.022.

Persistent start-up uses jatropha seeds to make profitable fuel. 2013.

Raja, K, V Srinivasa Raman, R Parthasarathi, K. Ranjitkumar, V. Mohanavel. 2019. "Performance Analysis of DEE-Biodiesel Blends in Diesel Engine."*International Journal of Ambient Energy* 1–5. 10.1080/01430750.2019.1670262.

Rakopoulos, DC, CD Rakopoulos, EG Giakoumis, A M. Dimaratos. 2012. "Characteristics of Performance and Emissions in High-speed Direct Injection Diesel Engine Fueled with Diethyl Ether/diesel Fuel Blends". *Energy* 43: 214–224. 10.1016/j.energy.2012.04.039.

Sathiyamoorthi, R, and G. Sankaranarayanan. 2017. "The Effects of Using Ethanol as Additive on the Combustion and Emissions of a Direct Injection Diesel Engine Fuelled with Neat Lemongrass Oil-diesel Fuel Blend." *Renew Energy* 101: 747–756. doi:10.1016/j.renene.2016.09.044.

Silitonga, AS, AE Atabani, TMI Mahlia, H.H. Masjuki, I A. Badruddin, S. Mekhilef. 2011. "A Review on Prospect of Jatropha Curcas for Biodiesel in Indonesia". *Renewable and Sustainable Energy Reviews* 15: 3733–3756. 10.1016/j.rser.2011.07.011.

Smigins, R, and A. Zakis. 2020. "Impact of Diethyl Ether/Rapeseed Oil Blends on Performance and Emissions of a Light-Duty Diesel Vehicle." *Energies* 13: 3788. doi:10.3390/en13153788.

Soudagar, MEM, NN Nik-Ghazali, M Abul Kalam. 2018. "The Effect of Nano-additives in Diesel-biodiesel Fuel Blends: A Comprehensive Review on Stability, Engine Performance and Emission Characteristics." *Energy Conservation Management* 178:146–177.

Soudagar, MEM, N-N Nik-Ghazali, MA Kalam, I A. Badruddin, N.R. Banapurmath, M A. Bin Ali, S. Kamangar, et al. 2020. "An Investigation on the Influence of Aluminium Oxide Nano-additive and Honge Oil Methyl Ester on Engine Performance, Combustion and Emission Characteristics". *Renew Energy* 146: 2291–2307. 10.1016/j.renene.2019.08.025.

Soudagar, MEM, N-N Nik-Ghazali, MA Kalam, I A. Badruddin, N.R. Banapurmath, T.M. Yunus Khan, M N. Bashir, et al. 2019. "The Effects of Graphene Oxide Nanoparticle Additive Stably Dispersed in Dairy Scum Oil Biodiesel-diesel Fuel Blend on CI Engine: Performance, Emission and Combustion Characteristics". *Fuel* 257: 116015. 10.1016/j.fuel.2019.116015.

Varpe, BR, YR Kharde, KF Rahman, A. Khidmatgar. 2020. "Effect of Diethyl Ether Additive in Jatropha Biodiesel-diesel Fuel Blends on the Variable Compression Ratio Diesel Engine Performance and Emissions Characteristics at Different Loads and Compression Ratios". *Heat Transfer* 49: 4427–4447. 10.1002/htj.21834.

Venu, H, and V. Madhavan. 2016. "Effect of Nano Additives (Titanium and Zirconium Oxides) and Diethyl Ether on Biodiesel-ethanol Fuelled CI Engine." *Journal of Mechanical Science and Technology* 30: 2361–2368. doi:10.1007/s12206-016-0446-5.

Xing-Cai, L, Y Jian-Guang, Z Wu-Gao, H. Zhen. 2004. "Effect of Cetane Number Improver on Heat Release Rate and Emissions of High Speed Diesel Engine Fueled with Ethanol-diesel Blend Fuel". *Fuel* 83: 2013–2020. 10.1016/j.fuel.2004.05.003.