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Experimental investigation to optimize fuel injection strategies and compression ratio on single cylinder DI diesel engine operated with FOME biodiesel

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A B S T R A C T

The present experimental investigation is devoted to optimize the nozzle geometry and compression ratio on single cylinder DI diesel engine fuelled with Fish Oil Methyl Ester (FOME) biodiesel. The FOME biodiesel with 20%, 40%, 60% and 80% are blended with diesel. The experiments have been conducted at three compression ratios 16.5:1, 17.5:1 and 18.5:1 at 240 bar and 260 bar IOP (Injection Opening Pressure) with 3 holes and 4 holes fuel injectors having 0.20 mm and 0.25 mm orifice diameter respectively. And these results are compared with pure diesel. The experimental results showed that the biodiesel blends have slightly lesser brake thermal efficiency and reduced smoke emissions in contrast to pure diesel. The blend B40D60 gives better results in comparison to all other blends with respect to brake thermal efficiency (BTE) and smoke emissions at compression ratio (CR) 17.5:1 and 4 hole fuel injector having 0.25 mm diameter at 260 bar IOP. Hence this is the optimized blend operating condition for improved brake thermal efficiency (27.15%) of FOME biodiesel with reduced smoke (14.34 HSU) emissions.

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1. Introduction

Globally the energy demand is more. Because of soaring prices and depleting fossil fuel sources biodiesels have got great attention as a promising and replaceable source for diesel because they have benefits like: superior combustion efficiency; cetane number is higher, highly biodegradable and less polluting characteristics.

As depicted by Parag Saxena et al. [1] to predict the different biodiesel and its blends properties it is necessary to prepare an experimental model; because there is lack of information about many significant properties of biodiesel due to least availability of experimental data regarding different thermodynamic properties of the feed oils.

The research work of S. Savariraj et al. [2] reveal that in India lot of researches have been done on producing biodiesels from polanga, mahua, karanja, jatropa, waste cooking oil, fish oil, algae etc. As stated by A.M. Liaquat et al. [3] the WFO biodiesel in comparison to diesel follow smaller heat release rate period along with greater in-cylinder pressure. And by using biodiesel and its blends without any big cycle to cycle changes highly steady burning could be achieved. S. Imtenana et al. [4] investigated that Ethanol could be a reliable and renewable substitute fuel source because it has hydroxyl group and hence it reduces the emission of particulate in CI engine. As stated by Madan Mohan Avulupati et al. [5] in contrast to diesel for blends BP and torque decrease and BSFC value will be higher. Due to greater availability of oxygen content there will be minimum emission of HC, CO and CO_2. Also for lesser C.V the NO emission reduced and for the additives the latent heat of evaporation is greater. R. Payri et al. [6] has investigated that the performance of engine may be greatly affected by the hole diameter of injector nozzle for every diesel engine, which is highly responding and limiting parameter. To have higher injection pressure with negligible loss due to increased number of injector hole will be the major aim in the design of injector for all diesel engines. As investigated by Shivaraj Harichandra et al. [7] and N.R. Banapurmath et al. [8] in comparison to diesel the performance reduces and emission characteristics are lowered for biodiesel because of higher viscosity, lower C.V and delayed combustion process. At full engine load HC & smoke are greatly reduced for combusted biodiesel blends but because of lower heating value the BSFC is greater. The WFO (Waste Fish Oil) blends have emissions of CO and CO_2

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Abbreviations

WFO	Waste Fish Oil
CI	Compression Ignition
BP	Brake Power
BSFC	Brake Specific Fuel Consumption
HC	Hydrocarbons
CO	Carbon Monoxide
CO_2	Carbon Dioxide
C.V	Calorific Value
NO	Nitrous Oxide
NOx	Nitrogen Oxide
VCR	Variable Compression Ratio
FFA	Free Fatty Acid
IC	Internal Combustion
SFC	Specific Fuel Consumption
EGR	Exhaust Gas Recirculation
CRDI	Common Rail Direct Injection

closer to diesel.

The investigations by V. Hariram et al. [9] reveal that on reducing the CR; there was an increase in BSFC and ignition delay period but peak cylinder pressure reduced. Whereas, on increasing CR the peak heat release rate was closer to TDC. Mohammed El-Adawy et al. [10] investigated that for the blend the engine performance obtained will be higher at higher CR. Y. Barakat et al. [11] has said that there is a linear relation between ethanol concentration and fuel consumption. Ashok Kumar Yadav et al. [12] depicts that at CR 18 for KOME-Diesel blends there were lower values of opacity and higher values of BTE in comparison to pure diesel. K.A. Abed et al. [13] said that in comparison to diesel for biodiesel the HC, CO emissions and smoke opacity were lower. Puneet Verma et al. [14] said that with the use of biodiesel the engine emission characteristics will improve. Jayashri N. Nair et al. [15] said that the BTE is higher for Neem biodiesel blends than diesel. S. Nagaraja et al. [16] depicts that for maximum load with increase in CR and blending ratio there is a drop in the CO, HC emissions. According to Noora Salih Ekaab et al. [17] in contrast to diesel the biokerosene has lower thermal efficiency and exhaust gas temperatures. Also, CO, HC and PM emissions are lower but NOx emission increases at low and medium operating loads for biokerosene. M. Vijay Kumar et al. [18] depicts that the quality of biodiesel can be improved by using the additives like; metallic, antioxidant, oxygenated, cetane number additives, which will improve biodiesel combustion performance with reduced emission. M.R. Noor El-Din et al. [19] depicts that in comparison to diesel the water diesel emulsions have lower SFC at 1 kW load also lowest CO, NOx and HC emissions is achieved. A. Prabu et al. [20] and A. Praveen et al. [21] experimentally investigated that the dispersed nanoparticles in the test fuel play a significant role in improving the engine BTE and reducing the emissions like NO, CO, HC & smoke in contract to 100% biodiesel. The research work of Nitin M. Sakharea et al. [22] reveals that the biodiesel having higher cetane number has decreased ignition delay in contrast to pure diesel. As well, because of lower C.V the BSFC of biodiesel increased. K.A. Abed et al. [23] depicted that the B10 and B20 biodiesel mixtures (Algae, palm and jatropha) have lower emissions of smoke, CO, CO_2 and HC in comparison to base diesel. K. Sivaramakrishnan et al. [24] investigated that for biodiesel blends the BTE increases with increasing CR. Also for increased CR the SFC decreased. The investigation made by Mohammed El-Adawy et al. [25] reveals that the blend gives higher performance at the CR of the engine. Also the engine brake thermal efficiency increases significantly with higher brake power. Senthil Ramalingam et al. [26] investigated that the combined effect of increase in injection timing and CR will increase the brake thermal efficiency and SFC is reduced with emissions lowered.

From the above literature survey we understand that the minimum work was carried out on the VCR engine with FOME biodiesel, nozzle geometry and variation of compression ratio, hence in the current work optimization of nozzle geometry and CR was carried in computerized VCR engine using FOME as biodiesel fuel.

2. Characterization of fuel

In the experiments Fish Oil Methyl Ester (FOME) is used as a test fuel. As stated by K. Kara et al. [27] the greater content of FFAs from fish oil may be reduced by rational purification method involving two stages viz. Esterfication and transesterification acid base from which the biodiesel percentage of methyl ester content present in the biodiesel sample extracted from the WFO. The test fuel properties like fire point, flash point, viscosity, density and C. Vs are found using instruments listed in Table 1. In this different blends of Fish Oil Methyl Ester (FOME) used for different operating conditions like, CR of 16.5:1, 17.5:1 and 18.5:1, blends like B20D80, B40D60, B60D40, and B80D20 shown in Fig. 1.

3. Experimental setup

The conduction of experiments was carried out on a Kirloskar TV1 type, single cylinder, 4 stroke, water cooled DI diesel engine operating on FOME.

Performance and emissions characteristics are studied on each blend. The BTE variation with reference to performance characteristics and smoke with reference to emission characteristics are studied.

The experimental setup used in the study shown in Fig. 2 is having technical specifications given in Table 2.

3.1. Fuel injector

The fuel injectors which are used in this study are shown in Fig. 3. The specifications are in Table 3.

3.2. Smoke meter

The MARS smoke meter SM-05 measures the opacity of exhaust gases produced by diesel engines shown in Fig. 4. Has technical specifications given in Table 4.

3.3. Experimental procedure

For conducting the experiments initially the fuel properties like fire point, flash point, viscosity and density are determined. The fuels FOME–diesel are mixed with different percentage of composition for preparing the testing fuel with continuous stirring then it is poured in fuel tank of diesel engine. The engine is started with electrical starter and load is applied 2–3 min waiting. Check the connections of computerized data acquisition system with engine and smoke meter software. Repeat the experiments for above said different blends at different load conditions. On the basis of experimental data collected from system software and drawings with necessary graphs identify the optimized bio-diesel with minimum emissions. Finally come to the conclusion to suggest the optimized best blend with highest thermal efficiency and lower emissions characteristics.

The mathematical relation b/w Brake Thermal Efficiency and Mechanical Efficiency,

Table 1
Diesel and FOME biodiesel properties.

Sl. No	Properties	Diesel	FOME biodiesel	Apparatus used
1)	Density (kg/m^3)	825	898.3	Redwood viscometer
2)	Kinematic Viscosity (centistokes)	2.52	4.18	Redwood viscometer
3)	Calorific Value (kJ/kg)	45,843	39,500	Bomb calorimeter
4)	Flash Point (°C)	55	172	Cleveland apparatus
6)	Fire Point (°C)	58	185	Cleveland apparatus

Fig. 1. Blends of Biodiesel and diesel.

Fig. 2. Experimental setup.

$\eta_{bth} = (\eta_{mech} \times 3600 \times IP)/(M_{fc} \times C_v) \ldots \ldots \ldots \%$
M_{fc}-Mass of Fuel Consumption, IP -Indicated Power
η_{bth}- Brake Thermal Efficiency, ηmech- Mech. Efficiency.

4. Results and discussions

The performance and emission characteristics variation with different blends used in experiments are discussed in detail below.

4.1. Optimization of injection parameters at CR 16.5:1

4.1.1. Variation of Brake Thermal Efficiency with load

The Fig. 5 depicts that diesel fuel showed higher BTE than biodiesel blend fuels in diesel engine due to higher calorific value of mineral diesel fuel. And due to higher presence of both density and viscosity of biodiesel fuel leads to lower the BTE of diesel engine. However, B40 blend has showed higher BTE as compared to B20, B60 and B80. This is because; there is a proper atomization in the B40 blend of biodiesel fuel to get higher BTE. The research work by Bhaskar Kathirvelu et al. [28] showed diesel fuel has given higher BTE than biodiesel blends at all loading conditions due to lower calorific value and greater specific energy consumption of blended biodiesel fuel.

4.1.2. Variation of Smoke with load

The Fig. 6 depicts that the fish oil blends produced higher smoke density as load increased. Greater viscosity of fish oil causes poor air-fuel mixing and vaporization which causes incomplete combustion and hence greater smoke density. The blend B40 has less smoke emission compared with other blends. According to Perowansa Paruka et al. [29] and S. Senthilkumar et al.[30] the lesser emission characteristics of biodiesel is because of its effective combustion even after having lower C.V and higher cetane number.

4.1.3. Variation of Brake Thermal Efficiency with load

Fig. 7 depicts that with increasing loading conditions the BTE increased for diesel. And diesel has more BTE than all biodiesel blends. But. B40D60 blend leads to better BTE in comparison to all blends. In addition to this at the pressure of about 240 bar the atomization of fuel takes place which exposes more surface area of fuel particles for combustion. The IOP can be increased by fuel injection technique to increase the BTE and reduce emissions.

4.1.4. Variation of Smoke with load

The Fig. 8 depicts that the fish oil blends produced higher smoke density as load increased. As stated by Bhaskar Kathirvelu et al. [28] the fuels properties with higher density and kinematic viscosity will affect the atomization and volatilization process attributing in greater smoke value.

4.1.5. Variation of Brake Thermal Efficiency with load

The Fig. 9 depicts that B40D60 blend leads to improved brake thermal efficiency compared to all blends. But as depicted by

Table 2
Technical specification of engine.

S.No.	Engine	Specifications
1	Engine Type	Single Cylinder, 4 stroke DI Diesel Engine,
2	Rated Power	5.2KW@1500rpm
3	Cylinder Dia.	87.5 mm
4	Stroke Length	110 mm
5	Connecting Rod Length	234 mm
6	Compression Ratio	12 to 18.5
7	Orifice Dia.	20 mm
8	Dynamometer Arm Length	185 mm
9	Software	“Engine soft LV” Engine performance analysis software
10	Load Indicator	Range 0–50 Kg, Digital, 230 V AC Supply
11	Load Sensor	Load cell, Strain gauge type, 0–50 Kg range

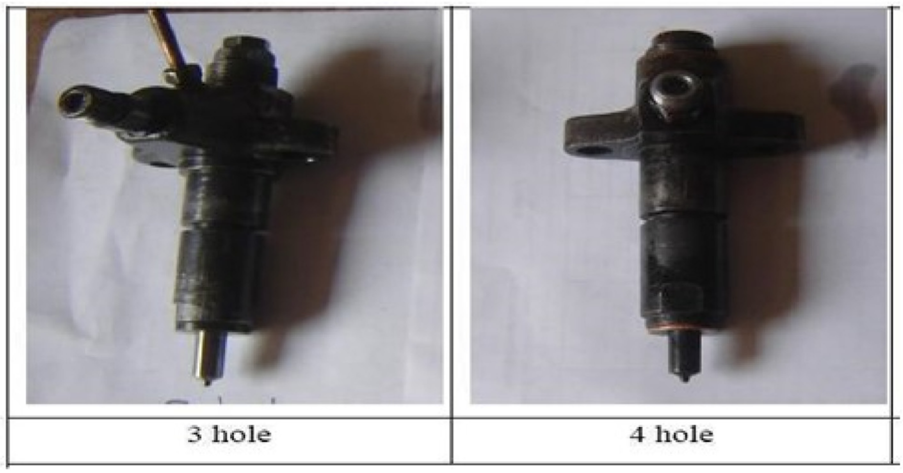

Fig. 3. Fuel injectors with 3, 4 nozzle holes.

Table 3
Specifications of fuel injectors used.

S.No.	Number of Holes	Orifice diameter in mm
1	3 hole orifice	0.20 mm
2	4 hole orifice	0.25 mm

Fig. 4. Smoke meter.

Table 4
Technical specifications of smoke meter.

S. No.	Smoke Meter SM-05	Specification
1	Light Source	Green LED of 5 mm dia.
2	Detector	Photocell
3	Measuring Range	HSU = 99.9%, k = 9.99
4	Resolution	0.1/m
5	Linearity	0.1/m
6	Drift	Span:0.1/m, Zero:0.1/m
7	Response time	<0.3 s
8	Engine Temperature	2 sources ranging from 0 to 150 °C (±1 °C)
9	Supply Voltage	140–240 V, 50 Hz
10	Make	MARS Technologies Inc.

Bhaskar Kathirvelu et al. [28] diesel has more brake thermal efficiency than all blends because the rate of heat release will be more due to increasing fuel accumulation at the time of lengthy delay period.

4.1.6. Variation of Smoke with load

The Fig. 10 depicts that the fish oil blends produced higher

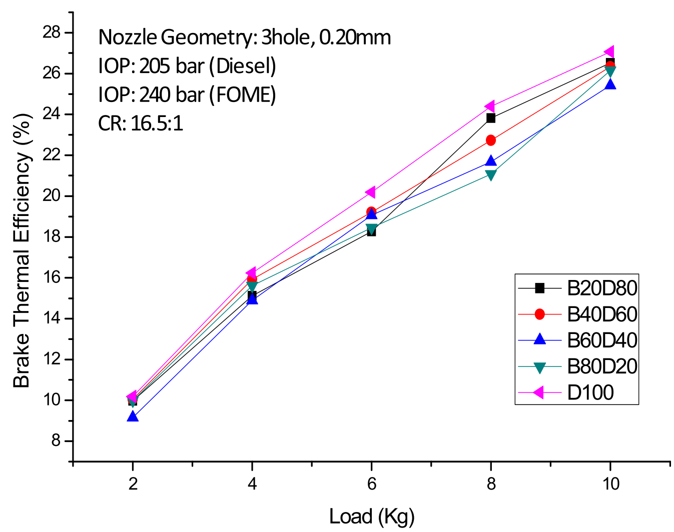

Fig. 5. Variation of brake thermal efficiency with load.

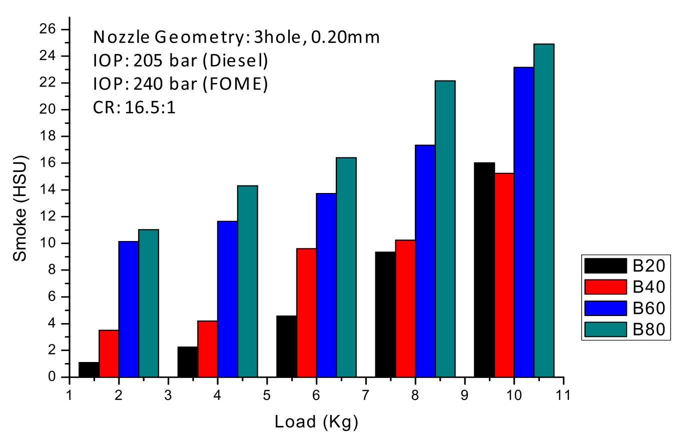

Fig. 6. Variation of smoke with load.

smoke density as load increased. Greater viscosity of fish oil causes poor air-fuel mixing and vaporization which causes incomplete combustion and hence greater smoke density. As said by K. Bhaskar

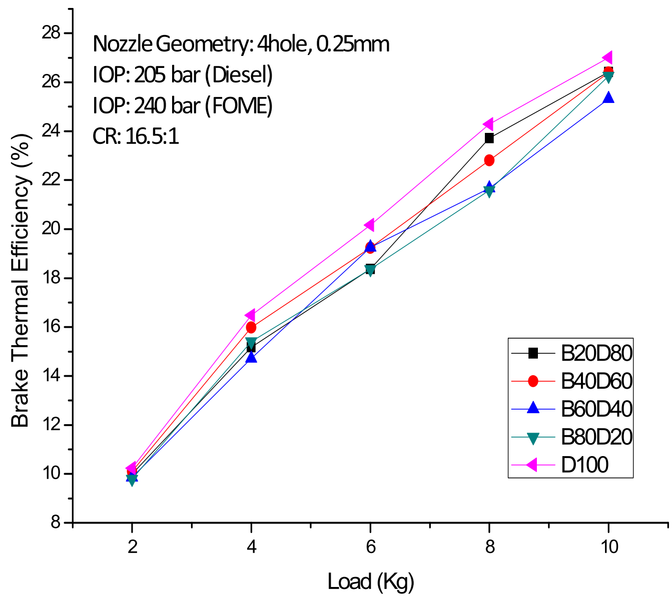

Fig. 7. Variation of brake thermal efficiency with load.

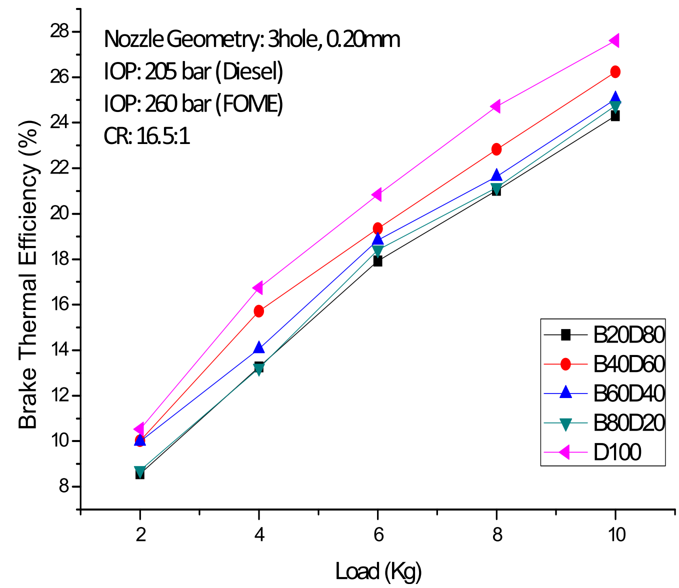

Fig. 9. Variation of brake thermal efficiency with load.

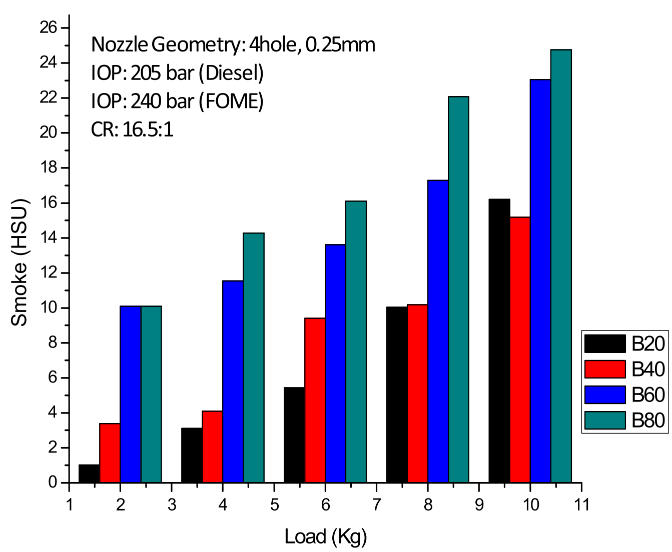

Fig. 8. Variation of smoke with load.

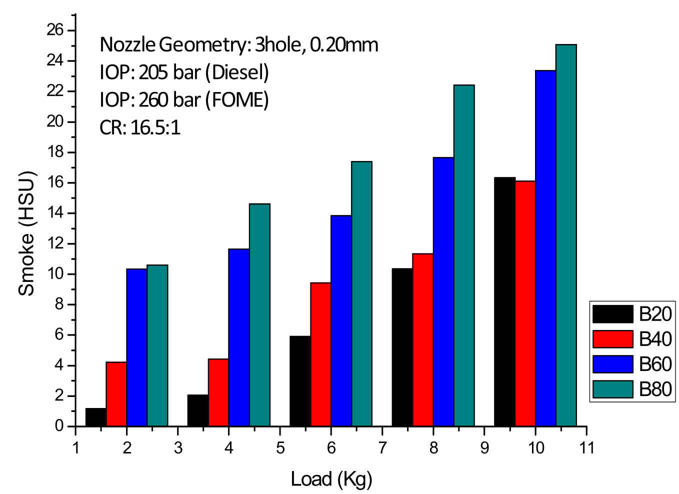

Fig. 10. Variation of smoke with load.

et al. [31] blend B40 exhibits less smoke emission compared with diesel and other blends because of its greater cetane index and greater content of oxygen availability attributes in effective combustion.

4.1.7. Variation of Brake Thermal Efficiency with load

The Fig. 11 depicts that B40D60 blend leads to enhanced BTE in comparison to all blends. For biodiesels during the expansion stroke burning of fractions of lengthy series of fatty acids will be delayed also heat taken away by exhausted gases is enhanced. Due to this for a specified power output the fuel consumption increases and brake thermal efficiency decreases as said by Bhaskar Kathirvelu et al. [28].

4.1.8. Variation of Smoke with load

The Fig. 12 depicts that the blend B40D60 has less smoke emission compared with other blends. As depicted by Ravi Kiran et al. [32] Greater viscosity of fish oil causes poor air-fuel mixing and vaporization which causes incomplete combustion and hence greater smoke density. Using higher content of biodiesel blends could increase emission. The blend B40 has less smoke emission compared with other blends.

4.2. Optimization of injection parameters at CR 17.5:1

4.2.1. Variation of Brake Thermal Efficiency with load

The Fig. 13 depicts that B40D60 blend leads to enhanced BTE in comparison to all blends. But diesel has more brake thermal efficiency than all blends. Bhaskar Kathirvelu et al. [28] said that in comparison to diesel, for biodiesel blends the power input given by (C.V $\times$ fuel mass flow rate) would be higher hence for biodiesels lesser BTE.

4.2.2. Variation of Smoke with load

From the Fig. 14 depicts that at the smoke emission increased with increasing load for biodiesel fuel. This is because the fuel properties with higher density and kinematic viscosity will affect

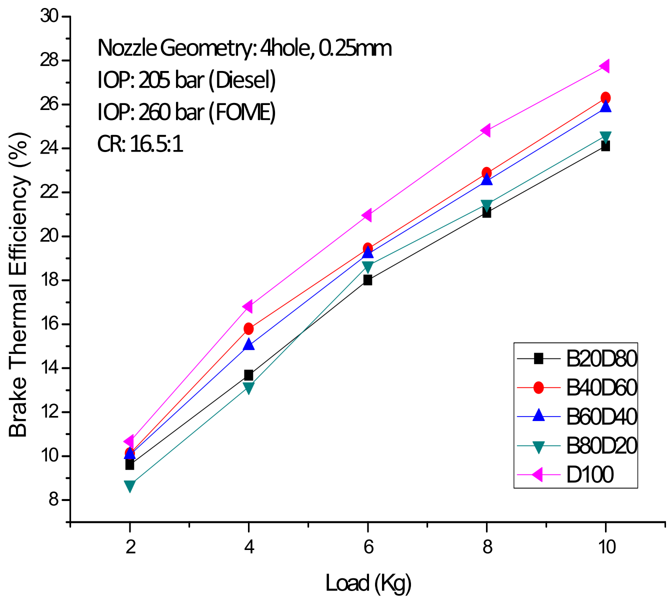

Fig. 11. Variation of brake thermal efficiency with load.

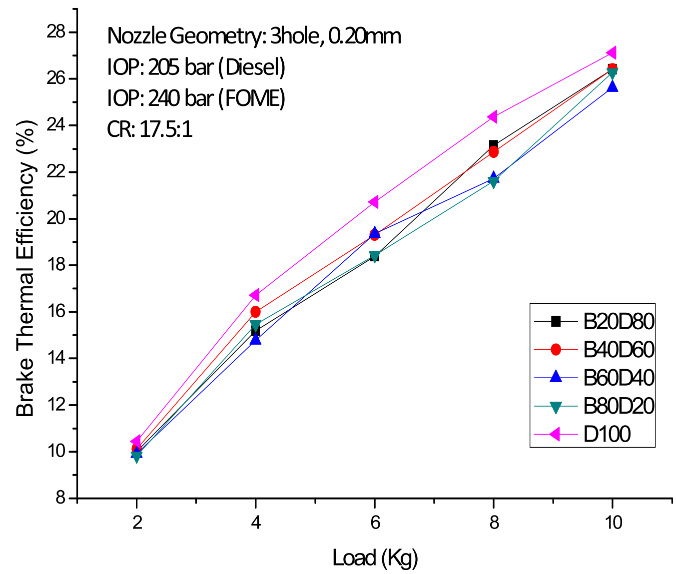

Fig. 13. Variation of brake thermal efficiency with load.

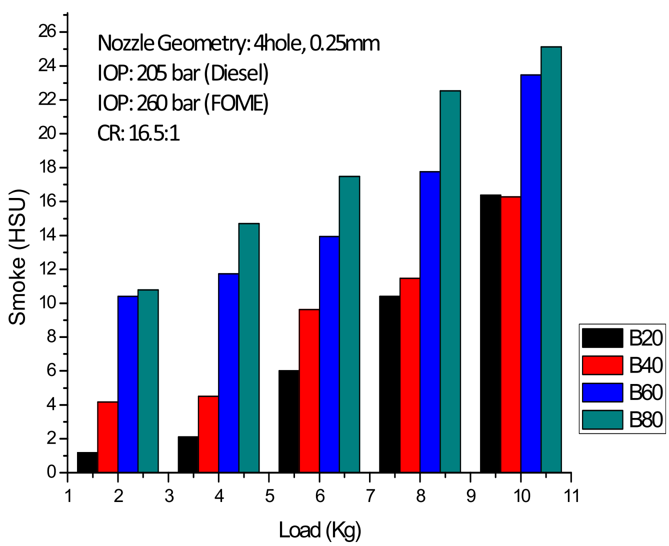

Fig. 12. Variation of smoke with load.

the atomization and volatilization process attributing in greater smoke value. However, the blend B40 has lesser smoke density in comparison to other blends.

4.2.3. Variation of Brake Thermal Efficiency with load

The Fig. 15 depicts that in comparison to all blends B40D60 blend leads to enhanced BTE as a result of reduced heat loss with increasing load. But as compared to all blends the diesel has more BTE. Other than this at the pressure of about 240 bar the atomization of fuel takes place which exposes more surface area of fuel particles the combustion.

4.2.4. Variation of Smoke with load

From the Fig. 16 it is observed that the fish oil blends produced higher smoke density as load increased. Greater viscosity of fish oil causes poor air-fuel mixing and vaporization which causes incomplete combustion and hence greater smoke density. The blend B40 has less smoke emission compared with other blends.

4.2.5. Variation of Brake Thermal Efficiency with load

The Fig. 17 depicts that in comparison to all blends B40D60 blend leads to enhanced BTE. In comparison to other blends, for B40D60 biodiesel blend the lesser BTE attained may be because of increased consumption of fuel and reduced C.V as depicted by Bhaskar Kathirvelu et al. [28].

4.2.6. Variation of Smoke with load

From the Fig. 18 it is observed that the fish oil blends produced higher smoke density as load increased. As said by K. Bhaskar et al. [31] blend B40 exhibits less smoke emission compared with diesel and other blends because of its greater cetane index and greater content of oxygen availability attributes in effective combustion. The blend B40 has less smoke emission compared with other blends.

4.2.7. Variation of Brake Thermal Efficiency with load

The Fig. 19 it is found that as said by K. Bhaskar et al. [31] as the engine operates at fixed injection timing the diesel has more brake thermal efficiency than all blends. The ignition delay period for blends of methyl ester is always very small, hence, before reaching TDC the combustion process will begin. Hence the engine will have reduced BTE and increased compression work.

4.2.8. Variation of Smoke with load

From the Fig. 20 it is observed that the fish oil blends produced higher smoke density as load increased. Greater viscosity of fish oil causes poor air-fuel mixing and vaporization which causes incomplete combustion and hence greater smoke density. The blend B40 has less smoke emission compared with other blends.

4.3. Optimization of injection parameters at CR 18.5:1

4.3.1. Variation of brake thermal efficiency with load

Fig. 21 depicts that in comparison to all blends B40D60 blend leads to enhanced BTE. But as depicted by K. Bhaskar et al. [31] diesel has more brake thermal efficiency than all blends it could be because for methyl ester blends well bTDC the heat release process initiated, which cause noticeable variation in contrast to ideal cycle,

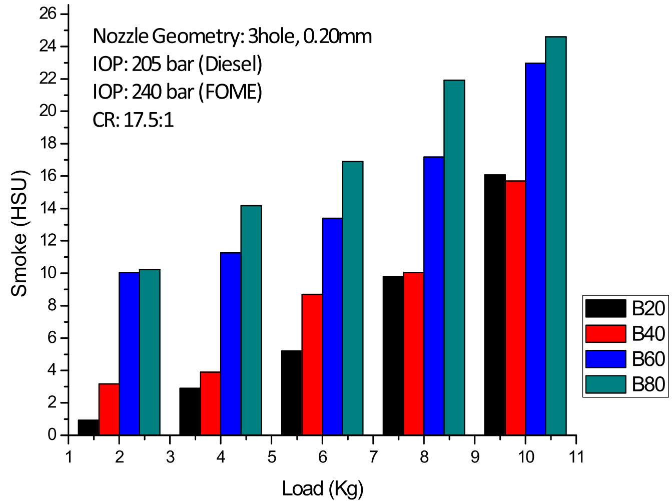

Fig. 14. Variation of smoke with load.

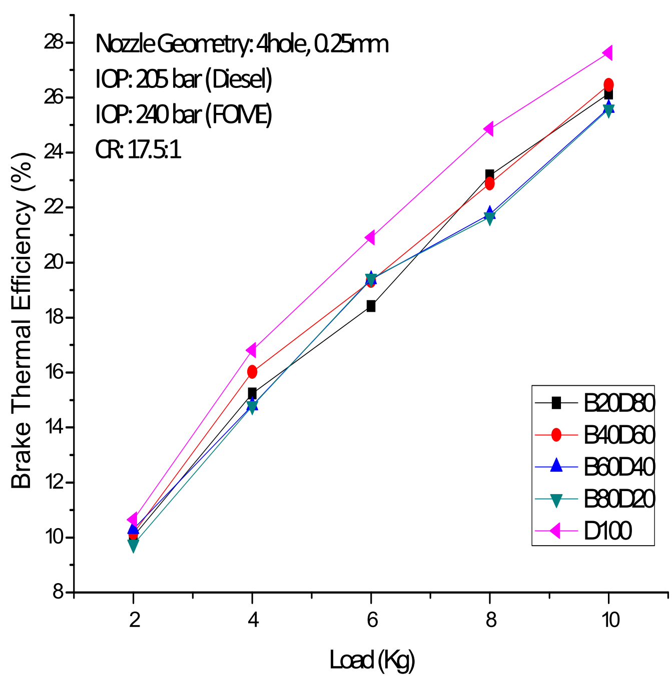

Fig. 15. Variation of brake thermal efficiency with load.

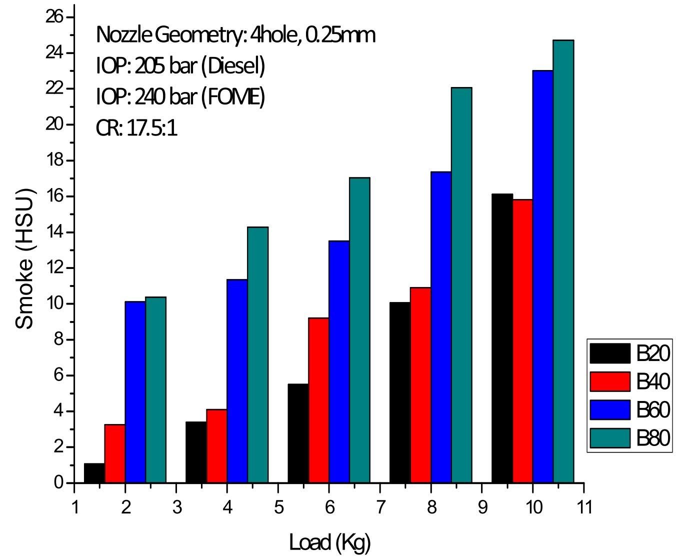

Fig. 16. Variation of smoke with load.

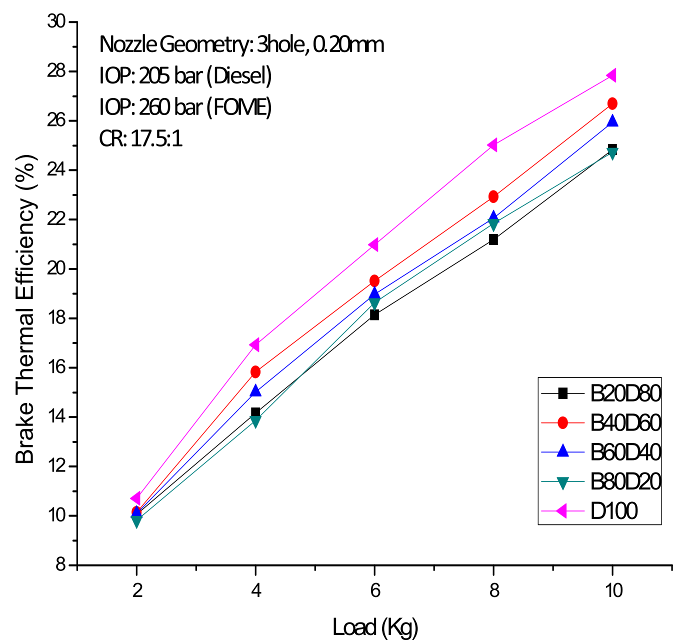

Fig. 17. Variation of brake thermal efficiency with load.

therefore lesser BTE.

4.3.2. Variation of Smoke with load

From the Fig. 22 it is observed that the fish oil blends produced higher smoke density as load increased. Because, as mass of air-fuel and gases increase in chamber, due to higher viscosity of fish oil causes poor air-fuel mixing and vaporization which results in incomplete combustion. The blend B40 has less smoke emission compared with other blends.

4.3.3. Variation of brake thermal efficiency with load

The Fig. 23 depicts that in comparison to all blends B40D60 blend leads to enhanced BTE. As stated by Ravi Kiran et al. [32] in contrast to diesel the BTE for biodiesel is good choice because almost all engines will be running on part load as its brake thermal efficiency is slightly lesser than pure diesel.

4.3.4. Variation of Smoke with load

From the Fig. 24 it is observed that the fish oil blends produced higher smoke density as load increased. Greater viscosity of fish oil causes poor air-fuel mixing and vaporization which causes incomplete combustion and hence greater smoke density. The blend B40 has less smoke emission compared with other blends.

4.3.5. Variation of Brake Thermal Efficiency with load

The Fig. 25 depicts that in comparison to all blends B40D60 blend leads to enhanced BTE. But as stated by Manish V. et al. [33] diesel has more brake thermal efficiency than all blends. In each case, for diesel fuel with increasing load the BTE increases. It is because with increasing load the power increases and heat loss reduces.

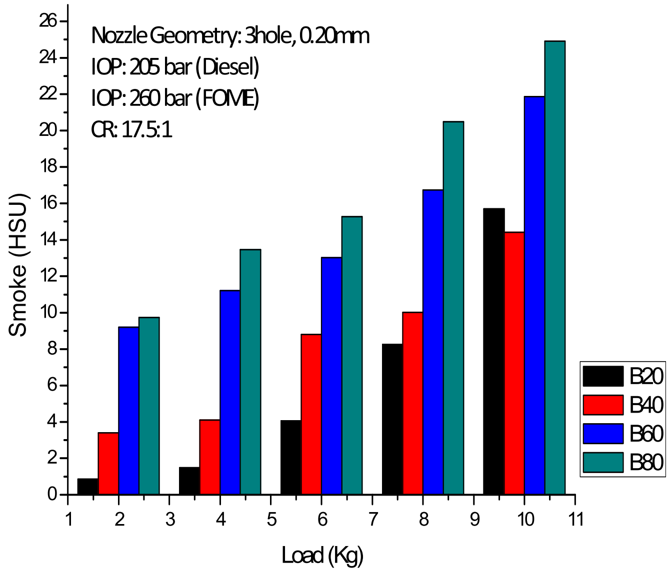

Fig. 18. Variation of smoke with load.

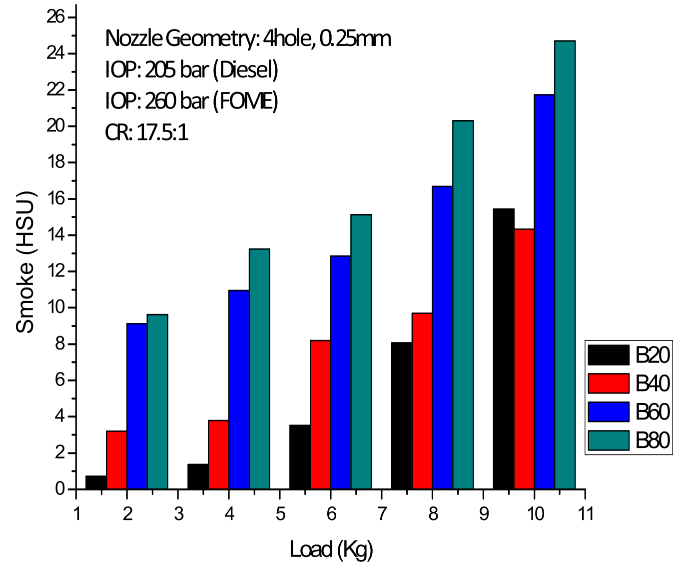

Fig. 20. Variation of smoke with load.

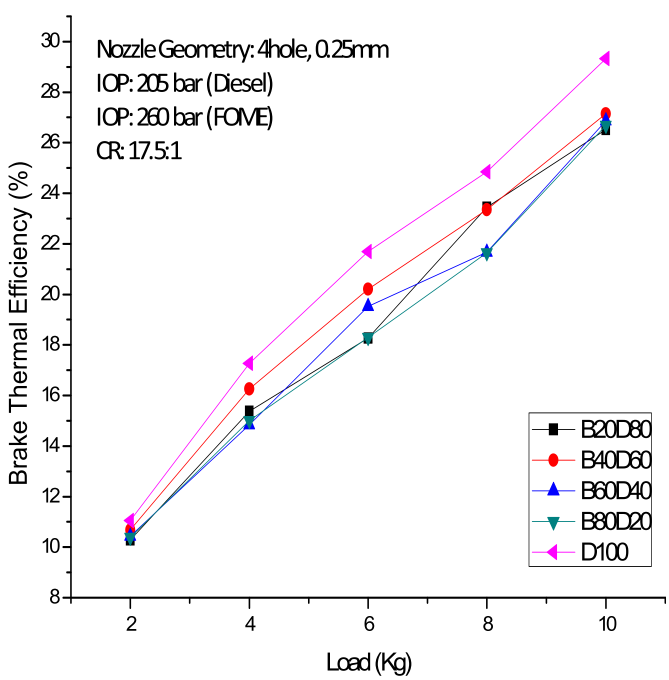

Fig. 19. Variation of brake thermal efficiency with load.

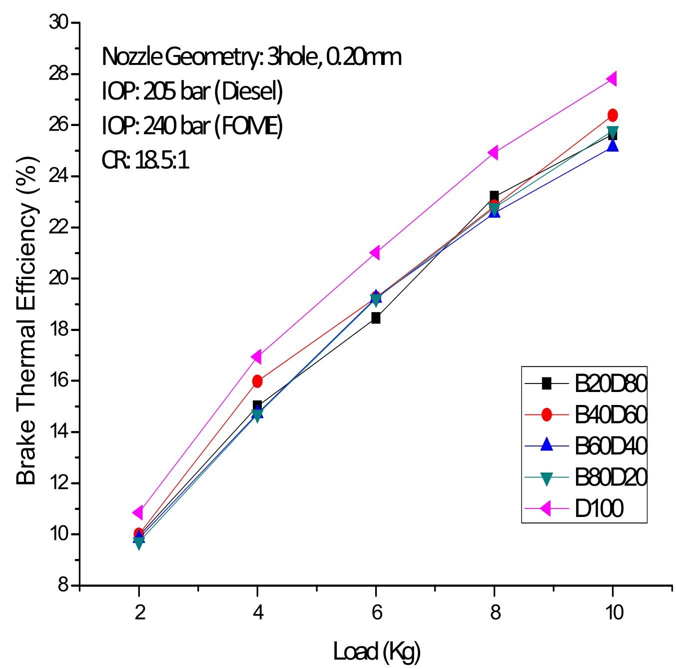

Fig. 21. Variation of brake thermal efficiency with load.

4.3.6. Variation of Smoke with load

From Fig. 26 it is observed that the fish oil blends produced higher smoke density as load increased. Because, as mass of air-fuel and gases increase in chamber, due to higher viscosity of fish oil causes poor air-fuel mixing and vaporization which results in incomplete combustion. The blend B40 has less smoke emission compared with other blends.

4.3.7. Variation of brake thermal efficiency with load

From Fig. 27 it shows that in comparison to all blends B40D60 blend leads to enhanced BTE. But diesel has more brake thermal efficiency than all blends. In addition to this at the pressure of about 260 bar the atomization of fuel takes place which exposes more surface area of fuel particles the combustion.

4.3.8. Variation of Smoke with load

From the Fig. 28 it is observed that the fish oil blends produced superior smoke density as load increased. As depicted by S. Kiran Kumar et al. [34]. Higher availability of oxygen causes better burning hence smoke emission is more. Greater viscosity of fish oil causes poor air-fuel mixing and vaporization which causes incomplete combustion and hence greater smoke density. The blend B40 has less smoke emission compared with other blends.

4.4. Optimized blend comparison with diesel

4.4.1. Variation of brake thermal efficiency with load

The Fig. 29 depicts that in contrast to diesel the BTE for biodiesel is good choice because almost all engines will be running on part

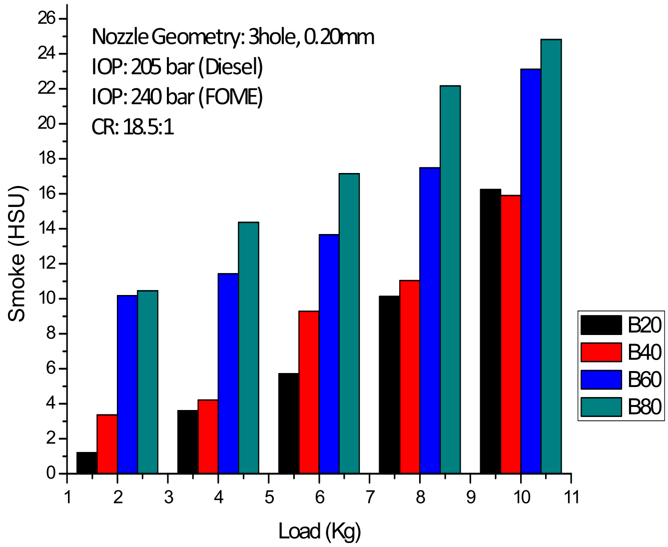

Fig. 22. Variation of smoke with load.

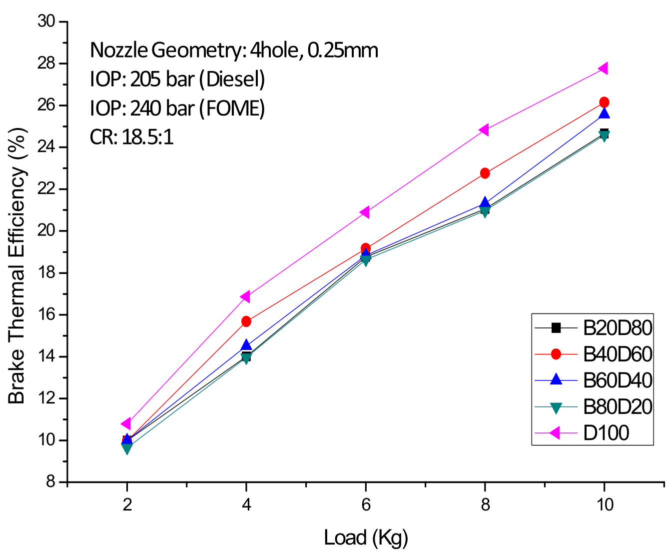

Fig. 23. Variation of brake thermal efficiency with load.

load. Then maximum brake thermal efficiency for B40D60 (27.15) is slightly less than that of diesel (29.33) for CR 17.5:1 & IOP 260 bar. But diesel has more brake thermal efficiency than all blends. B.R. Hosamani et al. [35] depicted that within the combustion chamber with increase in CR there is an increase in air pressure and temperature. The air density rises with superior CR thereby improving air-fuel mixing. The abandoned combustion quality enhances with increased vaporization develops superior cylinder pressure.

Conversely from the observation it is found that at lesser loads the tempo increasing brake thermal efficiency is great and at superior loads is lower as shown in figure.

4.4.2. Variation of smoke with load

The Fig. 30 depicts that the fish oil blends produced higher smoke density as load increased. The blend B40 exhibits less smoke emission compared with diesel and other blends because of its greater cetane index and greater content of oxygen availability attributes in effective combustion. The blend B40 has less smoke emission compared with other blends.

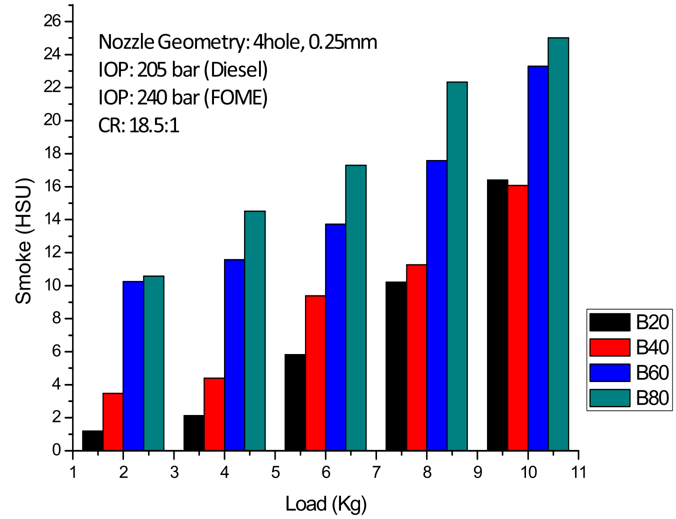

Fig. 24. Variation of smoke with load.

4.4.3. Variation of carbon monoxide with load

The Fig. 31 depicts that the FOME blend and diesel produced higher carbon monoxide as load increased. The blend B40 exhibits less smoke emission compared with diesel because increasing load attributes in increased in-cylinder temperature and greater oxygen content.

4.4.5. Variation of carbon dioxide with load

The Fig. 32 depicts that FOME and diesel blend produced higher CO2 emission as load increased. The blend B40 exhibits less CO2 emission compared with diesel because of greater content of oxygen availability attributes in effective combustion. The trend of rising CO2 with increasing load is because of more fuel entry in the combustion chamber.

4.4.6. Variation oxides of nitrogen with load

The Fig. 33 depicts that the NOx increases in FOME and Diesel as load increased. The blend B40 exhibits more NOx as compared with

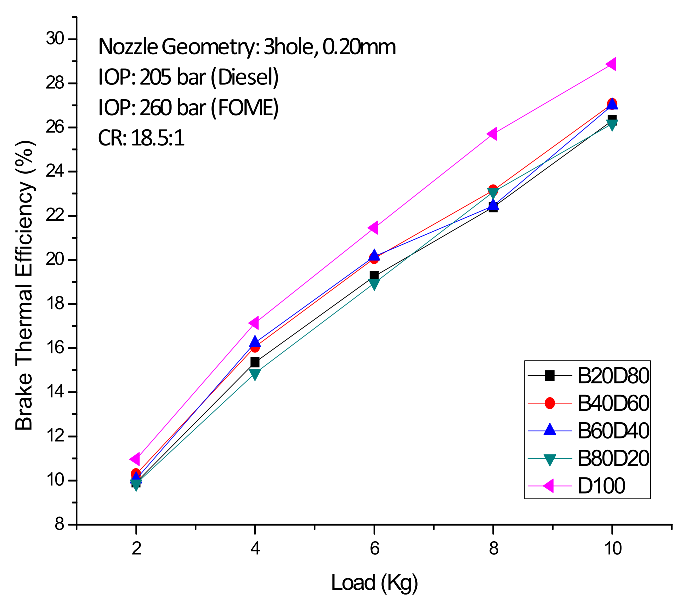

Fig. 25. Variation of brake thermal efficiency with load.

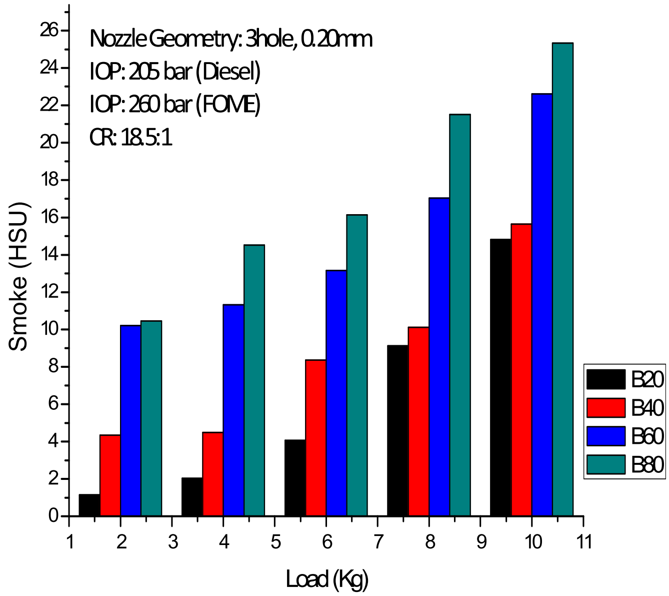

Fig. 26. Variation of smoke with load.

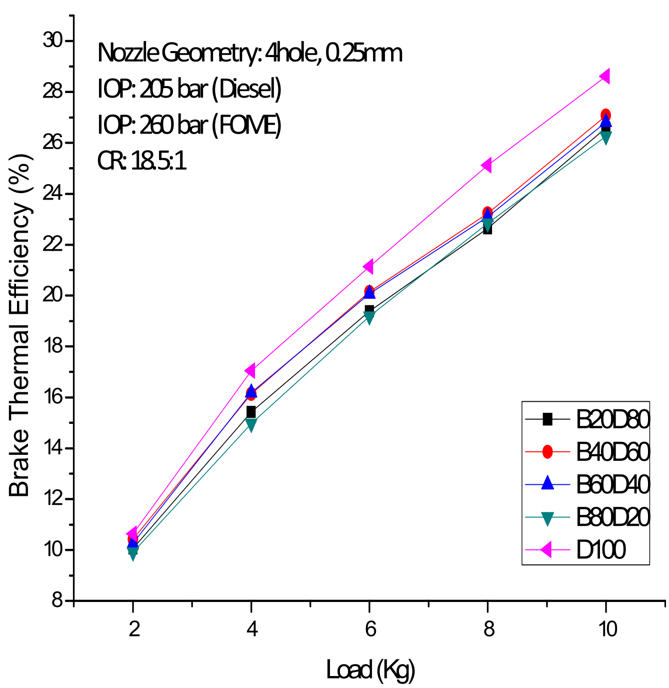

Fig. 27. Variation of brake thermal efficiency with load.

diesel because of its greater cetane index and greater content of oxygen availability attributes in ineffective combustion. The rise in combustion temperature will cause NOx emissions to rise.

5. Conclusion

The experiments were conducted using clean diesel and FOME biodiesel blends on a VCR engine, which is suitable for running on bio-fuel and the following conclusions were drawn.

- The biodiesel viscosity and density are comparatively close properties with diesel and also the biodiesel C.V is less i.e. 39500 kJ/kg.

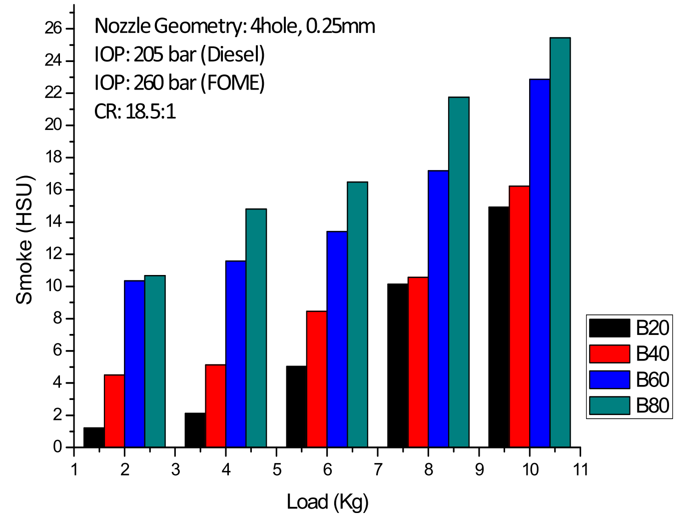

Fig. 28. Variation of smoke with load.

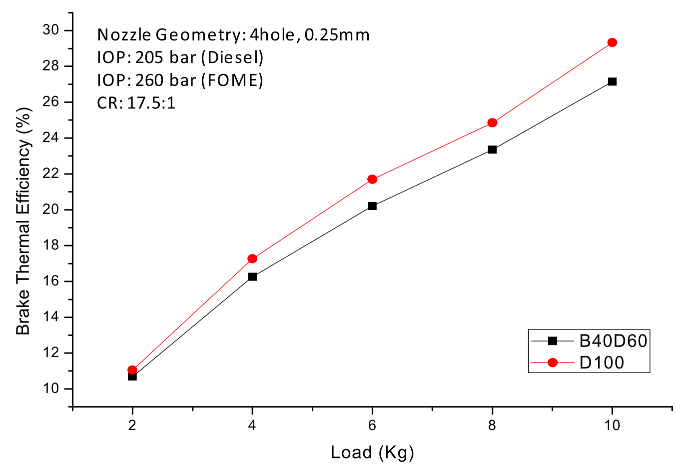

Fig. 29. Variation of brake thermal efficiency with load.

- The observations of this comprehensive study reveal that the blend B40D60 gives superior results than the other blends at CR17.5:1 and pressure 260 bar. This is due to complete combustion of fuel with biodiesel from various optimized parameters.

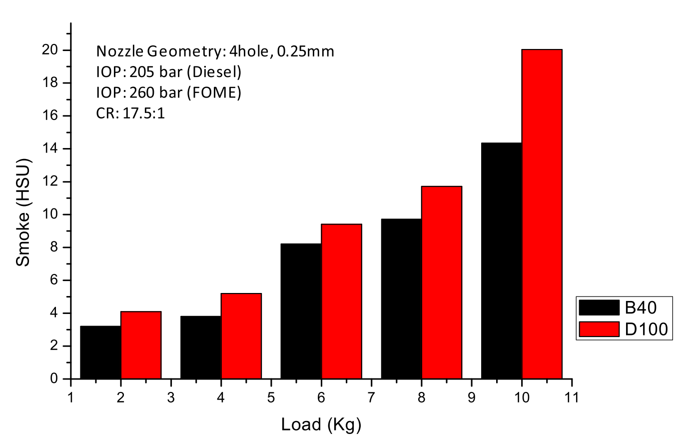

Fig. 30. Variation of smoke with load.

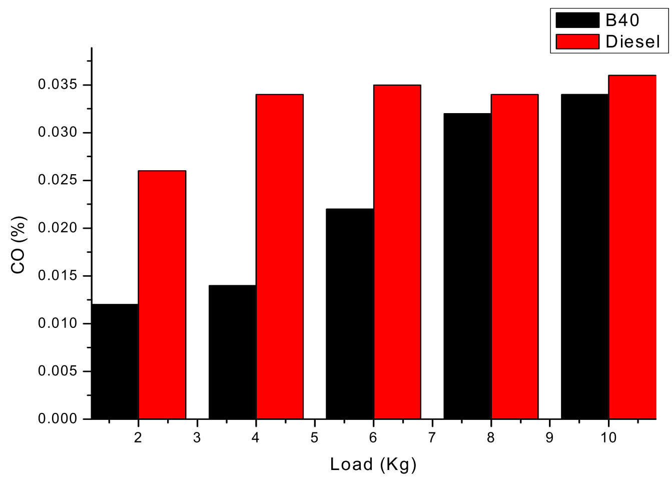

Fig. 31. Variation of carbon monoxide with load.

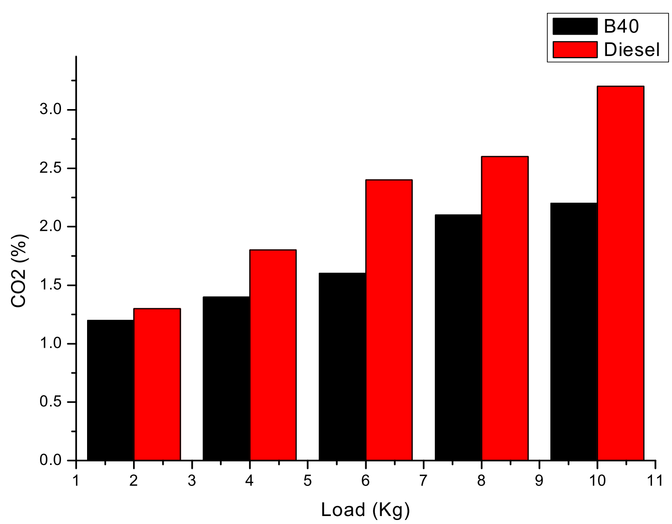

Fig. 32. Variation of carbon dioxide with load.

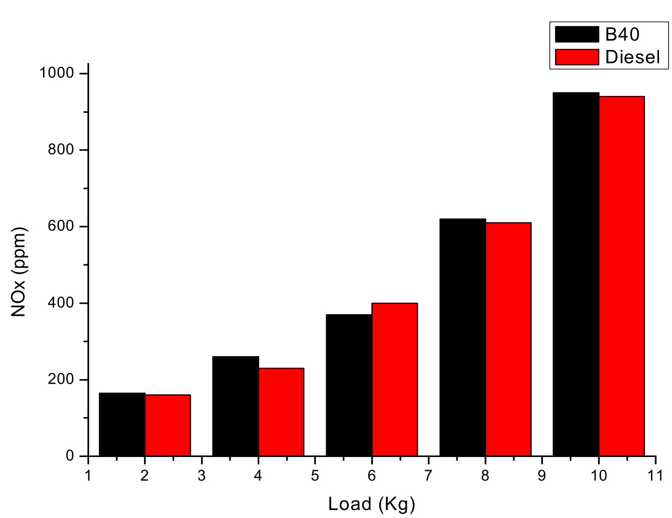

Fig. 33. Variation oxides of nitrogen with load.

- The IC engine needs no or minor modification in the engine configuration to run on FOME biodiesel.
- The advanced methods like EGR, CRDI can be used to reduce oxides of Nitrogen from the exhaust.
- At high injection pressure of 260 bar, the atomization and Vaporization of fuel droplets takes place which results in complete combustion of fuel with less appreciable emissions.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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