Taylor & Francis
Taylor & Francis Group

Biofuels

ISSN: 1759-7269 (Print) 1759-7277 (Online) Journal homepage: https://www.tandfonline.com/loi/tbfu20

Investigation on the performance of a variable compression ratio engine operated with raw cardanol kerosene blends

Ravindra, M. Aruna & Harsha Vardhan

To cite this article: Ravindra, M. Aruna & Harsha Vardhan (2020) Investigation on the performance of a variable compression ratio engine operated with raw cardanol kerosene blends, Biofuels, 11:6, 699-705, DOI: 10.1080/17597269.2017.1389195

To link to this article: https://doi.org/10.1080/17597269.2017.1389195

BIOFUELS, 2020
VOL. 11, NO. 6, 699–705
https://doi.org/10.1080/17597269.2017.1389195

Taylor & Francis
Taylor & Francis Group

Investigation on the performance of a variable compression ratio engine operated with raw cardanol kerosene blends

Ravindra, M. Aruna and Harsha Vardhan

Department of Mining Engineering, National Institute of Technology Karnataka, Surathkal, 575025, India

ABSTRACT

In this study raw cardanol, which is a renewable biofuel, was blended with kerosene and used as a test fuel in a four-stroke variable compression ratio 3.5-kW diesel engine. Volume basis test blends of cardanol and kerosene, such as BK20 (20% kerosene and 80% cardanol), BK30 (30% kerosene and 70% cardanol) and BK40 (40% kerosene and 60% cardanol), were prepared and tested for three different compression ratios (16:1, 17:1 and 18:1) at various load conditions and compared with diesel fuel. It was observed that when the compression ratio increased from 16:1 to 18:1, the brake thermal efficiency increased from 23.87 to 27.30% for BK20, 26.83 to 29.87% for BK30, and 24.28 to 28.62% for BK40, with reduction in carbon monoxide, unburned hydrocarbon and smoke emission. But NO_x emission was increased by 18.7, 1.8 and 7.3%, respectively, for BK20, BK30 and BK40 blends at the highest compression ratio relative to diesel. This study demonstrates that cardanol–kerosene blends can be used as diesel engine fuel at higher compression ratios.

ARTICLE HISTORY
Received 14 June 2017
Accepted 26 September 2017

KEYWORDS
Cardanol; kerosene; performance; compression ratio; emission

Introduction

The internal combustion engine plays a vital role in the power generation sector. The power utilised in irrigation, transportation, marine sector, electricity production, transportation, defence, etc. is mainly produced from internal combustion (IC) engines. At present most IC engines are operated by fossil fuels. It is a known fact that the reserves of fossil fuels are depleting at a fast rate, and also the burning of fossil fuels leads to environmental problems such as smog, acid rain, depletion of the ozone layer, global warming, etc. [1]. It is our duty to protect the environment and human health by minimising the usage of fossil fuels. However, day by day, world fossil fuel consumption is increasing rapidly.

Nomenclature

BTE	brake thermal efficiency
CO	carbon monoxide
BSFC	brake specific fuel consumption
CI	compression ignition
EGT	exhaust gas temperature
CNSL	cashew nut shell liquid
HC	unburned hydrocarbon
NO_x	oxides of nitrogen
VCR	variable compression ratio
BTDC	before top dead centre

The present liquid fuel reserves can meet half of the energy demand up to 2023 [2]. At present all over the world scientists are working on new energy alternatives. Biodiesel is one such alternative, which is produced from vegetable and animal origins and is renewable in nature [3]. Biodiesels are extracted from animal fats and vegetable oils by a transesterification process. They can be produced from edible and non-edible oils. However, the usage of edible oils for biodiesel production may affect the food supply system. Hence, keeping this in view, only non-edible oils are widely used for biodiesel production [4].

Already biodiesels have been produced from sources like fish oil, ox tallow, jatropha seeds, pongamia seeds, mustard oil, cotton seed, rubber seed, castor, etc. [5]. Karanja biodiesel was blended with diesel up to 30% and tested in a constant-speed diesel engine. The B20 blend (i.e. 20% biodiesel and 80% pure diesel) gave high thermal efficiency with low smoke emission compared to the other blends used in that study [6]. Performance of 20% blends of jatropha, moringa and palm oil biodiesel with diesel were compared, and it was resolved that palm biodiesel blend was better than the other two blends with respect to performance and emission [7]. Behcet et al. tested 25% blends of fish oil methyl ester and cooking oil methyl ester with diesel in a diesel engine and concluded that the brake power and brake thermal efficiency (BTE) of the blends were lower than those of diesel fuel. But CO (carbon monoxide), HC (unburned hydrocarbon) and smoke emissions were reduced compared to diesel fuel [8].

CONTACT M. Aruna ✉ arunamangalpady@gmail.com

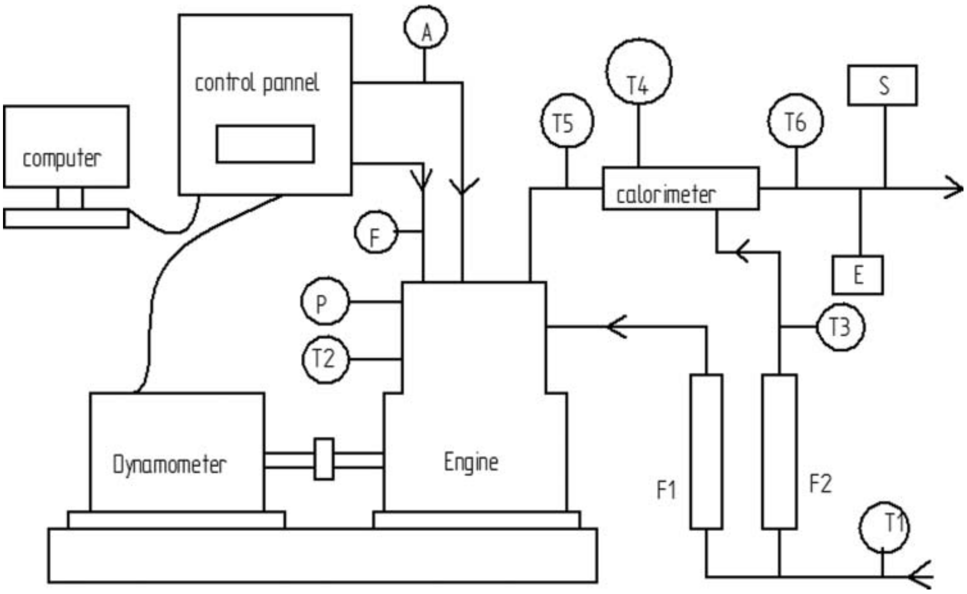

Figure 1. Experimental set-up. A: air flow measurement; E: exhaust gas analyser; F: fuel flow measurement; F_1: water flow rate through engine; F_2: water flow rate through the calorimeter; P: pressure sensor; S: smoke meter; T_1 and T_2: engine inlet and outlet jacket water temperature; T_3 and T_4: calorimeter inlet and outlet water temperature; T_5 and T_6 :exhaust gas temperature at inlet and outlet of calorimeter.

Cardanol is one of the non-edible biofuel sources abundantly available at lower cost in India [9]. Cardanol is a phenolic liquid produced from cashew nut shell liquid (CNSL) by a distillation process, and is a by-product produced during cashew processing in the cashew industry. In India cashew nut plantations occupy 0.7 million hectares of area [10]. Many researchers have blended cardanol with diesel in different percentages and tested the performance in diesel engines, and obtained positive results with respect to performance and emissions [10–12]. To reduce the viscosity of cardanol biofuel, Kasiraman et al. blended raw CNSL with camphor oil and tested it in diesel engine. They found that the performance of biodiesel with a 30% camphor oil and 70% CNSL blend was very close to diesel fuel performance [13].

Aydin et al. blended cottonseed biodiesel with 20% kerosene (BK20) and used it as a fuel in a diesel engine to study its performance [14]. The results showed lower emissions for the BK20 blend compared to diesel fuel and diesel–biodiesel blends. In another study pure mustard oil was blended with kerosene and its performance was tested in a diesel engine. This study found that the brake specific fuel consumption (BSFC) of 20% and 30% biofuel blends with kerosene was very close to that of diesel fuel, and thus the blends can be used as diesel engine fuel with a little reduction in power [15]. Roy et al. studied the performance of blends of canola oil biodiesel with kerosene in a diesel engine. They reported that a higher percentage of kerosene in the blend produces lower efficiency due to the higher volatility of kerosene compared to biodiesel, and HC emissions were reduced at peak load conditions [16]. To the authors' knowledge, cardanol has not been tested by blending with kerosene in diesel engines.

In the present study, raw cardanol was blended with kerosene and tested in a variable compression ratio diesel engine to test the suitability of kerosene blending as a biofuel. The test was carried out at three different compression ratios, 16:1, 17:1 and 18:1 [1,18], to study the effect of compression ratio on the performance of cardanol blends.

Experimental set-up and procedure

The experiments were conducted in a single-cylinder, four-stroke, water-cooled 3.5-kW variable compression ratio (VCR) diesel engine with 200 bar fuel injection pressure and 23 degree BTDC injection timing. The experimental set-up is shown in Figure 1. The load on the engine was applied with an eddy current dynamometer cooled by water and rated at 7.5 kW with a maximum speed of 3000 rpm. A burette connected with a Differential Pressure (DP) transmitter was used for fuel flow measurement. The engine was connected to a computer for capturing data. Technical specifications of the engine are given in Table 1.

Table 1. Technical specifications of the engine.

Number of cylinders	1
Number of strokes	4
Power	3.5 kW
Bore	87.5 mm
Stroke	110 mm
Rated speed	1500 rpm
Connecting rod length	234 mm
Compression ratio	12:1 to 18:1
Dynamometer arm length	184 mm
Orifice diameter	20 mm

Table 2. Multi gas analyser accuracy and range (Netel exhaust gas analyser, Model: NPM-MGA-1).

Parameter	Accuracy	Range
HC	± 10 ppm	0–20,000 ppm
CO	± 0.03%	0–9.9%
NO_x	± 25 ppm	0–5000 ppm

Source: Manufacturer's instruction manual.

The engine settings were checked and corrected to the specifications of the manufacturer. The calorimeter water flow and engine cooling water flow rate were set as per these specifications. Diesel and cardanol kerosene blends were filled in the dual fuel tank separately. The compression ratio was adjusted to the required value. The engine was started by hand cranking and allowed time to warm up and reach a steady-state condition. After that, the dynamometer was adjusted to apply the required load. Once the steady state was attained, the rate of fuel consumption was noted. The exhaust gas emissions (HC, CO and NO_x) were measured using an exhaust gas analyser (Netel exhaust gas analyser, model NPM-MGA-1) and the smoke opacity was measured with a smoke meter (Netel smoke meter, model NPM-SM-111B). Before using the exhaust gas analyser it was calibrated with standard zero gas. The specifications of the gas analyser and smoke meter are given in Tables 2 and 3, respectively. This procedure was repeated for different blends and different compression ratios. The fuel tank was drained and rinsed with the new blend before filling the tank with that new blend. The compression ratio was changed by tilting the cylinder head, as per the specifications. The trials were repeated for all test fuels and readings were noted after steady state. The BSFC, BTE and EGT readings were recorded and exhaust emissions were measured. The percentage uncertainties of all parameters were calculated and are tabulated in Table 4.

Test fuel

For this study raw cardanol and kerosene blends were used as test fuel. Kerosene and double-distilled cardanol were purchased from a local market. Volume-basis blends of cardanol and kerosene – BK20 (20% kerosene and 80% cardanol), BK30 (30% kerosene and 70% cardanol) and BK40 (40% kerosene and 60% cardanol) – were prepared. The calorific value of each blend was determined as per the D240 standard with a bomb calorimeter. Kinematic viscosity was determined using a Cannon–Fenske Viscometer as per American Society for Testing and Materials (ASTM) Standard D445. The flash point was determined using a Pensky–Martens closed cup apparatus as per ASTM Standard D93. The density of each blend was determined using a hydrometer as per ASTM Standard D1298. The properties of the test fuels are given in Table 5.

Table 3. Smoke meter accuracy and range (Netel smoke meter model, NPM-SM-111B).

Parameter	Accuracy	Range
Smoke intensity	± 1%	0–100% opacity
Light absorption coefficient (K)	± 0.1 m^{-1}	0–9.9 m^{-1}

Source: Manufacturer's instruction manual.

Table 4. Uncertainties of measured parameters.

S. no.	Parameter	Resolution	Uncertainty (%)
1	HC	1 ppm	± 0.2
2	CO	0.01%	± 0.3
3	NO_x	1 ppm	± 0.2
4	Smoke	0.1%	± 1
5	Load	0.1 N	± 0.5
6	Fuel measurement	0.1 cc	± 1

Results and discussion

Performance results

Brake thermal efficiency

The variation in BTE of various test blends at different compression ratios with respect to load are shown in Figure 2. It was observed that the BTE increased with an increase in load for all of the test fuels, due to a reduction in power loss with increased load. When the compression ratio was increased from 16:1 to 18:1, the BTE increased from 23.87 to 27.30%, 26.83 to 29.87%, and 24.28 to 28.62% (i.e. by 14.3, 11.3 and 17.8%) for the blends BK20, BK30 and BK40, respectively. This increase in BTE was due to a higher temperature at the time of fuel injection at higher compression ratios, which favours fast and complete combustion [17]. It was also observed that at all compression ratios, maximum thermal efficiency was recorded for the BK30 blend compared to other blends, which is very close to (only slightly lower than) the diesel fuel performance. Maximum efficiency of 29.87% and 30.36% was observed at full load for BK30 blend and diesel fuel, respectively, at Compression Ratio 18:1(CR18).

Brake specific fuel consumption

Figure 3 represents the variation of BSFC with load for all test fuels used at different compression ratios. It was observed that the BSFC values for biofuel blends were higher than those for diesel fuel at all loads, because the biofuels have lower calorific value than diesel. Similar observations were also recorded by the other researchers [18]. The BSFC decreased with an increase in compression ratio for all of the test blends. The BSFC was reduced by 6% when the compression ratio was increased from 16 to 17, and the reduction

Table 5. Properties of diesel and cardanol kerosene blends.

Properties	ASTM code	Diesel	BK20	BK30	BK40
Kinematic viscosity @40°C (in cSt)	D445	3.17	9.3	5.9	3.8
Density @ 15°C (in kg/m^3)	D1298	821	834	825	811
Flash point (in °C)	D93	51	82	65	59
Calorific value (in kJ/kg)	D240	43,580	40,960	41,331	41,712

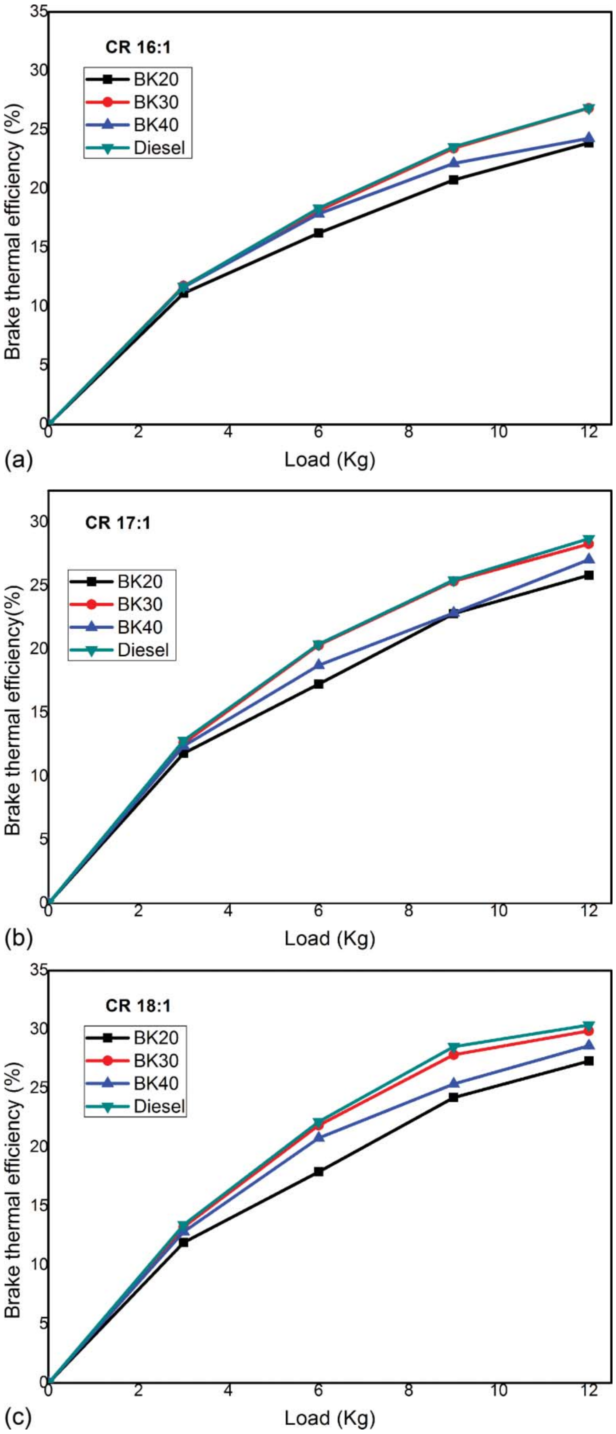

Figure 2. Variation of BTE with load at different compression ratios (CR): (a) 16:1; (b) 17:1; (c) 18:1.

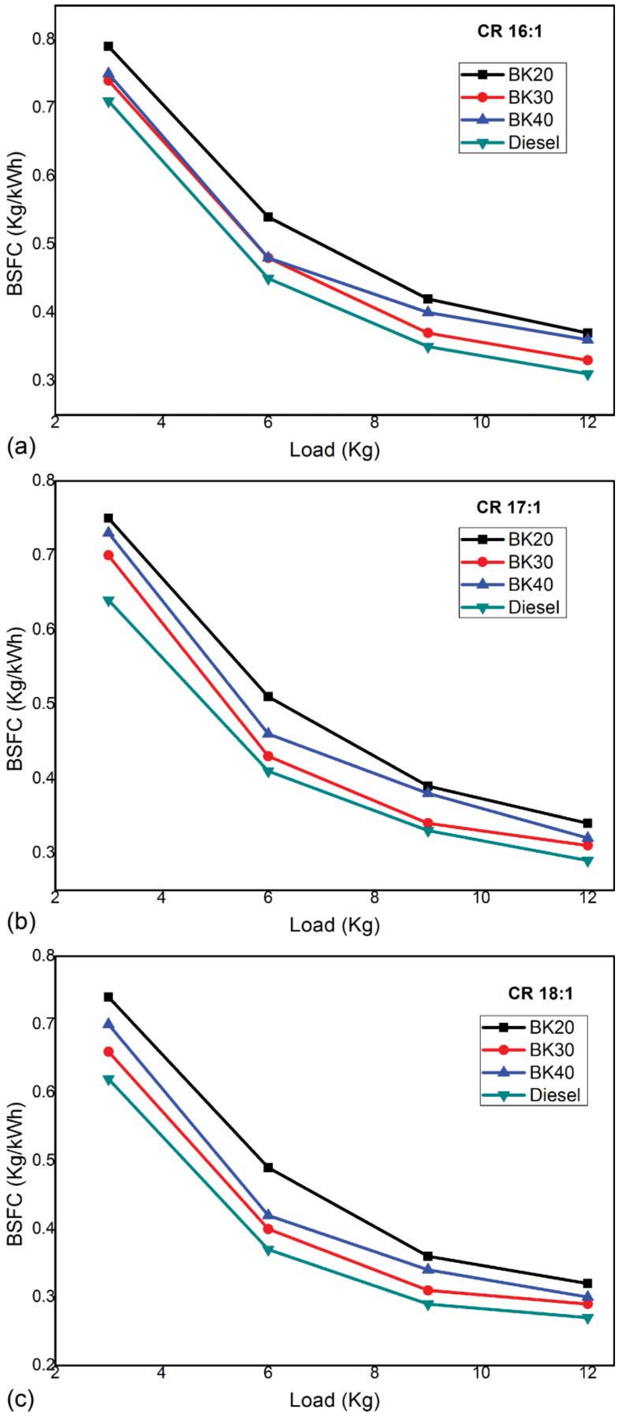

Figure 3. Variation of BSFC with load at different compression ratios (CR): (a) 16:1; (b) 17:1; (c) 18:1.

was 6.4% when CR was increased from 17 to 18 for the BK30 blend. At higher compression ratios the temperature in the combustion chamber will be high, so the combustion will be complete and the BSFC will be low.

Emission results

Carbon monoxide emissions

Carbon monoxide (CO) is produced due to a lack of oxygen during combustion in the combustion chamber. Figure 4 shows the variation of CO emission with load for biofuel blends and diesel fuel at various compression ratios. As depicted in Figure 4, the CO emission for the kerosene biofuel blends is decreased with an increase in load and with the kerosene percentage in the blend. In the case of diesel fuel, CO emissions were higher than those of the blends, and this may be due to extra fuel injection at full load [19]. It can be noted from the figure that with an increase in compression ratio the CO emission was reduced for all biofuel blends and for diesel fuel. This was mainly because of the higher air temperature at higher compression ratios, which leads to complete combustion. When the compression ratio was increased from 16 to

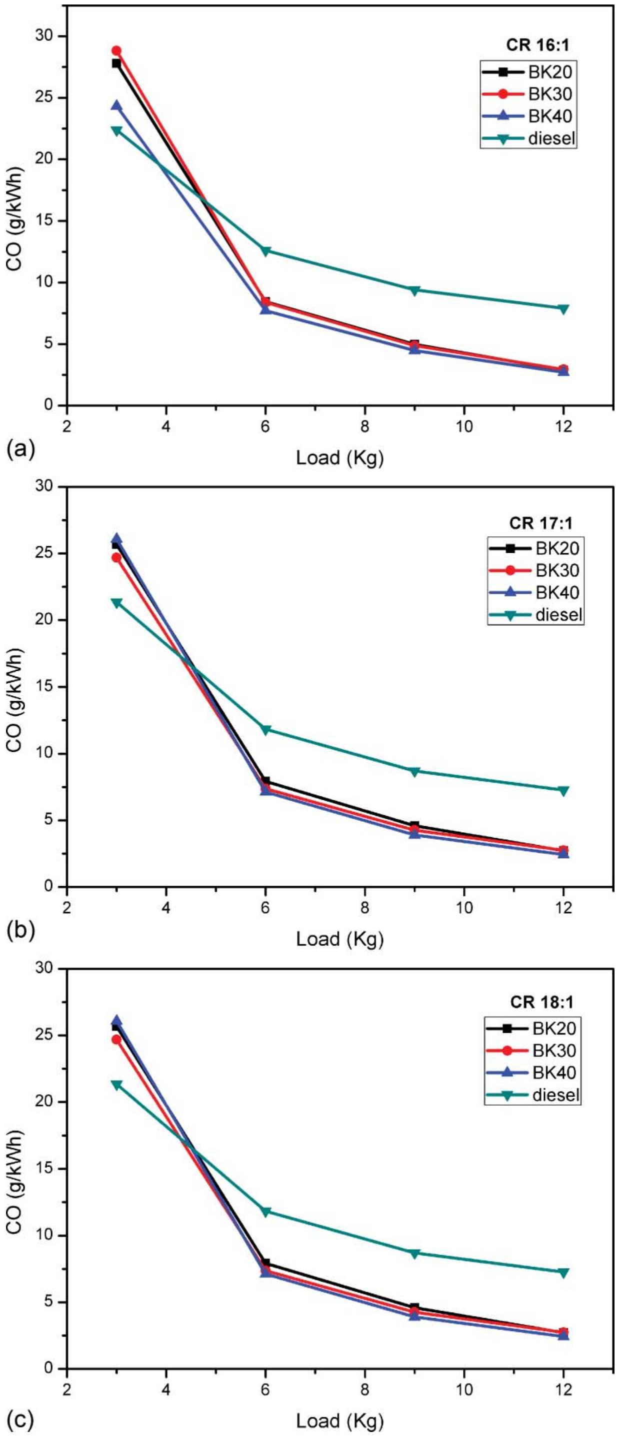

Figure 4. Variation of CO with load at different compression ratios (CR): (a) 16:1; (b) 17:1; (c) 18:1.

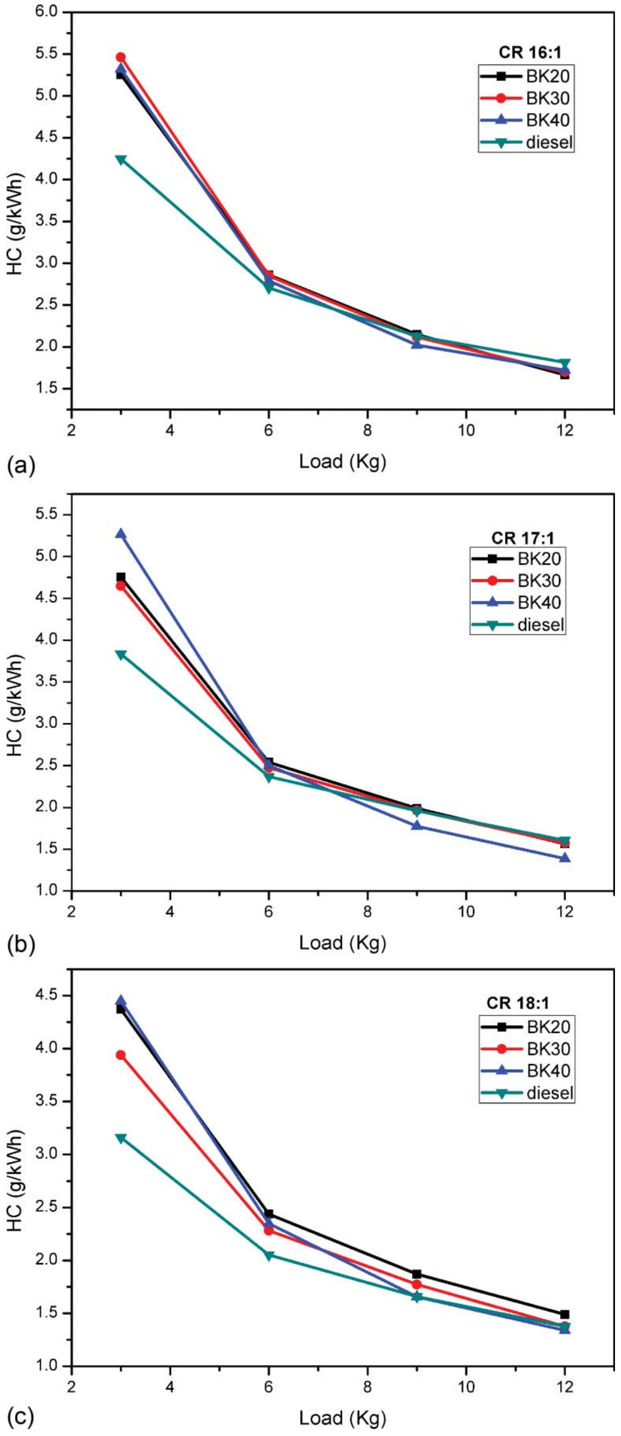

Figure 5. Variation of HC with load at different compression ratios (CR): (a) 16:1; (b) 17:1; (c) 18:1.

18 the CO emissions were reduced by 21, 13, 10 and 13% for blends BK20, BK30, BK40 and diesel fuel, respectively, at peak load.

Unburned hydrocarbon emission

Unburned hydrocarbons (HC) were emitted due to incomplete combustion. Figure 5 indicates the HC emission at various loads for all fuels tested at different compression ratios. As highlighted in the figure, the HC emission increases with an increase in load for all biofuel blends tested and for diesel fuel. Similar observations were reported by other researchers also [20]. With an increase in compression ratio the HC emission was reduced for all tested fuels. When the compression ratio is increased the delay period is reduced and combustion will be complete, which leads to a reduction in HC emission.

Nitrogen oxide (NO_x) emission

Oxides of nitrogen were formed inside the combustion chamber due to high temperature and availability of excess oxygen inside the combustion chamber. The variation of NO_x emission with load for different blends

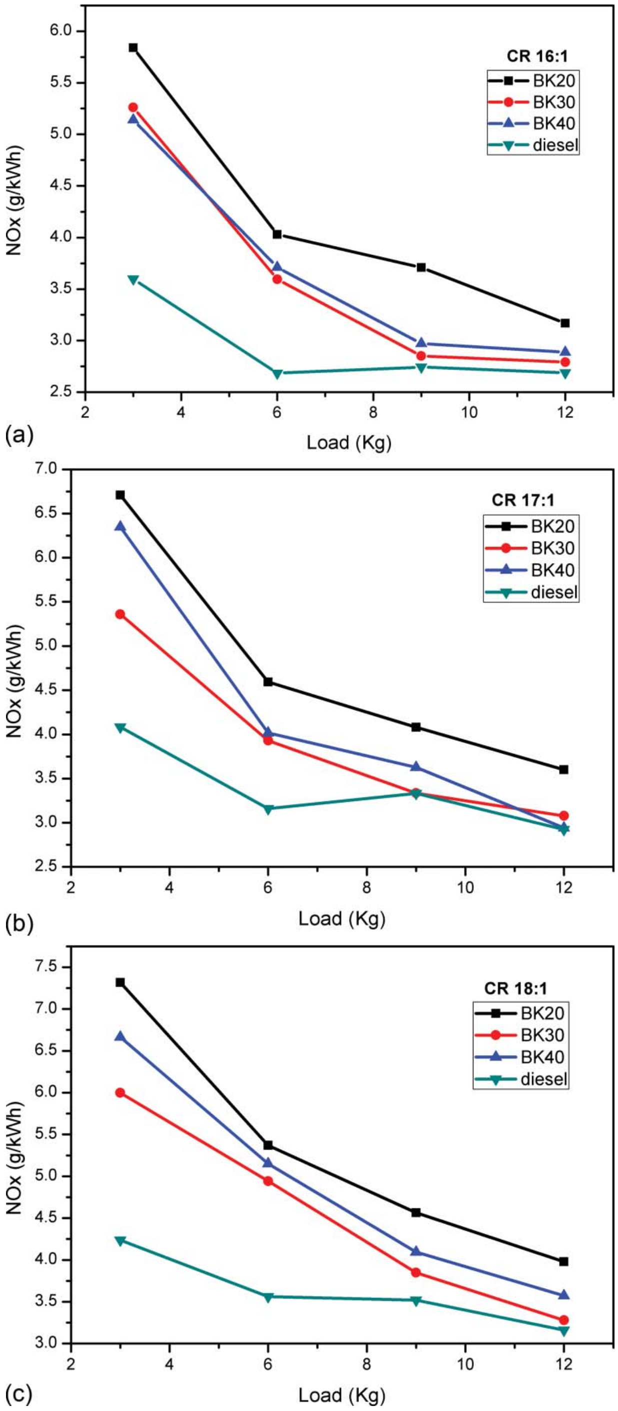

Figure 6. Variation of NO_x with load at different compression ratios (CR): (a) 16:1; (b) 17:1; (c) 18:1.

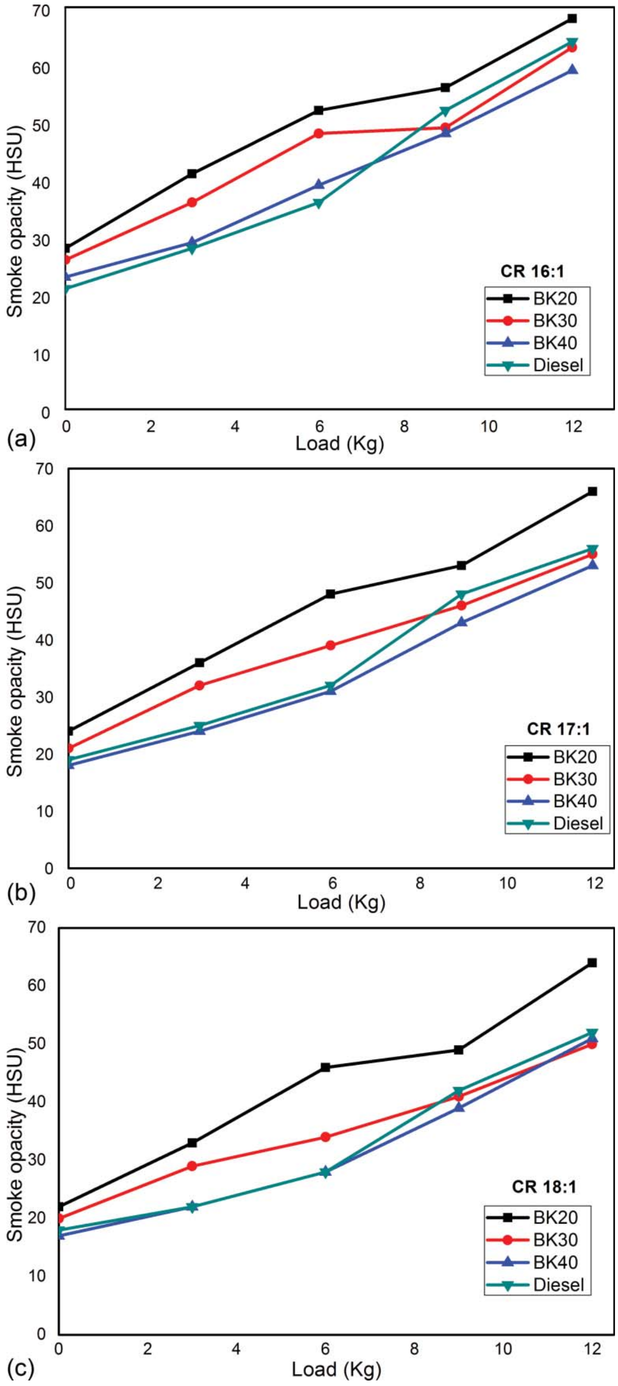

Figure 7. Variation of smoke opacity with load at different compression ratios (CR): (a) 16:1; (b) 17:1; (c) 18:1.

is shown in Figure 6. It can be observed from the figure that the NO_x emission increases with an increase in the compression ratio. This is mainly due to the higher temperature at higher compression ratios [21]. NO_x emissions for biofuel blends were higher than that of diesel fuel at all loads. The BK30 blend emitted less NO_x than the other tested blends did, at peak load. But this emission is slightly higher than that of diesel fuel. When the compression ratio was increased from 16 to 18 the NO_x emissions increased by 20, 23, 24 and 24% for BK20, BK30, BK40 and diesel fuel, respectively.

Smoke emission

Figure 7 presents the smoke emissions at various loads for all test fuels. From Figure 7 it can be observed that the smoke emission increases with an increase in load for all test fuels. When the percentage of kerosene in the blend is increased, the smoke emission is reduced. It was also observed that with an increase in compression ratio there was a reduction in the smoke emission. At peak load, BK30 and BK40 blends emit less smoke than diesel fuel at all tested compression ratios.

Conclusions

The performance of raw cardanol blends with kerosene was tested in a VCR diesel engine. The test was conducted at three different compression ratios: 16, 17 and 18. For the BK30 blend at peak load the BTE was 29.87%, and for the BK40 blend it was 28.62%. Also, the NO_x emission was lower for the BK30 blend compared to BK40, so it was concluded that engine performance was better with the BK30 blend. However, the HC emission for BK40 was lower than for BK30, which is due to the presence of more kerosene in the blend which leads to continuation of combustion during expansion. The emissions of CO, HC and smoke were lower for the biofuel blends than for diesel fuel. NO_x emissions for biofuel blends were higher compared to diesel fuel. Among the three blends tested, the BK30 blend emits less NO_x than the others at peak load. When the compression ratio was increased from 16 to 18 brake thermal efficiency also increased, from 23.87 to 27.30%, 26.83 to 29.87%, 24.28 to 28.62%, and 26.86 to 30.36% (that is, by 14.3, 11.3, 17.8 and 13%) for BK20, BK30, BK40, and diesel fuel, respectively. The emissions of CO, HC and smoke were reduced with an increase in compression ratio, whereas there was an increase in NO_x. From the test results it can be concluded that cardanol blended with kerosene can be used in diesel engines as an alternate fuel at all tested compression ratios without knocking.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] Bora BJ, Saha UK, Chatterjee S, et al. Effect of compression ratio on performance, combustion and emission characteristics of a dual fuel diesel engine run on raw biogas. Energy Convers Manag. 2014;87:1000–1009.

[2] Sanjid A, Masjuki HH, Klam MA, et al. Production of palm and jatropha based biodiesel and investigation of palm jatropha combined blend properties, performance, exhaust emission and noise in an unmodified diesel engine. J Clean Prod. 2014;65:295–303.

[3] Tuccar G, Tosun E, Ozgur T, et al. Diesel engine emissions and performance from blends of citrus sinensis biodiesel and diesel fuel. Fuel. 2014;132:7–11.

[4] Ong HC, Masjuki HH, Mahlia TMI, et al. Optimisation of biodiesel production and engine performance from high fatty acid Calophyllum inophyllum oil in CI diesel engine. Energy Convers Manag. 2014;81:30–40.

[5] Layek A. Engine performance and emission having Jatropha- diesel blend. Int J Renew Energy Res. 2016;6 (2):607–613.

[6] Mohite S, Kumar S, Maji S. Experimental studies on use of Karanja biodiesel as blend in a compression ignition engine. Int J Renew Energy Res. 2016;6(2):355–360.

[7] Kumar K, Sharma MP. Performance and emission characteristics of a diesel engine fuelled with biodiesel blends. Int J Renew Energy Res. 2016;6(2):658–662.

[8] Behcet R, Yumrutas R, Oktay H. Effect of fuels produced from fish and cooking oils on performance and emissions of a diesel engine. Energy. 2013;71:645–655.

[9] Vedharaj S, Vallinayagam R, Yang WM, et al. Performance emission and economic analysis of preheated CNSL biodiesel as an alternate fuel for a diesel engine. Int J Green Energy. 2015;12:359–367.

[10] Mallikappa DN, Rana Pratap R, Murthy CSN. Performance and emission characteristics of double cylinder CI engine operated with cardanol biofuel blends. Renew Energy. 2011;38(1):150–154.

[11] Santhanakrishnan S, Ramani BKM. Evaluation of diesel engine performance using diesel – cashew nut shell oil blends. Int J Ambient Energy. 2015; https://doi.org/10.1080/01430750.2015.1048898.

[12] Dinesha P, Mohanan P. Effect of oxygen enrichment of intake air on the performance and emission of single cylinder CI engine fuelled with cardanol blends. Distributed Generation & Alternative Energy Journal. 2015;30(1):6–14.

[13] Kasiraman G, Nagalingam B, Balakrishnan M. Performance, emission and combustion improvements in a direct injection diesel engine using cashew nut shell oil as fuel with camphor oil blending. Energy. 2012;47:116–124.

[14] Aydin H, Bayindir H, İlkiliç C. Emissions from an engine fuelled with biodiesel-kerosene blends. Energy Sources Part A. 2011;33:130–137.

[15] Azad AK, Uddin SMA, Alam MM. Mustard oil, an alternative fuel: an experimental investigation of Biodiesel properties with and without trans-esterification reaction. Global advanced research journal of engineering. Technology and Innovation. 2012;1(3):75–84.

[16] Roy MM, Wang W, Alawi M. Performance and emissions of a diesel engine fuelled by biodiesel-diesel, biodiesel-diesel-aditive and kerosene-biodiesel blends. Energy Convers Manag. 2014;84:164–173.

[17] Harkude H, Padalkar AS. Experimental investigation of the effect of compression ratio on performance and emissions of CI engine with waste fried oil methyl ester blend. Fuel Process Technol. 2014;128:367–375.

[18] Jindal S, Nandwana BP, Rathore NS, et al. Experimental investigation of the effect of compression ratio and injection pressure in a direct injection diesel engine running on Jatropha methyl ester. Appl Therm Eng. 2010;30:442–448.

[19] Natesan NK. The enhancement of the performance of a biodiesel operated diesel engine. Energy Sources, Part A. 2013;35:1648–1656.

[20] Sharma A, Murugan S. Investigation on the behaviour of a DI diesel engine fuelled with Jatropha Methyl Ester (JME) and Tyre Pyrolysis Oil (TPO) blends. Fuel. 2013;108:699–708.

[21] Muralidharan K, Vasudevan D. Performance, emission and combustion characteristics of a variable compression ratio engine using methyl esters of waste cooking oil and diesel blends. Appl Energy. 2011;88:3959–3968.