Energy 254 (2022) 124185

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Experimental investigation to optimize nozzle geometry and compression ratio along with injection pressure on single cylinder DI diesel engine operated with AOME biodiesel

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ARTICLE INFO

Article history:
Received 23 March 2021
Received in revised form
15 March 2022
Accepted 2 May 2022
Available online 7 May 2022

Keywords:
Algae Oil Methyl Ester
Biodiesel
Diesel Engine
Compression Ratio
Nozzle Geometry
VCR Engine

ABSTRACT

With the increase in population, energy demand is more in the automotive sector. Soaring prices and extinction of fossil fuels are reasons why researchers are focusing more on alternatives. This research work carried out on a single-cylinder DI diesel engine running on AOME biodiesel aims to optimize the nozzle geometry, the compression ratio and the injection pressure. The experiment on transesterified AOME biodiesel/diesel blends B80D20, B60D40, B40D60, and B20D80 was evaluated against pure diesel. 4 and 3 hole fuel injectors of 0.25 mm and 0.20 mm diameter respectively are used in the experimental study with 240 and 260 bar IOP at compression ratios 16.5:1 and 17.5:1 for optimization. The results of the experimental investigations prove that for biodiesel blends, the brake thermal efficiency is slightly lower and the smoke emissions are reduced compared to diesel. In addition, the results prove that at 260 bar IOP, the 4 hole, 0.25 mm diameter fuel injector at a compression ratio of 17.5:1, the B40D60 blend gives improved results against all blends in case of brake thermal efficiency and smoke emissions. Finally, these are the most efficient and optimized conditions for the biodiesel blend by improving brake thermal efficiency (25.43%) and reducing smoke emissions (53HSU).

1. Introduction

From recent research, it has been found that due to the rapid growth of transportation and modernization of industrialized sectors, the energy demand is increasing rapidly. As fossil fuel sources are also dwindling and rapid increases in fuel prices have focused researchers' attention on finding the best alternatives to meet this global demand.

Biodiesels have received wide attention as a promising and replaceable source of diesel because of their sustainable and less polluting characteristics. Biodiesels are generally extracted from fats of animal or vegetable oils, which are mono-alkyl esters of long-chain fatty acids (propyl, ethyl, or methyl). The process of forming biodiesel involves the reaction of lipids (soya bean oil, vegetable oils, and animal fats) and alcohol yielding end products in the form of fatty acid esters. The algae oil biodiesel is also one of the attractive biofuels, hydrothermal treatment with a temperature of 245 °C will treat lipids for the production of biodiesel Qiu, Y.et al. [1]. According to Sampriti Sarma et al. [2] globally, most countries have initiated the production of biodiesel for use in regular applications. Biodiesel has already begun to replace conventional fuels around the world. As it has become convenient to produce locally, biodegradable and renewable biodiesel, it does not affect the atmosphere like that of conventional fuels, and without extinguishing restrictions, biodiesel can be used frequently. Therefore, all vehicles can easily run on biodiesel fuel. This biodiesel meets ASTM D6751 (American Society for Testing Materials) qualifications for use in conventional fuel engines Nayak S. K. et al. [3] and by Hemendra C. Patil et al. [4] depict that biodiesel can be renewed and has less carbon emission proving that it replaces conventional fuels. New technologies are booming according to Panayiotis Tsaousis et al. [5] mentioned that modeling and simulation have a key role in the development and accelerate the investigations, giving a successful new method to consider an exclusive procedure of carrying out specific experimental tests. While biodiesels have

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https://doi.org/10.1016/j.energy.2022.124185
0360-5442/

Abbreviations

AOME	Algae Oil Methyl Ester
CI	Compression Ignition
BP	Brake Power
CO	Carbon Monoxide
CO_2	Carbon Dioxide
NOx	Nitrogen Oxides
IC	Internal Combustion
CRDI	Common Rail Direct Injection
BSFC	Brake Specific Fuel Consumption
CV	Calorific Value
HC	Hydrocarbons
VCR	Variable Compression Ratio
FFA	Free Fatty Acid

advantages such as: readily available, portable, low sulphur content, higher combustion efficiency, higher cetane number, extremely biodegradable, domestic sourced, higher flash point and improved lubrication property. The work of Avinash Kumar et al. [6] reveals that, unlike diesel, the microalgae-based biodiesel blend showed a reduction in SFC and exhaust gas temperature, as well as an increase in thermal efficiency. In addition, emissions have been reduced for biodiesel compared to pure diesel. The costs of various biodiesels are comparable to those of diesel, so biodiesels can replace diesel fuel, as mentioned by Rajak, Upendra et al. [7]. Algae biodiesel can have considerable calorific value compared to the diesel mentioned by Alpesh Mehta et al. [8]. Mohankumar Subramaniam et al. [9] and Rachan Karmakar et al. [10] pinpointed in their work a diesel engine using algae biodiesel produces greater thermal efficiency and low CO and HC emission. Studies by Manish Saraswat et al. [11] disclose that by adding butanol we get better results in the case of power, torque, CO, HC, NO and brake specific energy consumption. But higher CO_2 and NOx emissions are observed compared to gasoline and diesel. Algae fuel showed improved BSFC, CO, NOx emissions, but brake thermal efficiency was reduced. Emissions such as smoke, CO, and NOx were reduced by the effect of injection timing due to the advancement of crank angle degrees, but BTE improved, which is mentioned by R. Velappan et al. [12]. The research work by A. Ganesh et al. [13] found that when blending micro and macro biodiesels at a fixed speed with changing injection times, SFC increases as well as BTE readings were closer to diesel. These biodiesel blends compared to pure diesel produces less smoke, CO, unburnt HC and NOx emissions. Performance and emission characteristics were better during injection timing advancement than under retardation.

A study by Ganesh Nagane et al. [14] on a VCR engine for its performance is examined. The investigational results showed a smaller drop in torque, brake power, and BTE, also with an increase in the blend ratio, the SFC boosts. CO, HC, and CO_2 emissions decrease with a slight increase in NOx emission. An investigation by R. Velappan et al. [15] stated that the improved diesel engine performance as well as reduced emission characteristics due to the change in injection pressure with AME20; this is proof that while fueling the engine with spirulina-based biodiesel, there is an apparent decrease in CO, NOx, and HC emissions and the performance characteristics of the engine remain unchanged. Best engine performance was established at higher CR in the study of P. Govindasamy et al. [16] but limited by knocking and NOx emissions Rajak U et al. [17].

An investigation by the Nambaya Charyulu Tatikonda et al. [18] experimental results showed no significant impact of modified injection pressures on BSFC, while BTE was increased. A study by Ramón Piloto-Rodríguez et al. [19] showed that when fed with algae and microalgae, an increase in NOx is commonly observed in the combustion chamber related to high temperatures. Using emulsions as a substitute for blends or pure biodiesel produces a confident substitute with a significant reduction in NOx and CO_2. P. L. Navaneethakrishnan et al. [20], B. R. Hosamani et al. [21], Avinash Kumar Agarwal et al. [22] and M. P. Joshi et al. [23] shows that the performance can be improved by blending biodiesels with diesel compared to that of the engine running on biodiesel. Also, additives such as copper oxide nanoparticles can be added to improve the diesel engine performance according to Ümit Ağbulut et al. [24]. Numerical performance analysis of diesel engine running on micro biodiesel and diesel blends also gives results similar to experimental results such as lower BTE, CO, HC and NOx but higher CO_2 compared to diesel operating at all loads by Rajak U et al. [25].

By the literature work above, it has been observed that less work is being performed on optimizing nozzle geometry and compression ratio for both AOME and diesel blends, hence the same focus of this experimental investigation, emphasis has also been placed on improving the performance characteristics and the results obtained are satisfying. Experimentation for the prepared test fuel blend of diesel and AOME was successfully performed on a single-cylinder, variable compression ratio diesel engine. The various observations were recorded for different test fuel blends, compression ratio, nozzle geometry and IOP. The operating conditions optimized for improved performance and lower emissions for a given diesel engine have been presented in the present work.

2. Characterization of fuel

In the tests, Algae Oil Methyl Ester (AOME) is used as a research fuel. Fuel properties such as fire point, flash point, viscosity, density and calorific value (CV) were evaluated using the apparatus and recorded in Table 1.

3. Experimental setup

This experimental investigation was carried out on a single chamber, 4 strokes, water-cooled, DI Kirloskar TV1 diesel engine running on diesel/AOME. Fig. 1 depicts the test arrangement used for the experiment with specific details given in Table 2. In this case, various blends of diesel and AOME were used for various working parameters such as CR 17.5:1 and 16.5:1 with B80D20, B60D40, B40D60, and B20D80 blends. Nozzle hole diameters of 0.20 mm

Table 1
Properties of AOME biodiesel and diesel.

S. No	Properties	Diesel	AOME biodiesel	Apparatus used
1	**Fire Point (°C)**	57	186	Cleveland Apparatus
2	**Flash Point (°C)**	56	173	Cleveland Apparatus
3	**Kinematic Viscosity (centistokes)**	2.52	5.2	Redwood Viscometer
4	**Density (kg/m^3)**	824	864.2	Redwood Viscometer
6	**Calorific Value (kJ/kg)**	45,843	41,000	Bomb Calorimeter

Fig. 1. Investigational setup.

Table 2
Technical specifications of the engine.

Engine	Specifications
Cylinder	1
Strokes	4
Rated Power	5.2 KW at 1500 rpm
Fuel	H.S. Diesel
Compression Ratio	17.5:1
Dia. of Cylinder	87.5 mm
Length of Connecting Rod	234 mm
Dia. of Orifice	20 mm
Stroke Length	110 mm
Arm Length of Dynamometer	185 mm
Engine analysis Software	“Engine soft LV”
Load Sensor	0–50 kg range, Strain gauge type, Load cell,
Exhaust Gas Analyser	5 gas analyzer, Make – Indus Scientific
Load Indicator	Digital, 0–50 kg Range, 230 V AC Supply

and 0.25 mm have been studied. The manufacturer provided IOP 205 bar was used for diesel fuel operation and the 240, 260 bar IOP was used for diesel/AOME blends due to the higher viscosity of test fuel. Combustion and emission parameters are examined for each blend. BTE variation in runtime qualities and smoke in discharge attributes are taken into account.

3.1. Fuel injectors

The fuel-air mixture and its behaviour in the combustion chamber are considered significant. The fuel atomization and evaporation processes are strongly affected by cavitations and nozzle geometry. Fuel spraying and atomization processes greatly govern the performance and emission characteristics of the CI engine; likewise, the flow dynamics inside the injector nozzle strongly influences this spraying and atomization, as also explained by K. M. Akkoli et al. [26].

Fuel injectors whose specifications are listed in Table 3 are used in this investigation and displayed in Fig. 2.

Table 3
Fuel injectors' specifications.

S. No.	Fuel Injector	Dia. of Orifice
1	4 hole injector	0.25 mm
2	3 hole injector	0.20 mm

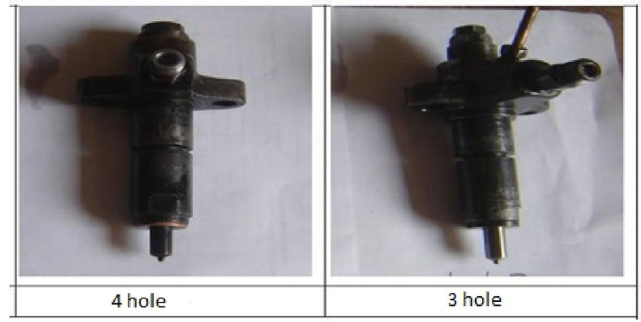

Fig. 2. 4, 3 nozzle holes fuel injector.

3.2. Smoke meter

The MARS SM-05 smoke meter is shown in Fig. 3 with technical specifications shown in Table 4. It measures the opacity of exhaust gases produced by diesel engines. The total light that is blocked by incoming smoke is called opacity. The measurement is performed internally in a smoke chamber which includes a mild supply, image detector and a replica on the opposite side. A green LED is used as the light source from which the beam is emitted with higher upper spectral intensity in the range of 550–570 nm. This photodetector has a spectral response of 400–1100 nm with a peak spectral response of 850 nm. The intensity of smoke emission is measured in HSU.

3.3. Changing the Compression Ratio

By providing a tilting cylinder block assembly configuration to adjust the CR to the required value for the given range, the engine would operate as a VCR (Variable Compression Ratio) on the engine running condition without transmuting the geometry of the combustion chamber. The Allen bolts must be loosened to set the CR to the desired value (Fig. 4). Later, by loosening the lock nut on the adjuster, the desired CR can be set by turning the adjuster to match with marking on the CR adjuster and locking it with a lock nut.

Fig. 3. 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.

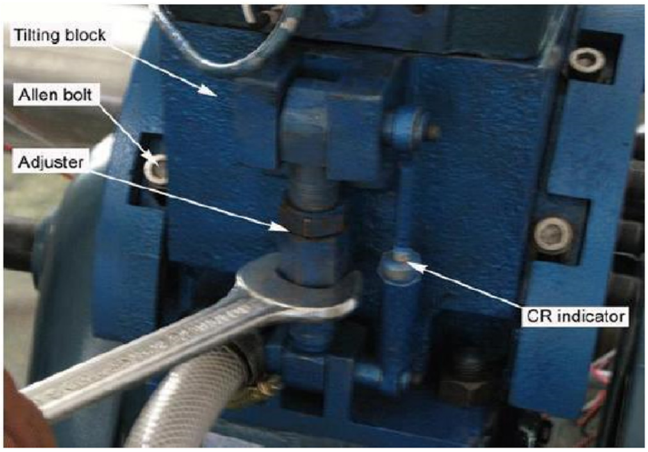

Fig. 4. Changing the compression ratio.

Finally, gently tighten the Allen bolts.

3.4. Procedure for experimental investigation

The following method was applied to determine the impact of AOME blends on diesel engine performance and emissions.

1. In the present experimental investigation, in the beginning, fuel properties such as density, viscosity, flash point, and fire point were found.
2. Diesel-AOME fuels are blended in different proportions to prepare the test fuel shown in Table 5.
3. After preparing the test fuel with different composition percentages under perpetual agitation, it is then added to the fuel tank of the diesel engine and the engine is started.
4. Insert all necessary data into computer software.
5. Wait for 2–3 min and apply load.
6. Engine connections to a smoke meter and a computer data acquisition system should be checked.
7. The experiments will be repeated for the above procedure at different loading conditions for different blend ratios.
8. By experimental conduction data collected from system software and graphs, identify the optimized biodiesel blend for minimum emissions.
9. Finally, the blend with higher brake thermal efficiency and minimum emissions is decided as an optimized blend.

Table 5
Biodiesel blends.

S.No.	Blends
1	B80-D20
2	B60-D40
3	B40-D60
4	B20-D80

Fig. 5. Diesel and biodiesel blends.

3.5. The blends of Diesel-AOME biodiesel

Different blends of diesel and biodiesel used for testing are shown below in Fig. 5.

3.6. The uncertainty analysis

Usually, uncertainties arise during experimentation due to various factors such as choice and calibration of types of equipment and instruments used during research, environmental conditions. Therefore, it is important to do the uncertainty analysis to know the precision of the experiment conducted. According to Dubey and Gupta et al. [27] explained the method and authors have given the formula of analysis done and the uncertainty calculated and found for the whole experiment conducted is ±0.56%.

The overall uncertainty is calculated using Equation (1),

$$\frac{U_y}{y} = \sqrt{\sum_{i=1}^{n}\left(\frac{1}{y}\frac{\partial y}{\partial xi}\right)^2} \tag{1}$$

where ‘y’ is a specific factor that relies on the parameter ‘xi’ and Uy indicates the level of uncertainties or variation in ‘y’.

Overall uncertainty

$$Overall\ \ Uncertainty = \sqrt{\begin{matrix} Uncertainty(\%)of\left(\mathrm{Enginespeed}^2\right)+ \\ \mathrm{Brake\ \ thermal\ \ efficiency}\left(\mathrm{BTE}^2\right)+\left(\mathrm{Smoke}^2\right)\end{matrix}} = \pm\ \ 0.56\%$$

4. Results and discussions

In this part, the variation of performance and emission qualities with various blends used in tests is discussed. Performance and smoke emission qualities are shown separately in Table 6 and Table 7. Performance with different blends and smoke emission qualities are shown separately in Table 8 and Table 9.

4.1. Variation of Brake Thermal Efficiency with load

Fig. 6 above depicts the BTE v/s load variation for various algae oil blends at CR 16.5:1 and 0.20 mm diameter 3-hole fuel injector at 240 bar IOP. The graph shows that diesel fuel had a high BTE than

Table 6
Performance characteristics of diesel.

Load (kg)	BP (kW)	IP (kW)	BMEP (bar)	IMEP (bar)	BTHE (%)	ITHE (%)	Mech. Eff. (%)
2	0.60	3.72	0.71	4.52	11.04	70.92	15.59
4	1.14	4.35	1.39	5.42	17.28	67.75	25.52
6	1.68	5.10	2.04	6.20	21.68	66.33	32.71
8	2.18	5.54	2.76	7.04	24.86	63.04	39.45
10	2.75	6.14	3.44	7.67	29.32	65.63	44.73

Table 7
Emission characteristics of diesel smoke.

Load (kg)	Smoke (HSU)
2	4.11
4	5.3
6	9.42
8	11.73
10	20.06

Table 9
Smoke emission characteristics of the optimized blend.

Load (kg)	Smoke (HSU)
2	3.3
4	3.9
6	8.3
8	9.75
10	14.34

fuels blended with biodiesel in diesel engines due to the higher CV of pure diesel fuel. Also due to the higher viscosity and density of biodiesel, this results in inferior BTE of the diesel engine. But, the B40 blend showed higher BTE than B20, B60, and B80. Because there is proper atomization in the B40D40 biodiesel fuel blends to achieve higher brake thermal efficiency. As demonstrated by Yaliwal V S et al. [28] that diesel fuel provides higher BTE than biodiesel blends under all load circumstances due to the lower CV and higher specific energy consumption of biodiesel fuel blends.

4.2. Variation of smoke with load

Fig. 7 shows the variation of smoke emission with load for various mixtures of algal oil. This figure shows that the algal oil mixture created high smoke concentrations with increasing load. The high viscosity of algal oil causes poor vaporization and mixing of air, and fuel, leading to incomplete combustion, resulting in high smoke density. The B40D60 mixture emits less smoke than the other mixtures. The lower emission characteristics of biodiesel are due to its efficient combustion, although it has a higher cetane number and lower CV.

4.3. Variation of Brake Thermal Efficiency with load

Fig. 8 shows the variation of the thermal braking efficiency v/s load for different blends of algae oil in a CR 16.5:1 and 0.25 mm diameter, 4-hole fuel injector at 240 bar IOP. The graph shows that the brake thermal efficiency has gradually increased with increasing load. The graph also shows that the B40D60 blend leads to an improved BTE than all blending ratios by exposing a greater surface area of the fuel particles to fuel combustion when atomization takes place at approximately 240 bar pressure. While the BTE is higher for diesel than for all biodiesel blends.

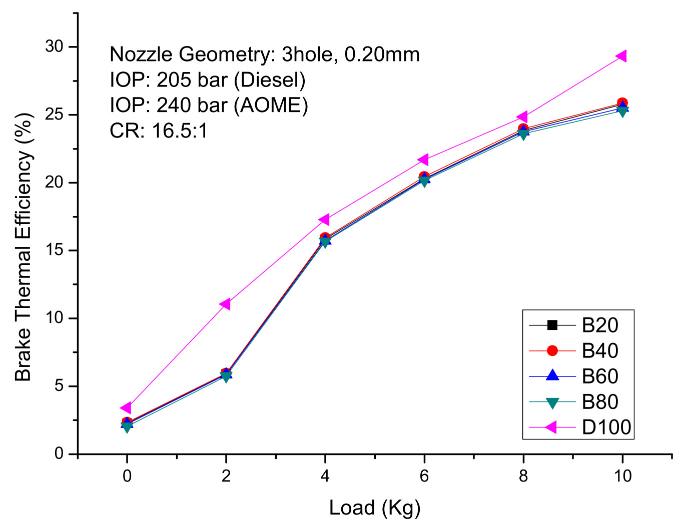

Fig. 6. Variation of brake thermal efficiency with load.

4.4. Variation of smoke with load

Fig. 9 shows the variation of the thermal braking efficiency v/s load for different blends of algae oil in a CR 16.5:1 and 0.25 mm diameter, 4-hole fuel injector at 240 bar IOP. The graph shows that the brake thermal efficiency has gradually increased with increasing load. The graph also shows that the B40D60 blend leads to an improved BTE than all blending ratios by exposing a greater surface area of the fuel particles to fuel combustion when atomization takes place at approximately 240 bar pressure. While the BTE is higher for diesel than for all biodiesel blends.

Table 8
Performance characteristics of the optimized blend.

Load (kg)	BP (kW)	IP (kW)	BMEP (bar)	IMEP (bar)	BTHE (%)	ITHE (%)	Mech. Eff. (%)
2	0.63	4.20	0.77	5.13	10.70	72.09	14.84
4	1.14	4.70	1.39	5.72	17.65	73.26	24.12
6	1.73	5.23	2.13	6.47	22.72	69.04	32.94
8	2.26	5.74	2.82	7.16	25.08	65.15	38.49
10	2.68	6.17	3.39	7.75	27.16	62.27	43.63

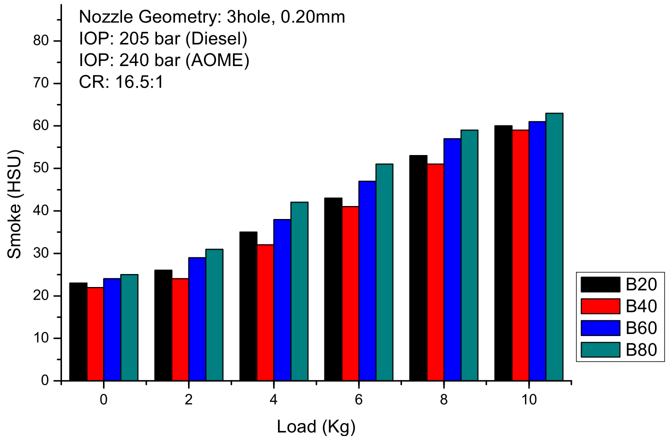

Fig. 7. Variation of smoke with load.

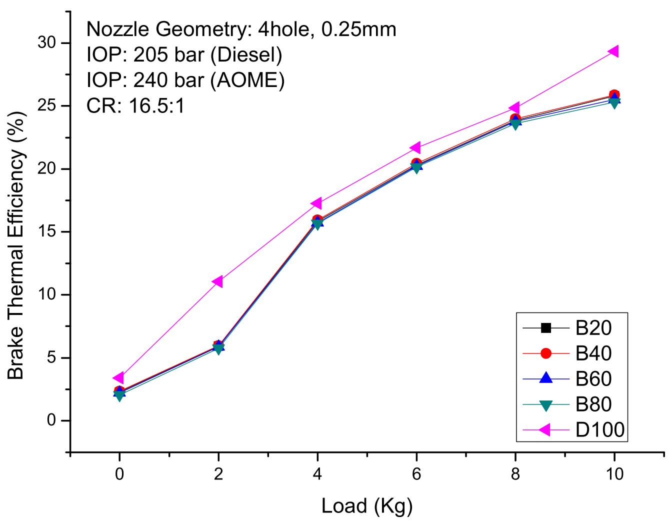

Fig. 8. Variation of brake thermal efficiency with load.

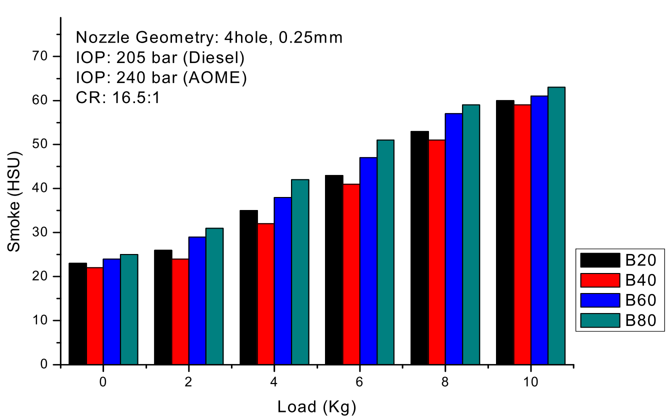

Fig. 9. Variation of smoke with load.

4.5. Variation of Brake Thermal Efficiency with load

Fig. 10 depicts the brake thermal efficiency v/s load variation for various blends of algae oil at CR 16.5:1 and 3 hole, 0.20 mm diameter fuel injector at 260 bar IOP. The graph shows that the brake thermal efficiency increased gradually with increasing load

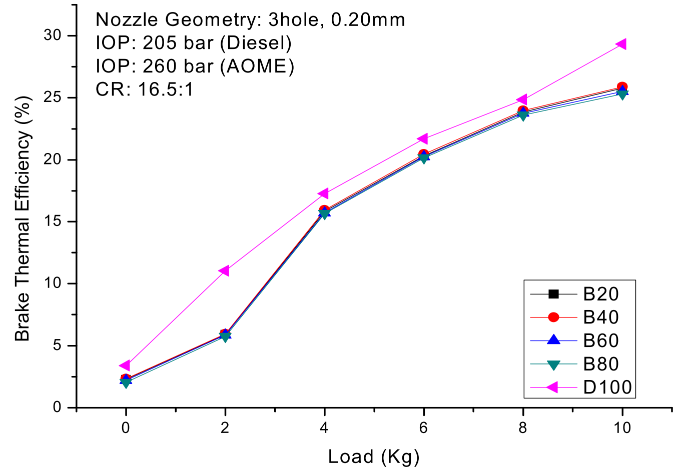

Fig. 10. Variation of brake thermal efficiency with load.

for all AOME-biodiesel blends compared to diesel in the above graph. From the graph, it shows that, unlike all biodiesel blends, the B40D60 blend gives enhanced BTE. Biodiesel blends have lesser brake thermal efficiency than diesel due to the fixed injection timing of the engines during operation.

4.6. Variation of smoke with load

Fig. 11 above shows the smoke emission v/s load variation for various blends of algae oil at CR 16.5:1 and 3hole, 0.20 mm diameter fuel injector at 260 bar IOP. From the graph, it can be seen that with increasing load, the algae oil blends emitted high smoke density. The vaporization and poor air-fuel mixing caused by the higher viscosity of algae oil is the reason for partial combustion, which in turn produces denser smoke. Because of the high cetane number and greater oxygen content, efficient combustion occurs in the B40 blend and hence produces less smoke emission when compared to pure diesel and other biodiesel blends.

4.7. Variation of Brake Thermal Efficiency with load

Fig. 12 above shows the brake thermal efficiency v/s load variation for various algae oil blends at CR 16.5:1 and 4 hole, 0.25 mm diameter fuel injector at 260 bar IOP. The graph indicates that the brake thermal efficiency increased gradually with increasing load for all AOME-biodiesel blends and compared with diesel in the

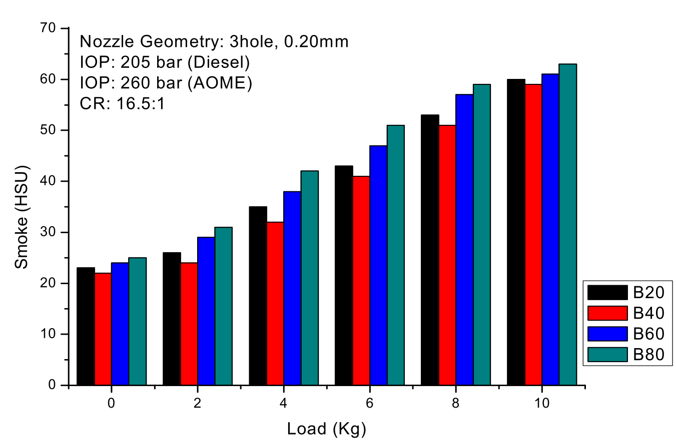

Fig. 11. Variation of smoke with load.

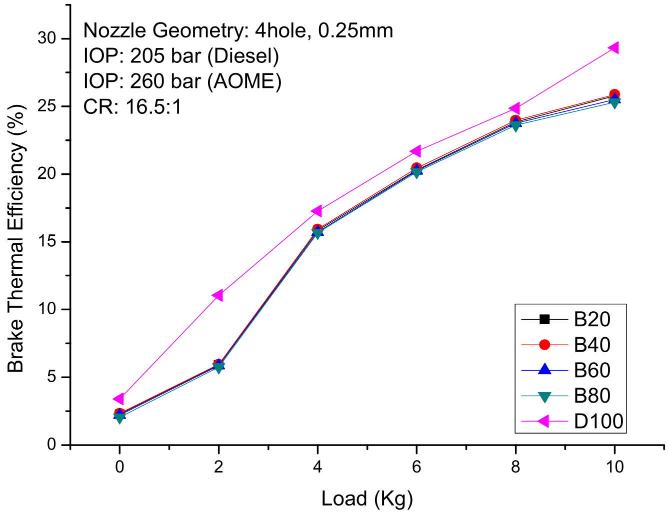

Fig. 12. Variation of brake thermal efficiency with load.

above graph. From the graph, it shows that, unlike all biodiesel blends, the B40D60 blend gives improved BTE. The heat release process in the case of biodiesel blends begins well before TDC causing considerable variations contrary to the ideal cycle hence the BTE is more for pure diesel.

4.8. Variation of smoke with load

Fig. 13 shows the smoke emission v/s load variation for various blends of algae oil at CR 16.5:1 and 4 hole 0.25 mm diameter fuel injector at 260 bar IOP. From the graph, it is seen that with increasing load the algae oil blends emitted high smoke density. Volatilization and atomization processes are greatly affected by kinematic viscosity and density for fuels causing more smoke emission. But on the contrary, all blends of the B40D60 blend produce less smoke.

4.9. Variation of Brake Thermal Efficiency with load

Fig. 14 shows the brake thermal efficiency v/s load variation for various blends of algae oil at CR 17.5:1 and 3 hole, 0.20 mm diameter fuel injector at 240 bar IOP. The graph indicates that brake thermal efficiency increased slowly with increasing load for all

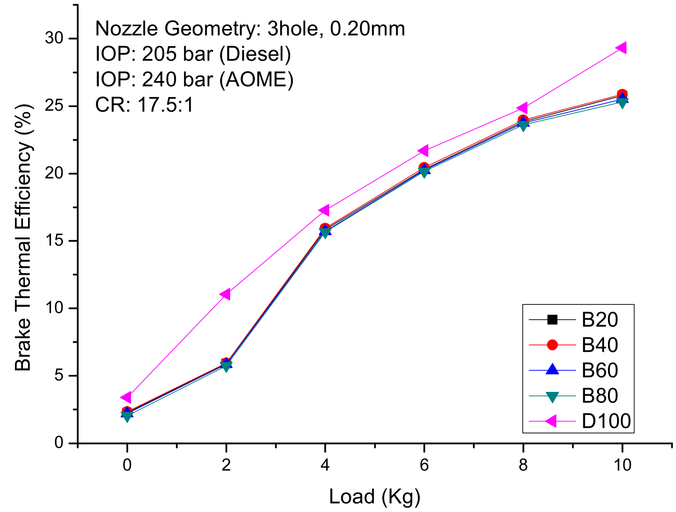

Fig. 14. Variation of brake thermal efficiency with load.

AOME-biodiesel blends are and compared with diesel in the graph. From the graph, it shows that contrary to all biodiesel blends B40D60 blend gives enhanced BTE. But, due to the longer delay period more fuel is accumulated in the combustion chamber causing a higher heat release rate hence BTE of the biodiesel blends is lesser contrary to diesel.

4.10. Variation of smoke with load

Fig. 15 illustrates the smoke emission v/s load variation for various blends of algae oil at CR 17.5:1 and 3 hole, 0.20 mm diameter fuel injector at 240 bar IOP. From the graph, it is seen that with increasing load the algae oil blends produced high smoke density. Vaporization and poor air-fuel mixing caused due to the higher viscosity of algae oil is also the reason for partial combustion, which in turn produces denser smoke. Because of the high cetane number and greater oxygen content, efficient combustion occurs in the B40D60 blend and hence produces less smoke emission when compared to pure diesel and other biodiesel blends.

4.11. Variation of Brake Thermal Efficiency with load

Fig. 16 depicts the brake thermal efficiency v/s load variation for

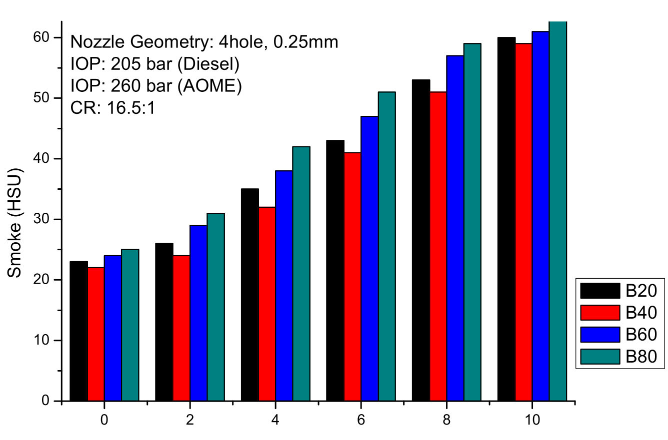

Fig. 13. Variation of smoke with load.

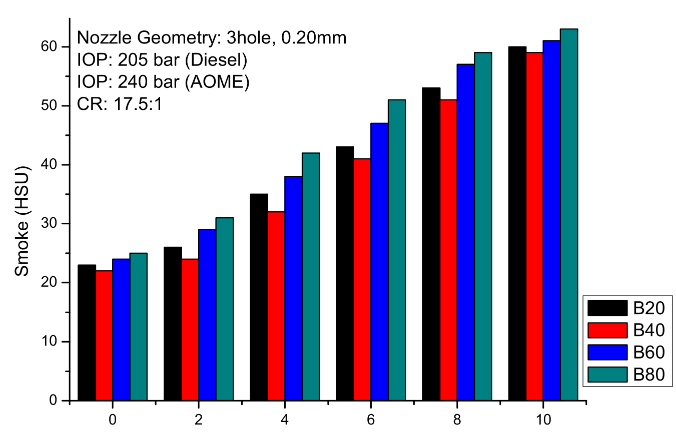

Fig. 15. Variation of smoke with load.

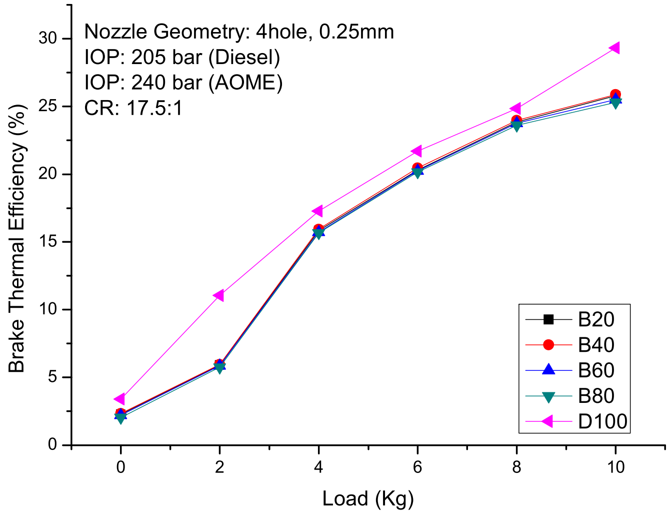

Fig. 16. Variation of brake thermal efficiency with load.

various blends of algae oil at CR 17.5:1 and 4 hole, 0.25 mm diameter fuel injector at 240 bar IOP. The graph indicates that brake thermal efficiency increased progressively with increasing load for all AOME-biodiesel blends and compared with diesel in the graph. The graph shows that because of reduced heat loss with increasing load, the B40D60 blend gives improved BTE contrary to all biodiesel blends. But diesel has higher BTE contrary to all other blends. Fuel atomization occurs at 240 bar pressure which exposes fuel particles larger surface area for combustion.

4.12. Variation of smoke with load

Fig. 17 above represents the smoke emission v/s load variation for various blends of algae oil at CR 17.5:1 and 4 hole, 0.25 mm diameter fuel injector at 240 bar IOP. From the graph, it is seen that with increasing load the algae oil blends produced the high smoke density. Vaporization and poor air-fuel mixing caused due to the higher viscosity of algae oil is the reason for partial combustion, which in turn produces denser smoke. Because of the high cetane number and higher oxygen content, efficient combustion occurs for the B40D60 blend and hence produces less smoke emission when compared to pure diesel and other biodiesel blends.

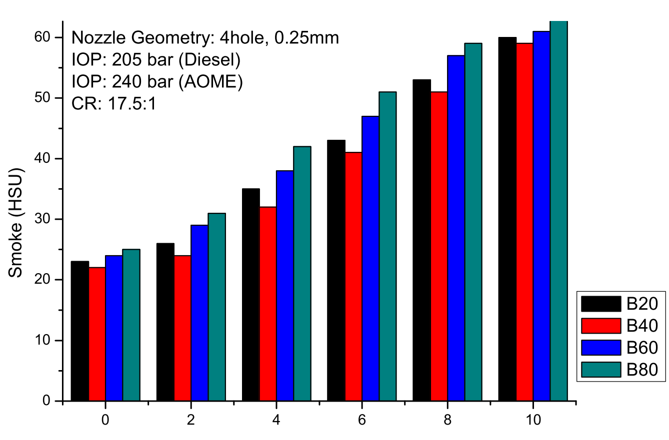

Fig. 17. Variation of smoke with load.

4.13. Variation of Brake Thermal Efficiency with load

Fig. 18 shows the brake thermal efficiency v/s load variation for various blends of algae oil at CR 17.5:1 and 3 hole, 0.20 mm diameter fuel injector at 260 bar IOP. The graph indicates that brake thermal efficiency increased progressively with increasing load for all AOME-biodiesel blends and compared with diesel in the graph. From the graph, it shows that in contrast to all biodiesel blends B40D60 blend gives enhanced BTE. But diesel has higher BTE than all other blends. The air pressure and temperature increase with increasing compression ratio hence air density within the combustion chamber increases attributing to proper mixing of air-fuel. This leads to proper combustion and increased vaporization tends to produce higher cylinder pressure.

4.14. Variation of smoke with load

Fig. 19 shows the smoke v/s load variation for various blends of algae oil at CR 17.5:1 and 3 hole, 0.20 mm diameter fuel injector at 260 bar IOP. From the graph, it is seen that with increasing load the algae oil blends produced high smoke density. Vaporization and poor air-fuel mixing caused due to the higher viscosity of algae oil is the reason for partial combustion, which in turn produces denser smoke. Because of the high cetane number and higher oxygen

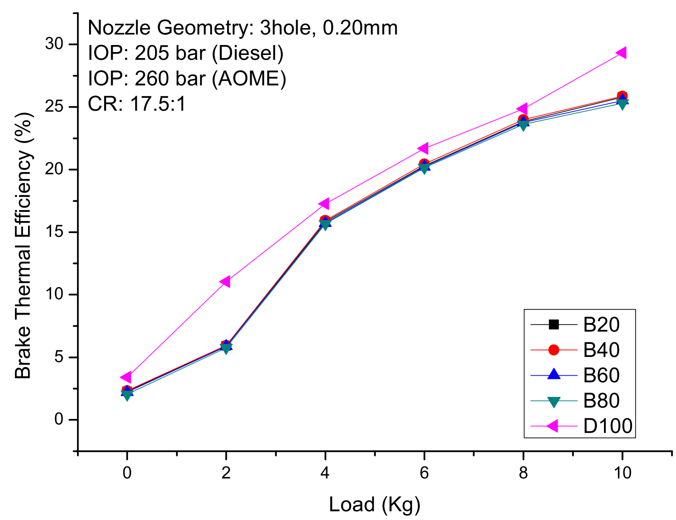

Fig. 18. Variation of brake thermal efficiency with load.

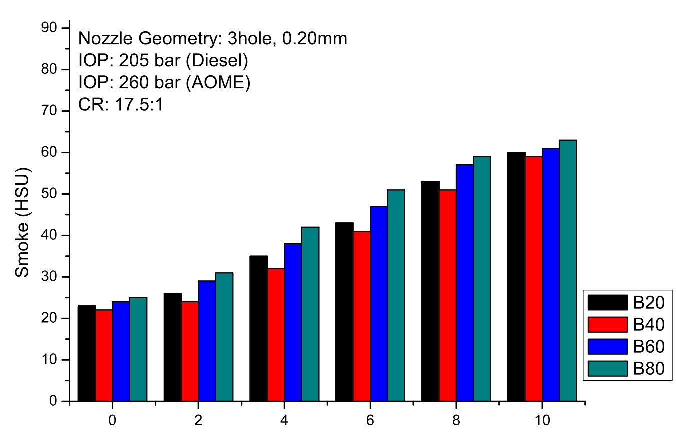

Fig. 19. Variation of smoke with load.

content, efficient combustion occurs for the B40D60 blend and hence produces less smoke emission when compared to pure diesel and other biodiesel blends.

4.15. Variation of Brake Thermal Efficiency with load

Fig. 20 depicts the brake thermal efficiency v/s load variation for various blends of algae oil at CR 17.5:1 and 4 hole, 0.25 mm diameter fuel injector at 260 bar IOP. The graph indicates that brake thermal efficiency increased progressively with increasing load for all AOME-biodiesel blends compared with diesel in the graph. From the graph, it is seen that the blend B40D60 gives enhanced contrary to all other biodiesel blends. Whereas all blends have lesser BTE than diesel. Also, the fuel atomization takes place at 260 bar pressure exposing a greater surface area leading to the efficient combustion of fuel particles. From the graph, it is also clear that the BTE of the biodiesel is higher in comparison to pure diesel.

4.16. Variation of smoke with load

Fig. 21 shows the smoke emission v/s load variation for various blends of algae oil at CR 17.5:1 and 4 hole 0.25 mm diameter fuel injector at 260 bar IOP. From the graph, it is seen that with increasing load the algae oil blends produced high smoke density. Vaporization and poor air-fuel mixing caused due to the higher viscosity of algae oil is the reason for partial combustion, which in turn produces denser smoke. Because of the high cetane number and higher oxygen content, efficient combustion occurs for the B40D60 blend and hence produces less smoke emission when compared to pure diesel and other biodiesel blends.

Diesel compared with Optimized Blend.

4.17. Variation of Brake Thermal Efficiency with load

Fig. 22 shows the brake thermal efficiency v/s load variation for various blends of algae oil at CR 17.5:1 and 4 hole, 0.25 mm diameter fuel injector at 260 bar IOP. The graph shows that brake thermal efficiency increased progressively with increasing load. From the graph, it is observed that the B40D60 blend gives enhanced BTE contrary to all other biodiesel blends. Whereas all blends have lesser BTE than pure diesel. Also, the fuel atomization takes place at 260 bar pressure exposing a greater surface area leading to the efficient combustion of fuel particles.

From the graph, it is found that during comparison for BTE between biodiesel and diesel, biodiesel is the better option since most engines will be operating on part load. With CR 17.5:1 at 260 bar IOP, the maximum BTE for diesel (27.27) is slightly greater than the B40D60 (25.43) biodiesel blend. This blend gives properties closer to that of diesel and comparable viscosity and improved combustion with effective consumption of air might be the reasons for the improved performance of the B40D60 optimized blend.

4.18. Variation of smoke with load

Fig. 23 shows the smoke emission v/s load version for different blends of algae oil at CR 17.5:1 and 4 hole, 0.25 mm diameter fuel injector at 260 bar IOP. From the graph, it is seen that with increasing load the algae oil blends produced high smoke density. As depicted by Sunilkumar et al. [29] the vaporization and poor air-fuel mixing caused due to higher viscosity of algae oil is the reason for partial combustion, which in turn produces denser smoke. Because of the high cetane number and higher oxygen content, efficient combustion occurs in the B40D60 blend and hence produces less smoke emission when compared to pure diesel and other biodiesel blends.

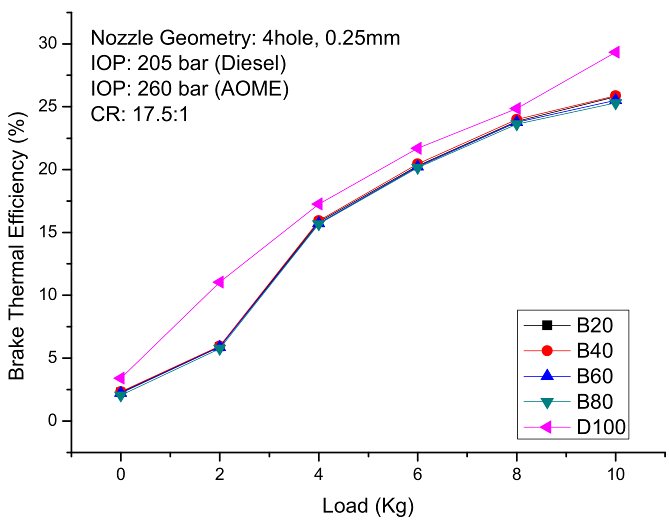

Fig. 20. Variation of brake thermal efficiency with load.

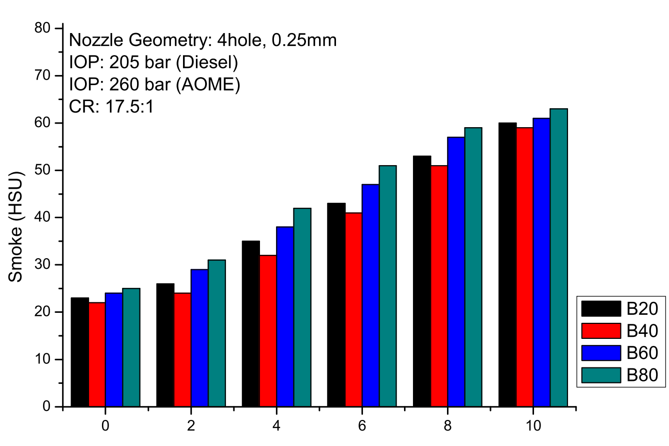

Fig. 21. Variation of smoke with load.

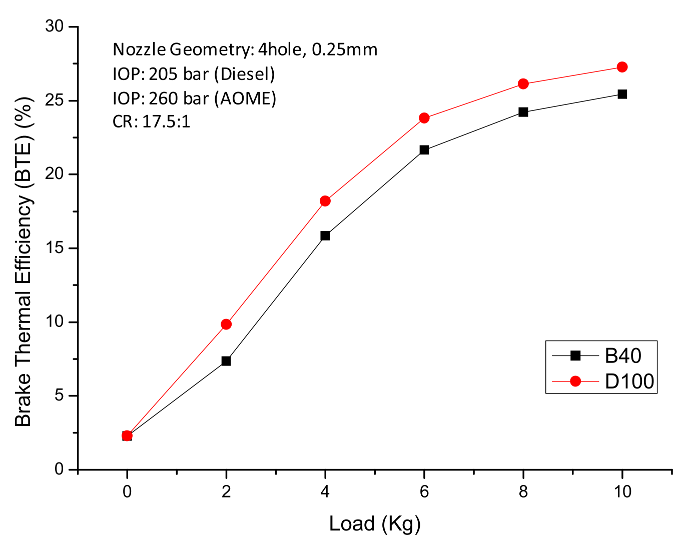

Fig. 22. Variation of brake thermal efficiency with load.

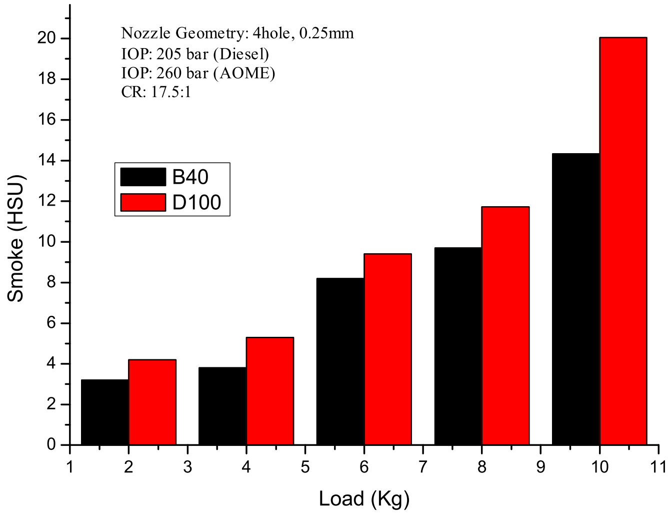

Fig. 23. Variation of smoke with load.

5. Conclusion

The experiments are carried out on a VCR engine using blends of AOME biodiesel and diesel, further conclusions are drawn based on the experimental results obtained.

- The properties of biodiesel such as density and viscosity are quite close to the diesel properties but the CV of biodiesel is lower i.e. 41000 kJ/kg.
- The remark of this comprehensive investigation reveals that at 260 bar IOP and CR17.5:1 the biodiesel blend B40D60 provides better results than the remaining alternative blends. This is achieved by optimizing different operating parameters with the absolute combustion of biodiesel fuel.
- To run the engine using AOME biodiesel, there is little or no need to modify engine configurations.
- To minimize exhaust emissions like NOx, highly developed techniques like EGR, CRDI can be used.
- Complete combustion takes place with the lowest emissions due to vaporization and atomization of fuel droplets at a high injection pressure of 260 bar.

Credit author statement

Basavaras B. Patil: Writing–original draft. **S. N. Topannavar:** Methodology. **K. M. Akkoli:** Writing-review & editing. **M. M. Shivashimpi:** Conceptualization, Resources, Supervision. **Sunilkumar S. Kattimani:** Supervision, Formal analysis.

Declaration of competing interest

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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