



Combustion and emission characteristics of diesel fuel blended with raw jatropha, soybean and waste cooking oils



Prem Kumar Chaurasiya^{*}, Sanjay Kumar Singh, Rashmi Dwivedi, Ravishanker V. Choudri

Department of Mechanical Engineering, Sagar Institute of Science and Technology Gandhi Nagar, Bhopal, M.P, India

ARTICLE INFO

Keywords:

Chemical engineering
Mechanical engineering
Petroleum engineering

ABSTRACT

In the present investigation raw oil (jatropha, soybean, and waste cooking fuel) has analyzed to prove its suitability as an alternative fuel in compression ignition (CI) engines. The blends of high vegetable oils with diesel are created and analyzed experimentally. The raw oil is blended with diesel in varying proportion (from 20 % to 50 %) using raw vegetable oil (100 %). Two sets of experiments are conducted for each fuels blends, one for performance analysis & other for emission test. The analysis has been performed for pure diesel and diverse blends of Jatropha-diesel, Soybean-diesel and waste cooking oil-diesel at compression ratio (CR) of (16.5). The performance and emission characteristic for each raw oil-diesel blends are investigated and the comparison results are presented. The result reveals that B20 blends of all biodiesel have shown very close values of Brake Thermal Efficiency (BTE) at all loading.

1. Introduction

The increase in utilization of conventional energy and the increasing cost of crude oil has forced the need to look for an alternative of diesel fuel for diesel engines. Various renewable oxygenated fuels have been used according to their safety, cost, accessibility and compatibility with diesel engines [1]. Among various fuels, biodiesel is a most investigated alternative and has also shown a positive impact in mitigating the challenges related to insufficient energy demand. Biodiesel is a non-hazardous, non-toxic, and biodegradable and can extensively reduce toxic, noxious and carbon dioxide emissions from engines [2]. Bio-diesel is also a viable fuel and can be mixed directly with diesel in different proportions. Moreover, biodiesel is used to run diesel engines without any alteration. However, engine performance and emissions are affected due to a difference in their physical-chemical properties.

The internal combustion engines are extensively used in various places such as locomotive engines, transportation, power, agricultural machinery etc. However, a diesel engine plays a vital role in increasing environmental pollution by emitting hydro carbon (HC), nitrogen oxides (NO_x), carbon monoxides (CO) during combustion process. The increasing concern over depletion of conventional resource and global environmental issues has gained the attraction to encourage the utilization of alternative fuels [3, 4]. Biodiesel has a huge prospective with a low heating value, lower CO and HC emission, higher cetane number and

oxygen content [4, 5, 6].

Osama Ahmed Elsanusi et al. [5] investigated the characteristics of emulsion fuel and its effect on a diesel engine at different water levels. The results revealed that the content of water in blend increases the brake thermal efficiency (BTE), whereas exhaust gas emission (EGT), nitrogen oxides (NO_x) and smoke emission decreases with increase in water content. Upendra Rajak et al. [7] investigated performance characteristics of *spirulina microalgae* biodiesel at different loading conditions on four stroke water cooled direct ignition single cylinder compression engine and observed that there is a reduction in BTE, exhaust gas temperature (EGT), NO_x and smoke emission and also found that using 20 % *spirulina* blend increases specific fuel consumption and carbon di-oxides (CO₂) emission.

Upendra Rajak et al. [8] numerically determined the diesel engine characteristics using vegetable oil, waste oil, animal fat and alcohols by means of Diesel-RK tool. The study shows that delay in ignition delay was lower for biodiesel than diesel and reduces by increasing engine loads. The combustion timing was observed lower for biodiesel. Upendra Rajak et al. [9] performed numerical study to study the performance of nine different alternative biofuels and diesel. The results reveal that the bio-fuels may be used an optional fuel in CI engines. The numerical result was validated against two experimental data using suggested numerical tool and shows an approximate good agreement with experimental results. Upendra Rajak et al. [10] investigated characteristics of emulsion fuel

^{*} Corresponding author.

E-mail addresses: premkumarchaurasiya@sistec.ac.in, prem.chaurasiyaa@gmail.com (P.K. Chaurasiya).

microalgae spirulina biodiesel (MSB-20) with B20 blend level and studied its effect on performance of diesel engine characteristics. The results shows an reduction in cylinder parameters, brake thermal efficiency, particulate matter, nitrogen oxides, whereas parameter like peak heat release rate, specific fuel consumption, carbon dioxide emission, ignition delay period shows an increment using MSB-20 biodiesel at full engine load. Tse H et al. [13] studied the effect of diesel-biodiesel-ethanol on the combustion characteristics of diesel engine and observed that the blended fuels performs better by suppressing brake specific number characteristics, leading to a diminution of ultrafine and nano-particles. L Wei et al. [14] performed the investigation to evaluate the effect of biodiesel (cooking oil) on combustion and emission characteristics of an 18 Japanese 13-mode test diesel engine using B20, B50, and B75 fuel.

The available literature survey shows that there are not too many research conducted on the non edible raw oil. The purpose of the investigation is to estimate the effect of incineration along with the evaluation of performance and emission characteristics of diesel engine using Jatropa, Sybean, and Waste cooking oil. Each raw oil is blended with diesel in varying proportion (from 20 % to 50 %) using raw oil (100 %). The performance and emissions characteristic for each oil-diesel blends are studied and results are compared with diesel fuel alone. Additionally, the CO and NOx emissions are also examined in this study.

2. Material and methods

2.1. Biodiesel production and properties

In this study, the raw materials, Jatropa, Soybean, waste cooking oil, methanol, sodium hydroxide, and other preservative were purchased from a local supplier. The biodiesel was produced by transesterification process from the Jatropa, Soybean and waste cooking oil as shown in Fig. 1 based on the American Society of Testing and Materials (ASTM D6751) standard. The Jatropa, Soybean, and waste cooking oil of 20, 30, 40 and 50 % were used with pure diesel fuel volume based to form a blend. The properties of fuel are summarized in Table 1.

2.2. Experimental procedure

The present investigation has been performed in a single cylinder (1-C) direct injection 4-Stroke diesel engine, (TV1, Kirloskar) which was integrated with an eddy current dynamometer (air cooled). Fig. 2 shows the experimental setup which is used to conduct the experiments for this investigation. The technical specification of the test engine is shown in Table 2. The Testo 350 flue gas analyzer was coupled with a different sensor to analyze capabilities of O₂, HC, NO, CO, NO_x, CO₂ emissions from the test engine. The specification of the Testo 350 flue gas analyzer is specified in Table 3. The experiment is performed with blends of Jatropa, Soybean and Waste cooking oil biodiesel (20 %, 30 %, 40 %, and 50%) and pure diesel.

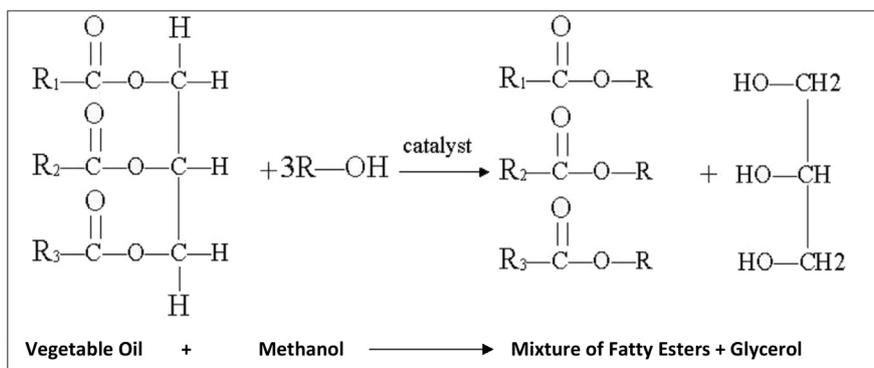


Fig. 1. Transesterification reaction.

Table 1
Physical properties of test fuels [15, 16].

Fuel properties	Diesel	Jatropa	soybean	waste cooking
LHV (MJ/kg)	42.5	41.1	37.5	37.5
Viscosity at 40 °C (mm ² /s)	3.2	4.3	4.1	2–6
Density (kg/m ³)	830	873	885–914	874.5
CN	48	54	52	63
Flash point (° C)	74	148	160	176

3. Result and discussions

3.1. BTE

The illustration of BTE for diesel and different blend at different engine loads is shown in Fig. 3. The augmentation in brake thermal efficiency or the reduction in brake specific fuel consumption with changing load is mainly because of enhanced burning, whereas reduction in BTE at high engine load is due to faulty ignition. The BTE of biodiesel blends and diesel at various loads and the compression ratio is shown in the Fig. 3 and also shows that the BTE of biodiesel blends is slightly lower as compared to standard diesel at all loading.

The Fig. 3 below shows the variation of BTE of the engine operated using B-20, B-30, B-40, B-50, and diesel at a constant speed, varying load (20–100 %) and constant CR-16.5. The addition of blends in biodiesel increases the BTE with engine load. The BTE of BJ20 i.e. 80 % diesel to 20 % Jatropa (BJ20) fuel blend gives higher efficiencies at all loading followed by 80 % diesel to 20 % Soybean (BS20) and 80 % diesel to 20 % Waste cooking oil (BWCO20). The BTE increases with load as a result of oxygen content which improved the better ignition of biodiesel.

3.2. BSFC

BSFC depends on properties of fuel. The BSFC is a measure of the effectiveness of the engine in using the fuel [11,12]. At constant speed and compression ratio the performance of biodiesel blends have shown similar tendency as that of pure diesel can be seen in Fig. 4.

The Fig. 4 shows that BSFC reduces with the load up to 80 % loading for all the blends. Amongst all the blends Jatropa blend has shown least BSFC for all the loads. BJ20 of Jatropa biodiesel has shown 0.28 kg/kWhr of fuel consumption at 80 % load which is very close to diesel fuel 0.27 kg/kWhr for 80 % load followed by Soybean 0.31 kg/kWhr and Waste cooking oil 0.32 kg/kWhr at 80 % load. The possible reason for the above behaviour may be the Jatropa biodiesel has higher calorific value as compared to other blends, and also it has low viscosity.

3.3. EGT

The Fig. 5 shows the deviation in temperature of exhaust gas with the load. It is identified that CR and temperature of exhaust gas increases



Fig. 2. Experimental test rig.

Table 2
Engine specifications.

Parameters	Values
Manufacturer	M/s Kirloskar oil engines Ltd.
Model	TV 1
Cycle	4-stroke
Rated power	3.5 kW @ 1500 rpm
Combustion system	Direct injection
Cylinders	1-C
Bore diameter	87.5
Length of Stroke	110 mm
Compression ratio (CR)	16.5 : 1
Type of cooling	Water
Fuel injection	Inline

with engine. The discrepancy of EGT for blends (B20, B30, B40, and B50) of Jatropha-Biodiesel, Soybean-Biodiesel, and Waste cooking oil-Biodiesel are shown in Fig. 5 for the constant speed of 1500 rpm and CR 16.5.

The Fig. 5 shows that as the load increases the exhaust gas temperature increases for the biodiesel blends. The exhaust gas temperature for the BJ20 blends of Jatropha, Soybean, and waste cooking oil is 373 °C, 382 °C and 384 °C respectively. The Jatropha biodiesel blends have shown that average exhaust gas temperature is 0.14 % higher than diesel. Similarly, Soybean biodiesel blends have shown an average exhaust gas temperature is 0.23 % higher than diesel, and the waste cooking oil (WCO) biodiesel blends have shown that average exhaust gas temperature is 0.24 % greater than diesel.

Table 3
Technical specification of gas analyser.

Measuring parameter	HC, CO, CO ₂ , O ₂ , NO _x			
Method of measurement	HC,CO,CO ₂ –NDIR (Non Dispersive Infrared) Method O ₂ , NO _x – Electronic Chemical Method			
Range of measurement	HC	0–15000 ppm	CO	0.000–9.999 %
Resolution		1ppm		0.001 %
Display type		Five digit FND		Four digit FND
Range of measurement	CO ₂	0–20 %	O ₂	0–25 %
Resolution		0.01 %		0.01 %
Display type		Upto Four digit		Upto Four digit
Range of measurement	NO _x	0–5000 ppm		
Resolution		1ppm (parts per million)		
Repeatability		Less Than ±2 %	O ₂	Less than = 0.2 %
Time of Response		10 seconds (More Than 90 %)		
		O ₂ –20 seconds		
Warming Up Time		About 5–10 minutes		
Rate of flow		2–4 litre per minute		
Power		Alternating current AC 90–250 V/50 Hz (hertz)		
Operating Temperature		0 °C ~ 40 °C		
Measurement		270 (Width) x 370 (Length) x 165 (Height) mm		

3.4. Carbon monoxide

The emission of CO with different fuel at different engine load is shown in Fig. 6. The CO emission pointers were attainable in the percentage units since the alternative fuels and diesel have different heat values. The CO emission is the main products of the imperfect ignition process [13]. It is seen, from Fig. 6 that CO emission reduces with increase in percentage of biodiesel in the fuel blends. The average values of CO (%) emissions with B20 are 0.0552, 0.0578, and 0.0598 for Jatropha (BJ20), Soybean (BS20), and (BWCO20) respectively and for B50 these values are 0.0518, 0.0536, and 0.0546 for Jatropha (BJ50), Soybean

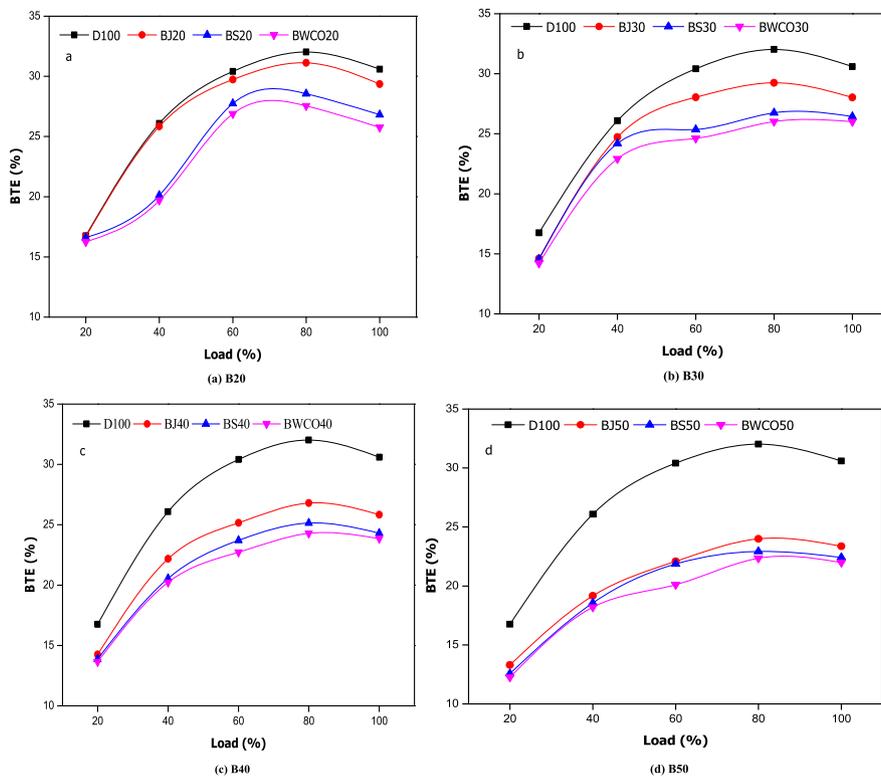


Fig. 3. BTE with Engine Load a) B20, b) B30, c) B40 and d) B50.

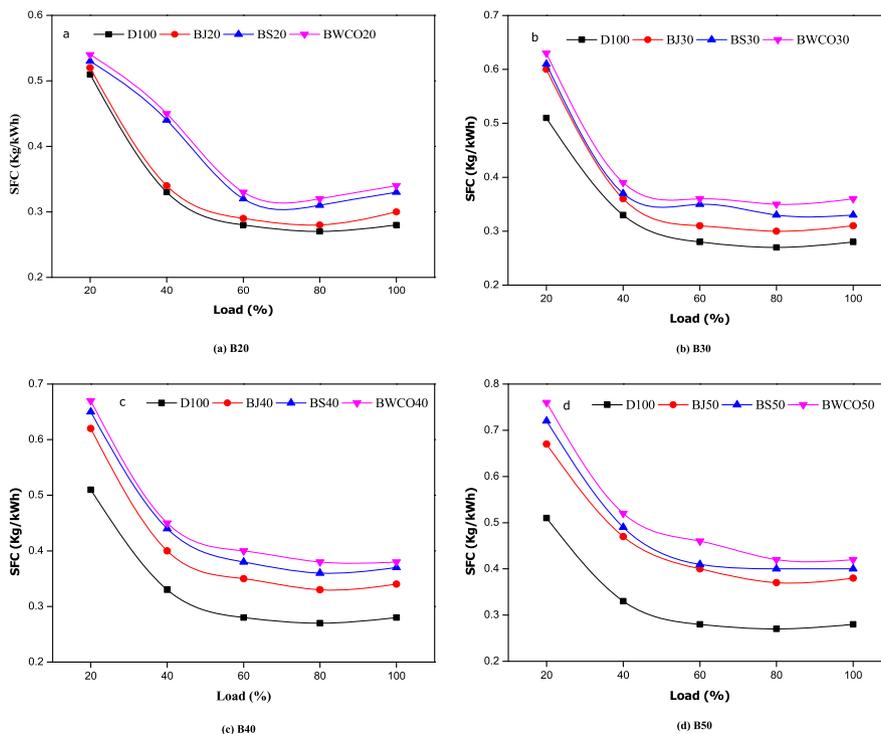


Fig. 4. SFC at Engine Load a) B20, b) B30, c) B40 and d) B50.

(BS50), (BWCO50) respectively, which are lower as compared to diesel fuel emission. This is because, at higher temperature, the engine performance gets superior with improved burning of fuel which results in reduction of CO emission for biodiesel blends. However, further loading leads to the development of more smoke and this smoke restricted the oxidation of CO into CO₂ which suddenly increases the CO emissions.

3.5. Unburned hydrocarbon (UBHC)

The reduction of HC emissions belongs to an alternative fuels blend which has a higher oxygen content, which leads to complete burning process. The Fig. 7 below shows a reduction in HC emission because of greater number of cetane value for alternative fuels.

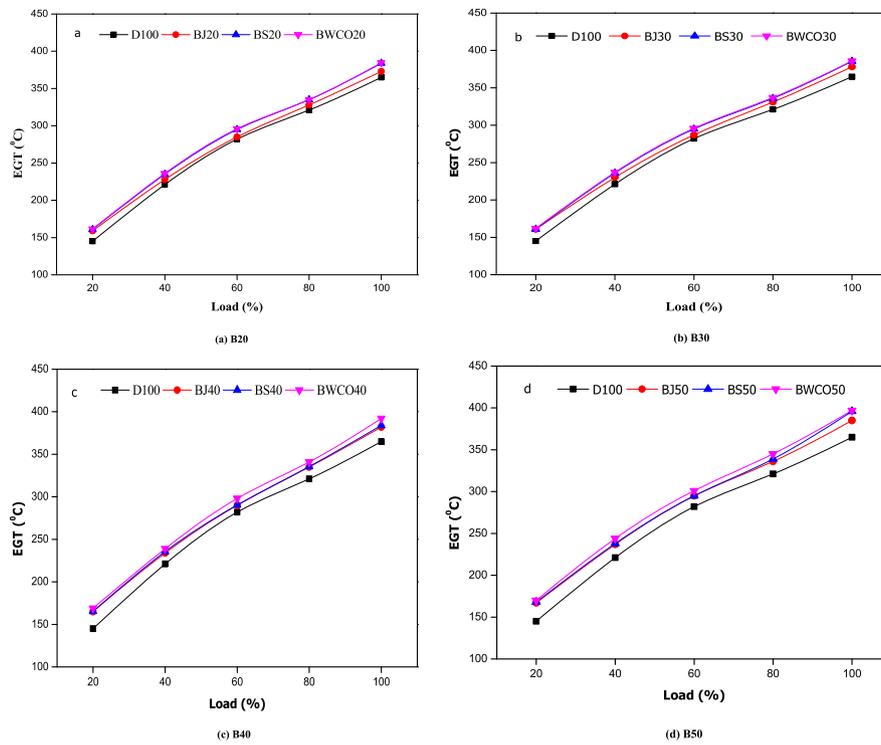


Fig. 5. SFC at Engine Load a) B20, b) B30, c) B40 and d) B50.

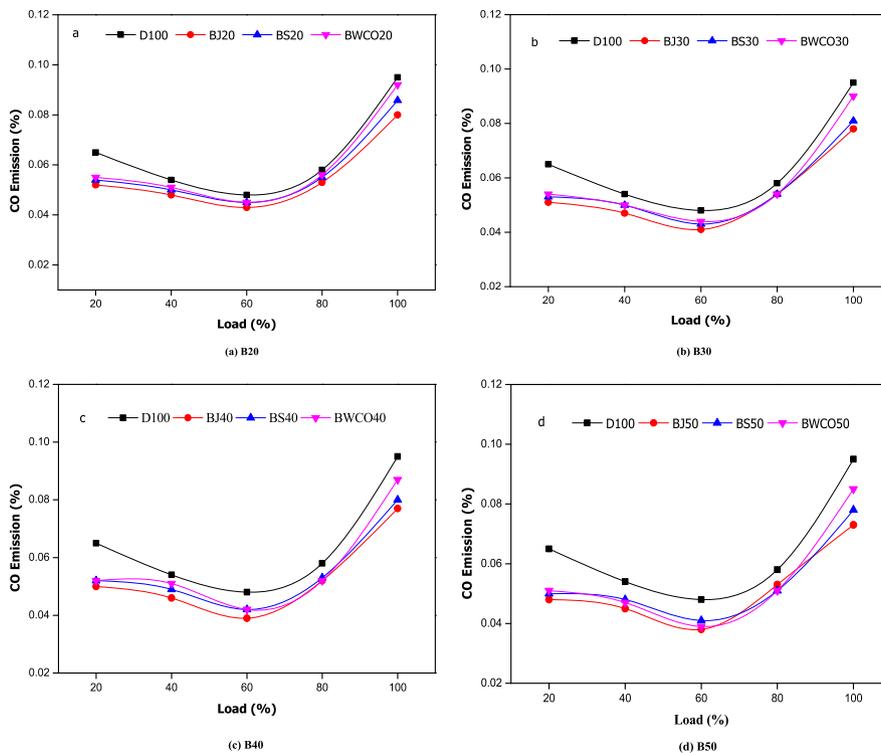


Fig. 6. CO Emission at Engine Load a) B20, b) B30, c) B40 and d) B50.

The unburned fuel components present in the exhaust of an engine consists of UBHC emission. The incomplete combustion of fuel molecules leads to emissions of unburned hydrocarbon (UBHC). The primary cause of UBHC emission is the non-homogeneity of the fuel-air mixture. The investigation of UBHC emissions is very important because they add to photochemical smog. The UBHC emissions with varying load is shown in

the Fig. 7. The increase in load increases UBHC emissions because of the fuel-rich blend at higher loads. The UBHC emissions of biodiesel blend is found lesser than diesel fuel which is due to complete ignition of the fuel at all ratios of compression.

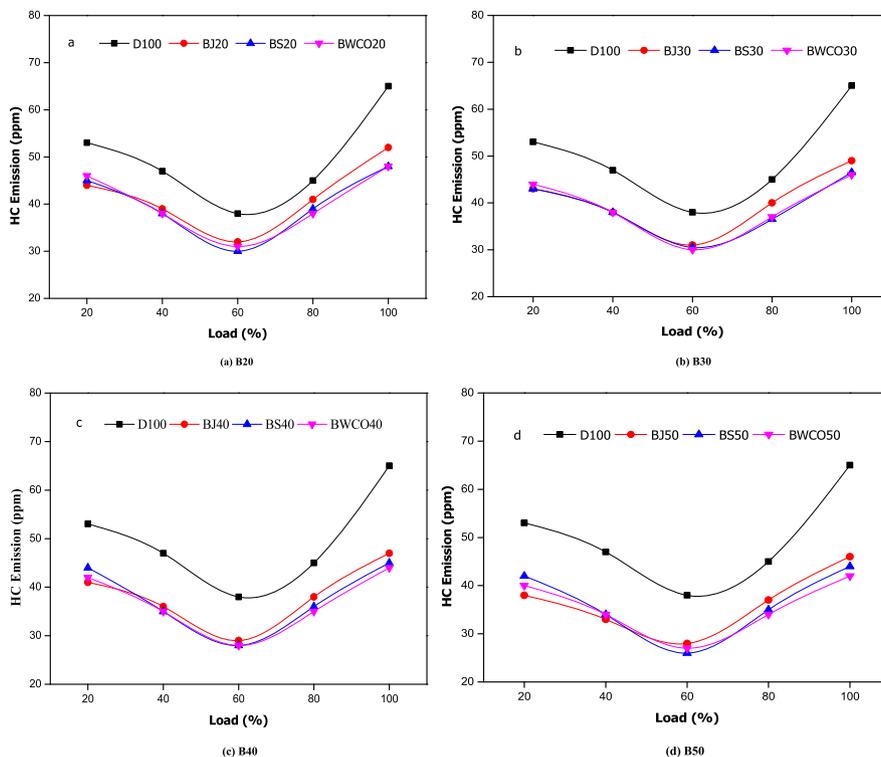


Fig. 7. Unburned hydrocarbons at Engine Load a) B20, b) B30, c) B40 and d) B50.

3.6. Nitrogen oxides

The NO_x emission is greater due to the higher temperature in CI engines. The variation of NO_x emissions at varying load is shown in Fig. 8. It observed that there is a significant increase in NO_x emissions

with loads for all biodiesel blends compared to diesel. The blend B20 of all the biodiesel showed lower NO_x than that of B50 for the CR-16.5 at all loads. The Fig. 8 shows that NO_x emission increases with an increase in biodiesel proportion in diesel fuel. The temperature of cylinder increases due to the increase in the oxygen content. The readily available oxygen at

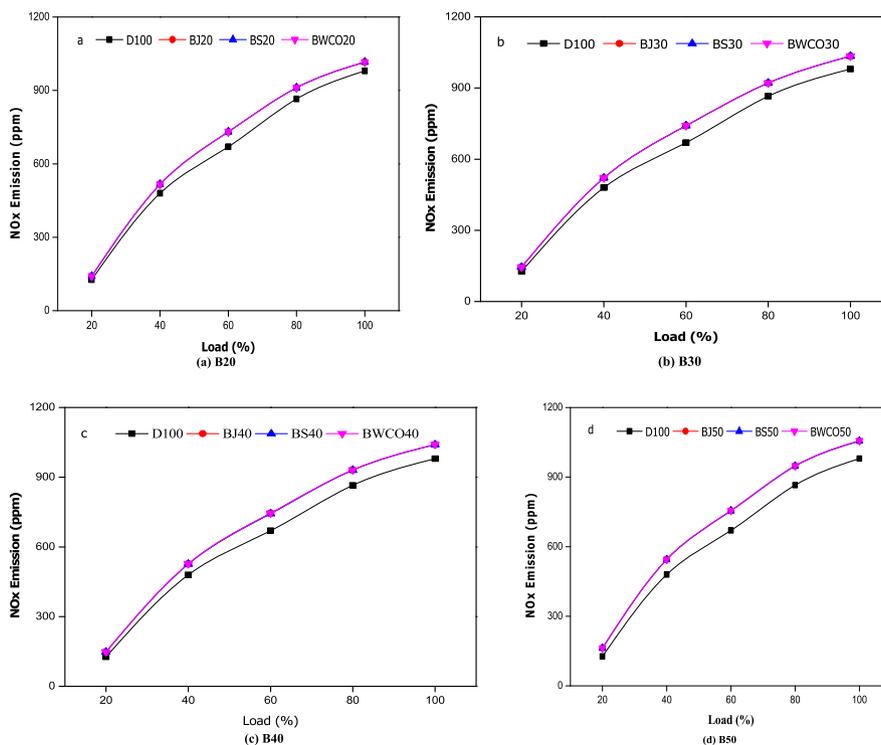


Fig. 8. Nitrogen oxides at engine load (a) B20 (b) B30 (c) B40 (d) B50.

a higher temperature will lead to more NO_x .

4. Conclusions

In the present study following conclusion is drawn:

- A performance test on the variable compression ratio (VCR) test rig is carried out at different compression ratios (16.5). Biodiesel blends B00, B20, B30, B40, and B50 have been tested for Soybean, waste cooking oil and Jatropha.
- The B20 blends of all biodiesel have shown very close values of BTE at all load conditions than that of the diesel fuel. The BTE of biodiesel blends is slightly lower than standard diesel at all loads.
- At constant speed and compression ratio biodiesel blends have shown similar performance as that of pure diesel. Amongst all the blends Jatropha blend have shown least BSFC at all the loads. BJ20 of Jatropha biodiesel has shown BSFC very close to diesel fuel followed by soybean and waste cooking oil for the same load conditions.
- The diesel fuel shows lower exhaust gas temperature as compared to all the biodiesel blends at all loads because of higher oxygen mixture in the biodiesel blends compared to diesel fuel which leads to total combustion.
- The emission CO decreases with load till 80 % then it sharply increases for all the biodiesel blends.
- The Jatropha BJ20 has the lowest NO_x emissions followed by Soybean BS20 and waste cooking oil BWC20. Whereas the BWC50 of waste cooking oil has shown more NO_x emission at the maximum load condition.

Declarations

Author contribution statement

Prem Chaurasiya: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sanjay Singh, Rashmi Dwivedi & RaviShankar Choudri: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors would like thanks Sagar Institute of Science and Technology Gandhi Nagar Bhopal for providing facilities for this research.

References

- [1] Ertan Alptekin, Emission, injection and combustion characteristics of biodiesel and oxygenated fuel blend in a common rail diesel engine, *Energy* 119 (2017) 44–52.
- [2] B. Ashok, K. Nanthagopal, A.K. Jeevanantham, Pathikrit Bhowmick, Dhruv Malhotra, Pranjali Agarwal, An assessment of Calophyllum inophyllum biodiesel fuelled diesel engine characteristics using novel antioxidant additives, *Energy Convers. Manag.* 148 (2017) 935–943.
- [3] Hasan Bayindir, Mehmet Zerrakki Isik, Zeki Argunhan, Halit Lutfu Yucel, Huseyin Aydin, Combustion, performance and emissions of a diesel power generator fueled with biodiesel-kerosene and biodiesel-kerosene-diesel blends, *Energy* 123 (2017) 241–251.
- [4] Yage Di, C.S. Cheung, Zuohua Huang, Comparison of the effect of biodiesel-diesel and ethanol-diesel on the gaseous emission of a direct-injection diesel engine, *Atmos. Environ.* 43 (17) (2009) 2721–2730.
- [5] Osama Ahmed Elsanusi, Murari Mohon Roy, Manpreet Singh Sidhu, Experimental investigation on a diesel engine fueled by diesel-biodiesel blends and their emulsions at various engine operating conditions, *Appl. Energy* 203 (2017) 582–593.
- [6] Seyyed Hassan Hosseini, Ahmad Taghizadeh-Alisaraei, Barat Ghobadian, Ahmad Abbaszadeh-Mayvan, Performance and emission characteristics of a CI engine fuelled with carbon nanotubes and diesel-biodiesel blends, *Renew. Energy* 111 (2017) 201–213.
- [7] Upendra Rajak, Tikendra Nath Verma, Effect of emission from ethylic biodiesel of edible and non-edible vegetable oil, animal fats, waste oil and alcohol in CI engine, *Energy Convers. Manag.* 166 (2018) [704]–[718].
- [8] Upendra Rajak, Prerana Nashine, Tikendra Nath Verma, Assessment of diesel engine performance using spirulina microalgae biodiesel, *Energy* 166 (2019) 1025–1036.
- [9] Shrivastava, Pankaj, and Tikendra Nath Verma. Chapter-6 experimental investigation of performance and emission of lal ambari biodiesel and its blends in a compression ignition engine, *Adv. Eng. Technol.*: 95.
- [10] Murari Mohon Roy, Jorge Calder, Wilson Wang, Arvind Mangad, Fernando Cezar Mariano Diniz, Cold start idle emissions from a modern Tier-4 turbo-charged diesel engine fueled with diesel-biodiesel, diesel-biodiesel-ethanol, and diesel-biodiesel-diethyl ether blends, *Appl. Energy* 180 (2016) 52–65.
- [11] Jorge Calder, Murari Mohon Roy, Wilson Wang, Performance and emissions of a diesel engine fueled by biodiesel-diesel blends with recycled expanded polystyrene and fuel stabilizing additive, *Energy* 149 (2018) 204–212.
- [12] H. Tse, C.W. Leung, C.S. Cheung, Investigation on the combustion characteristics and particulate emissions from a diesel engine fueled with diesel-biodiesel-ethanol blends, *Energy* 83 (2015) 343–350.
- [13] Gokhan Tuccar, Tayfun Ozgur, Kadir Aydin, Effect of diesel–microalgae biodiesel–butanol blends on performance and emissions of diesel engine, *Fuel* 132 (2014) 47–52.
- [14] L. Wei, C.S. Cheung, Z. Ning, Influence of waste cooking oil biodiesel on combustion, unregulated gaseous emissions and particulate emissions of a directinjection diesel engine, *Energy* 127 (2017) 175–185.
- [15] Parvaneh Zareh, Ali Asghar Zare, Barat Ghobadian, Comparative assessment of performance and emission characteristics of castor, coconut and waste cooking based biodiesel as fuel in a diesel engine, *Energy* 139 (2017) 883–894.
- [16] Upendra Rajak, Tikendra Nath Verma, Comparative assessment of the emission characteristics of first, second and third generation biodiesels as fuel in a diesel engine, *J. Therm. Eng.* (2018). Article in press, <http://www.eds.yildiz.edu.tr/journal-of-thermal-engineering/ArticleInPress>.