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Performance Studies on Diesel Engine Using Dairy Scum Oil Methyl Ester (DSOME)

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Abstract

The compression ignition (CI) engines are most efficient and robust but they rely on depleting fossil fuel. Hence there is a speedy need to use alternative fuels that replaces diesel and at the same time engine should yield better performance. Accordingly, Dairy Scum oil methyl ester (DSOME) was selected as an alternative fuel to power CI engine in the study. In the first part, this paper aims to evaluate best fuel injection timing (IT) and injector opening pressure (IOP) for the biodiesel fuels (BDF). The experimental tests showed that DSOM yielded overall better performance at IT of 27° before top dead centre (BTDC) and IOP of 240 bar. In the second part, the effect of number of holes on the performance of BDF powered CI engine was studied keeping optimized IT and IOP. An injector of five holes with 0.3 mm orifice diameter yields better performance when engine powered with BDF at optimized conditions.

Keywords: Dairy Scum oil methyl ester (DSOME); Number of holes; Performance

Introduction

Biodiesel is a renewable, clean burning replacement to India dependence on foreign petroleum, and creating jobs. It is prepared from a various feedstock's including animal fats [1]. The word biofuel covers a wide range of production, some of which presently commercially available and some of which are still in research and developments [2]. Biodiesel fuels burns up to 75% cleaner than diesel fuel. Biodiesel to a great extent reduces unburned hydrocarbons, carbon monoxide and particulate matters from the exhaust gas. Sulphur dioxide emissions are completely eliminated, 80% less carbon dioxide and provides a 90% reduction in cancer risks. Biodiesel helps preserve natural resources for every units of energy needed to produce biodiesel, 3.24 units of energy are gained nearly four times more than diesel [2].

India has set out plans to boost market over the next few years in an effort to strength its energy security. Fuel consumption profile derived from domestic feed stocks would lead to decrease in this dependence on crude oil imports. The Indian government has proposal for blending of bioethanol increased to 20% with diesel. By this adoption of fuel processing and production biodiesel and bioethanol faster, it can improve the society. Research and development centres had done lot of work on boosting performance of engine and even today research going on to get rid of energy crisis and still engine manufactures trying to make the necessary changes to engines to ensure compatibility with biofuels [3].

Literature Review

The plant oil fuels have longer ignition delay with slower burning rates so alternative fuel requires injection advance appropriate to its delay period. Engine at 2400 rpm, there will increase in brake thermal efficiency and a small reduce in mechanical Efficiency when rapeseed oil fuel is used in standard injection timing. There seems to be reducing in carbon monoxide (CO) and carbon dioxide (CO_2) emissions. Overall results showed in this paper, there will be longer combustion duration with moderate rates of pressure rise [4]. Advancing in injection timing (IT) could cause reduction in brake specific fuel consumption (BSFC), CO, hydrocarbon (HC) and smoke and increase in brake thermal efficiency (BTE) and peak cylinder pressure and also oxides of nitrogen (NOx) emission. With five crank angle retard in IT causes increase in BSFC, CO, HC and smoke with reduction in BTE, peak pressure and NOx. With proper IT tuning process can lead to benefits in terms of performance and emissions, when the diesel engine is operate with jatropa biodiesel [5]. The similar result is obtained by use of waste cooking oil and diesel with changes in fuel IT. With earlier IT, combustion started earlier and reached higher peak pressures in better engine at earlier crank angle. For optimum IT, waste cooking oil will get shortest ignition delay (ID) and the premixed combustion intensity will be reduced. In exhaust emission, advancing timing reduces the CO emission and increases the NO emissions [6]. The influence of IT on the performance of a direct ignition diesel engine experimentally investigated using waste plastic oil with retarded IT. Engine an able to run 100% waste plastic oil, reduced peak pressure, increased in BTE, NO and CO is reduce and unburned HC dramatically reduced [7].

Literature Survey on it and Injector Opening Pressure (IOP)

The effect of IT is quite significant on the performance of internal combustion (IC) engines. Advance in fuel IT could compensate these effects of late burning and late combustion [4]. The best IT for engine run on Jatropha biodiesel was reported to be 20^{o} BTDC for minimum fuel consumption and emissions. Advancing the IT by 4^{o} from 15^{o} BTDC, the diesel engine gave 1.6% more thermal efficiency [6]. When IT was retarded from 23^{o} BTDC to 20^{o}, 17^{o} and 14^{o} BTDC with waste plastic oil, it was found that reported increase in BTE and CO_2 at all test conditions [7]. Direct injection diesel engine fuelled with soybean oil also showed slight increase in fuel consumption with IT retardation [8]. Higher fuel injection pressure resulted in improved performance in terms of BTE [9]. Fuel injection pressure of 240 bar is the optimum and at this optimum injection pressure the BTE was close to diesel engine with decreased CO but increased NOx [10]. When IT was to 20^{o}, 17^{o} and 14^{o} BTDC for a diesel engine run on waste plastic oil, 30% reduction in unburnt HC at all test conditions was reported [7]. Lower BSFC, CO and smoke with higher BTE and more NOx at 225 bar and 30^{o} BTDC of injection pressure and IT respectively. However, an injection pressure of 225 bar, IT of21^{o} BTDC and 2.5 mmnozzle tip protrusion were found to be optimum values [11]. Use of biodiesel and different methods of using them in normal diesel engine could be seen in the literature [12-14]. The effects of injection timing (IT), injector opening pressure (IOP) and compression ratio (CR) on brake thermal efficiency (BTE) of a single-cylinder direct injection (DI) diesel engine was reported. Mathematical models developed provide the relationship between the process parameters and the varied input characteristics. The RSM based result analysis reveals that retarding the IT improved the performance of diesel engine [15].

The objective of this current study is to test the locally available Dairy Scumoil methyl ester (DSOME)for CI engine application and to improve their performance in terms of higher BTE and lower exhaust emissions with different injection strategies.

Fuels Used and Experimental Procedure

Fuels used: An important factor in selection of oil for the biodiesel production is the fatty acid profile. Vegetable oils with certain fatty acids yield a biodiesel with characteristics close to conventional diesel. The ratio of unsaturated fatty acids to saturated fatty acids is an important factor in deciding the properties of biodiesel obtained. If the oil has more saturated fatty acids than the unsaturated fatty acids, the biodiesel obtained has more viscosity. Whereas, the oils with higher unsaturated fatty acids yield biodiesel that is less viscous and have higher cloud and pour points. Biodiesel produced from feedstock with higher unsaturated fatty acids have a strong effect on the long term oxidative stability of biodiesel. In the current study, Dairy Scumoil methyl ester (DSOME) derived from the locally available Dairy Scum oil. Milk production of nearly 150 million tonnes per year is reported in India. In large dairies the residual butter and related fats get collected during washing in effluent treatment plants as a scum. A large diary which processes 5 lakh liters of milk per day will produce approximately 200- 350 kg of effluent scum per day which makes it difficult for its disposal.

Scum is usually formed by a mixture of fat, lipids, proteins, and packing materials. Most of the dairies dispose this scum which is turbid white in colour and semi solid in texture, in solid waste disposal site or by incinerating. Scum oil extracted from waste and can be used for its biodiesel production through transesterification process to produce Dairy Scum Oil Methyl Ester (DSOME). DSOME has fuel properties similar to diesel. In the present study, dairy scum oil methyl ester was used as a potential alternative fuel for a modified diesel engine application.

The properties of DSOME were measured at Bangalore Test House Laboratory, Bengaluru, India. The properties of the fuels used are given in Table 1.

Sl. No.	Properties	Diesel	DSOME	Standard Limits		ASTM standard
				Min.	Max.	
1	Kinematic Viscosity (cSt at40°C)	2.54	3.9	1.9	6	ASTM D445
2	Flash point (°C)	54	130	100 –	-	ASTM D93
3	Calorific Value (kJ/kg)	43500	39940	-	-	ASTM D5865
4	Density (kg/m^3 at 15°C)	830	870	860	900	ASTM D4052
5	Cetane Number	50	52.8	47	-	ASTM D613

Table 1: Properties of Diesel and DSOME.

Experimental Procedure: Initially the experimental tests were carried out on compression ignition (CI) engine at the engine speed of 1500 RPM at different loading conditions to obtain best BTE conditions. The readings recorded only after engine attained stable condition. Next the experiments were conducted only at 80% and 100% load using diesel, DSOME fuels with 3, 4 and 5 hole injectors. Specifications of the CI engine test rig used for the experimental study are shown in Table 2. Engine cooling was achieved by applying circulating water through the jackets of the engine and cylinder head. A piezoelectric transducer (Make: PCB Piezotronics, Model: HSM 111A22, Resolution: 0.145 mV/kPa) fitted to the cylinder head was utilized to measure the in cylinder gas pressure. The heat release rate (HRR) of the fuel causes variation of gas pressure and temperature within the engine cylinder. The HRR was calculated using the procedure followed in literature [16,17]. The start of combustion process was determined from the differentiated cylinder gas pressure variation time data where a sudden rise in the slope at the point of ignition due to the sudden high premixed heat release. The end of combustion process was taken as the point where 90% of the heat release had occurred (calculated from the cumulative heat release curve). The ID is the time lag between the start of injection and the start of ignition. The start of injection was obtained based on the static fuel IT.

Exhaust gas composition during the steady-state operation was measured by employing a Hartridge smoke meter and five-gas analysers (A DELTA 1600 S-non dispersive infrared analyzer) (Figure 1).

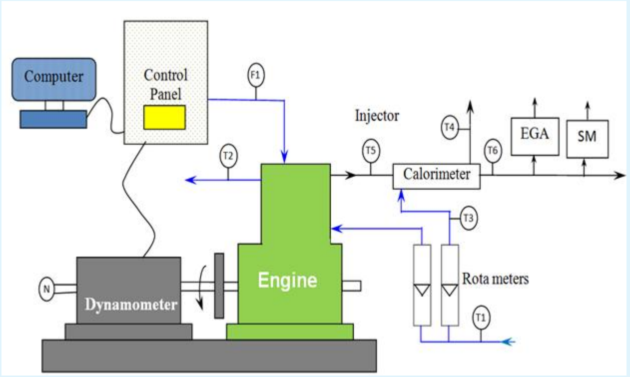


Figure 1: CI engine test rig used for the current experimental study.
T1, T3 - Intake Water Temperature. T2 - Outlet Engine Jacket Water Temperature. T4 - Outlet Calorimeter Water Temperature, T5 - Exhaust Gas Temperature before Calorimeter, T6 - Exhaust Gas Temperature after Calorimeter, F1- Fuel Flow DP (Differential Pressure) unit. N - RPM encoder, EGA - Exhaust Gas Analyzer, SM - Smoke meter.

Banapurmath NR, et al. Performance Studies on Diesel Engine Using Dairy Scum Oil Methyl Ester (DSOME). Pet Petro Chem Eng J 2018, 2(2): 000143.

Sl No	Parameters	Specification
2	Type	TV1 (Kirloskar make)
3	Software used	Engine soft
4	Nozzle opening pressure	200 to 225 bar
5	Governor type	Mechanical centrifugal type
6	No. of cylinders	Single cylinder
7	No. of strokes	Four stroke
8	Fuel	H. S. Diesel
9	Rated power	5.2 kW (7 HP at 1500 RPM)
10	Cylinder diameter (Bore)	0.0875 m
11	Stroke length	0.11 m
12	Compression ratio	17.5 : 1
Air Measurement Manometer:		
13	Made	MX 201
14	Type	U- Type
15	Range	100 – 0 – 100 mm
Eddy current dynamometer:		
16	Model	AG – 10
17	Type	Eddy current
18	Maximum	7.5 (kW at 1500 to 3000 RPM)
19	Flow	Water must flow through Dynamometer during the use
20	Dynamometer arm length	0.180 m
21	Fuel measuring unit – Range	0 to 50 ml

Table 2: CI Engine specifications.

Uncertainty analysis of the experimental data: The accuracies of the measurements and the uncertainties in the calculated parameters of the current investigation are provided in the Table 3. In order to minimize the errors of physical parameter measurements five readings were recorded and averaged out results are only taken for the analysis.

Measured Variable	Accuracy (±)
Load, N Engine speed, rpm Temperature, ^oC Fuel consumption, g	0.1 4 1 0.1
Measured Variable	**Uncertainty (%)**
HC CO NOx Smoke	±4 ±2.5 ±2.4 ±1.2
Calculated Parameters	**Uncertainty (%)**
BTE , % HRR, J/^{o}CA	±1.1 ±1.2

Table 3: Accuracies of measurements and uncertainties in the calculated output parameters.

Results and Discussion

This section explains the effect of IT, IOP, NG on the performance of diesel engine fueled with diesel and DSOME respectively.

Optimization of IT

In the first phase of this work, studies on basic performance of a single cylinder diesel engine when fueled with diesel, and DSOME were carried out. At the rated speed of 1500 rev/min, variable load tests were conducted at four ITs of 19°, 23°, 27° and 31° BTDC keeping IOP constant at 205 bar. For each load, air flow rate, fuel flow rate, exhaust gas temperature, HC, CO, CO_2, smoke and NO_x emissions were recorded. Based on the averaged out results from five readings at each of the conditions specified, optimum IT was determined for each of the fuel tested. The effect of IT on BTE with diesel, and DSOME at four IT is shown in Figure 2. The highest BTE is obtained with diesel at a static IT of 23° BTDC. BTE values were lower for DSOME as compared to diesel for all four IT tested. The decrease in BTE for DSOME might be attributed to lower energy content of the fuel and higher fuel consumption required for the same power output. Due to higher viscosity of DSOME the formation of the mixture and subsequent combustion were poorer than diesel. The maximum BTE at 23^0BTDC is 25% as compared to 31.25 % for diesel. However, by advancing the IT by 4^oCA an improvement in BTE was obtained. It is about 25.6 % at an IT of 27° BTDC. Based on the magnitudes of BTE the optimum IT for diesel, and DSOME are selected accordingly as 23° BTDC, and 27^0 BTDC respectively.

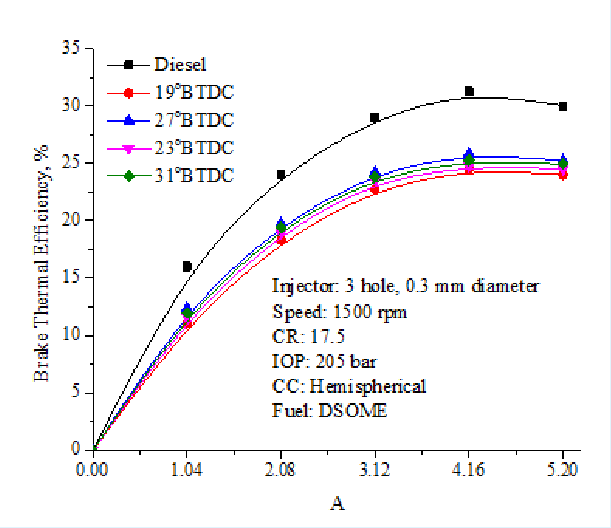


Figure 2: Effect of injection timing on Brake Thermal Efficiency.

Effect of IT on smoke opacity: The effect of IT on smoke emission for diesel, and DSOME is shown in Figure 3. Smoke opacity for both fossil diesel and renewable fuel DSOME increased with increased brake power. Increased quantity of pilot fuels injected in the engine cylinder results into increased smoke emissions. The greater smoke opacity observed with DSOME compared to diesel fuel could be mainly due to emission of higher molecules of HC and particulate associated. Comparatively heavier molecular structure of DSOME due to its higher viscosity and density could also be responsible for the higher smoke emissions. For the same loading operation lower volatility and lower energy content of the biodiesel compared to diesel operation results into varied air-fuel ratio and hence incomplete combustion with higher smoke emissions. The smoke emission with DSOME generally increases as the IT is retarded. The smoke emission with DSOME is found to be minimal for retarded IT of 27° BTDC as shown in Figure 3. The reasons for incomplete combustion are incorrect air-fuel ratio and improper mixing. It is seen that with DSOME the smoke level falls when the IT is advanced to 27° BTDC from 19 and 23° BTDC. When the injection is advanced to 27° BTDC, fuel injection occurs at lower temperature and pressure in the cylinder. This results in an increase in the ID and hence a significant portion of the injected fuel burns in the premixed mode. This results in lower smoke. However, with the further increase in IT to 31° BTDC the smoke level increased due to fall in BTE.

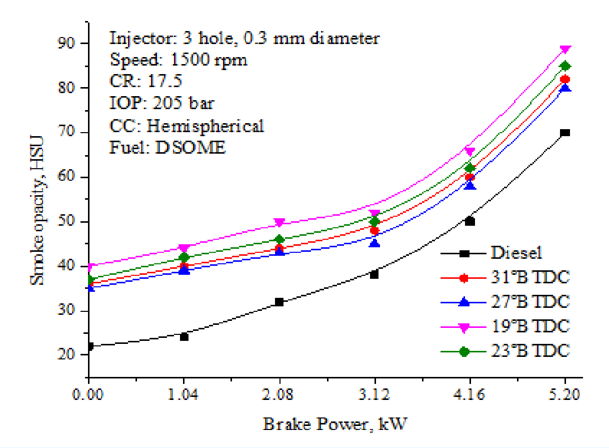


Figure 3: Effect of injection timing on Smoke opacity.

Effect of IT on HC and CO emissions: Figure 4 & 5 shows the effect of IT on HC and CO for diesel, and DSOME. HC emissions exhausted from diesel engines are caused due to incomplete combustion. Lean mixture existing in the engine cylinder during ID and non-uniform mixing of fuel that leaves the fuel injector orifice at reduced velocity could also be responsible for these results. The general trend of increased HC and CO emissions for DSOME is observed as compared to diesel for all four IT tested. This may be because of decreased combustion efficiency with DSOME as injected biodiesel resulting in wall wetting.

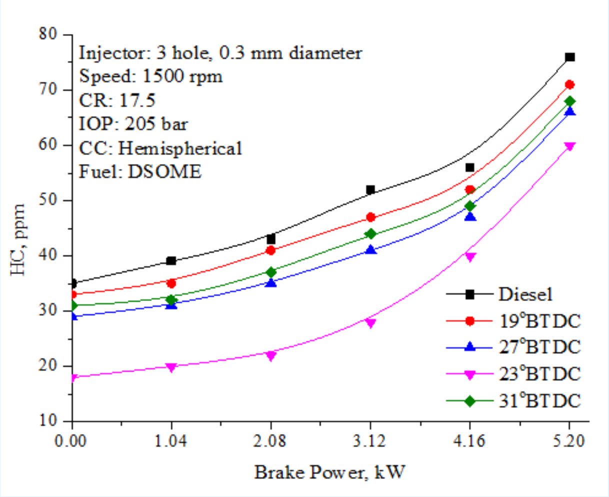


Figure 4: Effect of injection timing on Unburned Hydrocarbon Emissions.

Carbon monoxide emissions: The amount of CO decreased at part loads and increased at higher loads at all the IT for the injected pilot fuels. DSOME showed comparatively higher CO emissions for the probable reasons explained in HC emissions. HC and CO emissions were also lowest at 27° BTDC as compared to other IT with DSOME as fuel.

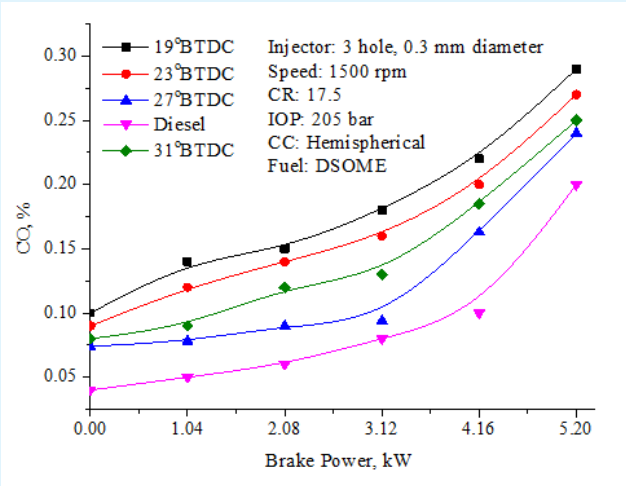


Figure 5: Effect of injection timing on Carbon Monoxide Emissions.

Effect of IT on NOx Emissions

The effect of IT on emissions of NOx with brake power for diesel, DSOME is shown in Figure 6. With DSOME NOx emissions were lower compared to diesel fuel at all the IT. Higher BTE obtained with fossil diesel and the associated higher premixed combustion phase could be responsible for the observed increased NOx trends. The main factors responsible for NOx formation are increased temperature, oxygen availability and residual time. In general, retarded injection results in substantial reduction in NOx emissions. As the IT is retarded, the combustion process gets retarded. NOx concentration levels are lower as peak temperature is lower. NOx levels are higher with DSOME operation at advanced IT of 23°,27° and 31° BTDCas they lead to a sharp premixed heat release due to higher ID. From these results it could be said that the IT of 27° BTDC (static) is the optimum for DSOME as the BTE increased while smoke, HC and CO were lower at this IT.

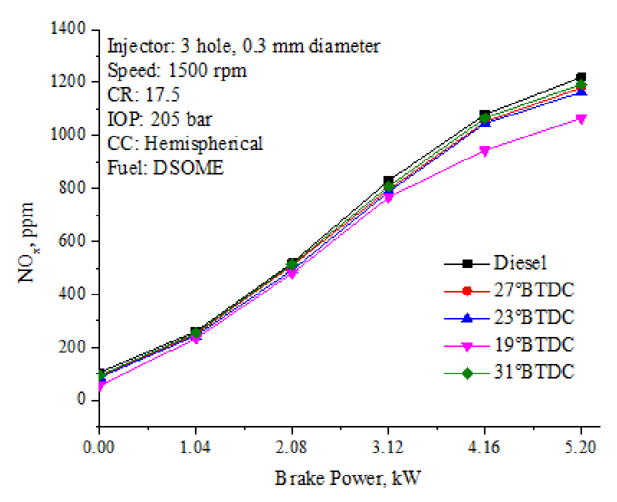


Figure 6: Effect of injection timing on NO_x Emissions.

Effect of IT on Combustion Parameters

Peak Pressure: Figure 7 shows the effect of IT on peak pressure with brake power for diesel and DSOME operation respectively. Lower peak pressures were resulted with DSOME operation at all the IT compared to fossil diesel due to its lower energy content. It could be due to the combined effect of longer ID, lower adiabatic flame temperature and slower fuel burning nature of the biodiesel. However, when the IT is advanced the peak pressure increased as the delay period also increased for DSOME operation. For the retarded IT, ID lowers and the engine operation was found to be noiseless and smooth. Lower pressure and temperature at the beginning of injection results with the retarded IT and hence the peak pressure lowered.

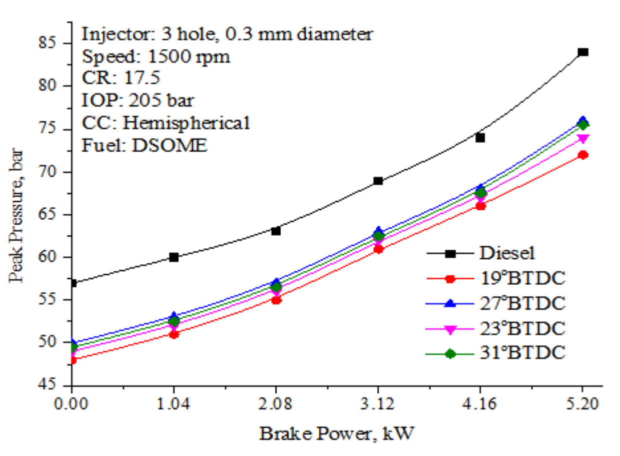


Figure 7: Effect of injection timing on Peak Pressure.

Ignition delay: The effect of IT on ID with brake power is shown in Figure 8. ID is calculated based on the static IT. ID decreased with load and increased with biodiesel operation. DSOME showed longer ID as compared to diesel. However, when the IT is advanced the ID decreased as the increased BTE provides improved combustion for DSOME operation.

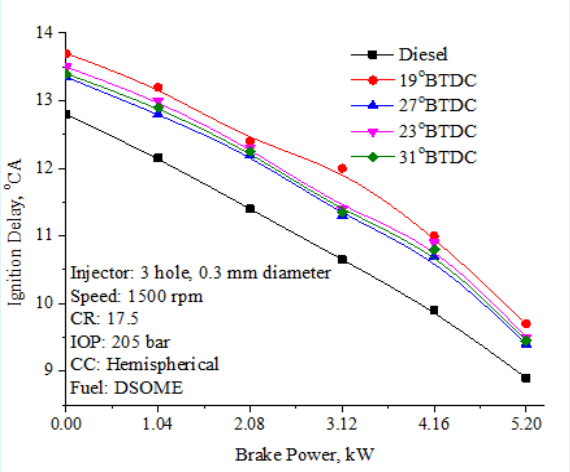


Figure 8: Effect of injection timing on Ignition Delay Period.

Combustion duration: The combustion duration is shown in Figure 9. The combustion duration increased with increase in the power output with both fuels and IT as well. Higher combustion duration is observed with DSOME than diesel due to enlarged diffusion combustion phase. With the advanced IT the combustion duration reduced. This could be attributed to the amount of fuel being burnt inside the cylinder gets increased.

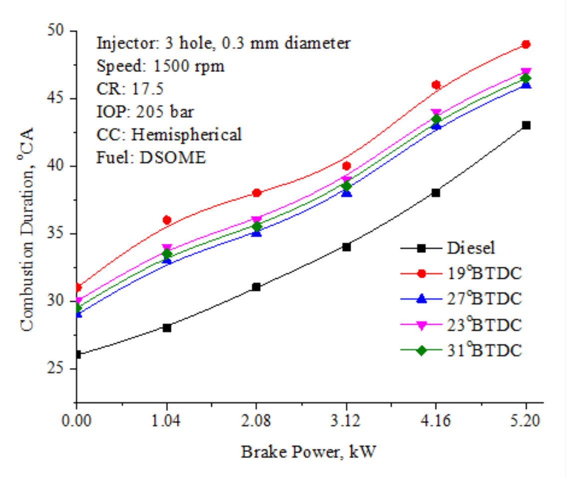


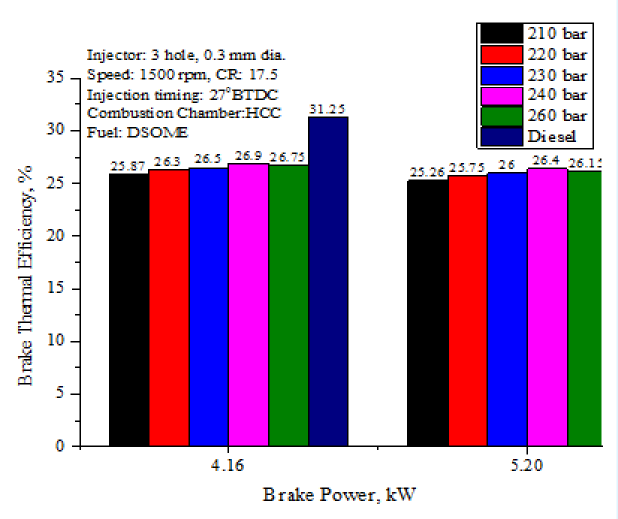
Figure 9: Effect of injection timing on Combustion Duration.

Optimization of IOP

In the second phase of this work, studies on performance of engine were carried out with DSOME at different IOP at 1500 rev/min. At each load, air flow rate, DSOME flow rates, exhaust gas temperatures, HC, CO, smoke and NOx emissions were recorded. Engine was operated only at IOP of 205 bar on diesel mode. The effect of IOP and different nozzle geometry such as 3, 4, and 5 holes at the static IT of 27° BTDC, IOP of 240 bar is presented in the following graphs.

Effect of IOP and Different Nozzle Geometry on BTE

The effect of brake power on BTE at different IOP and different nozzle geometry is shown in Figure 10. Amongst all the IOPs tested, the highest BTE achieved at 240 bar. This is because at higher IOP atomization, spray characteristics and mixing with air are better. Too high a IOP (260 bar) will lead to delayed injection negating the gain due to higher IOP. BTE was 28% at 80% load with 5-hole nozzle and at an IOP of 24 MPa. However, BTE for 3-hole and 4-hole nozzles were found to be 27.25% and 27.6% respectively at 24 MPa. Based on the results, BTE was found to be high with 5-hole injector nozzle geometry and IOP of 24 MPa. Engine operation at an IOP of 24 MPa, other two nozzles (3-hole and 4-hole) were also found to be higher respectively. It is seen that increase in number of holes may increase the fuel-air mixing rate.



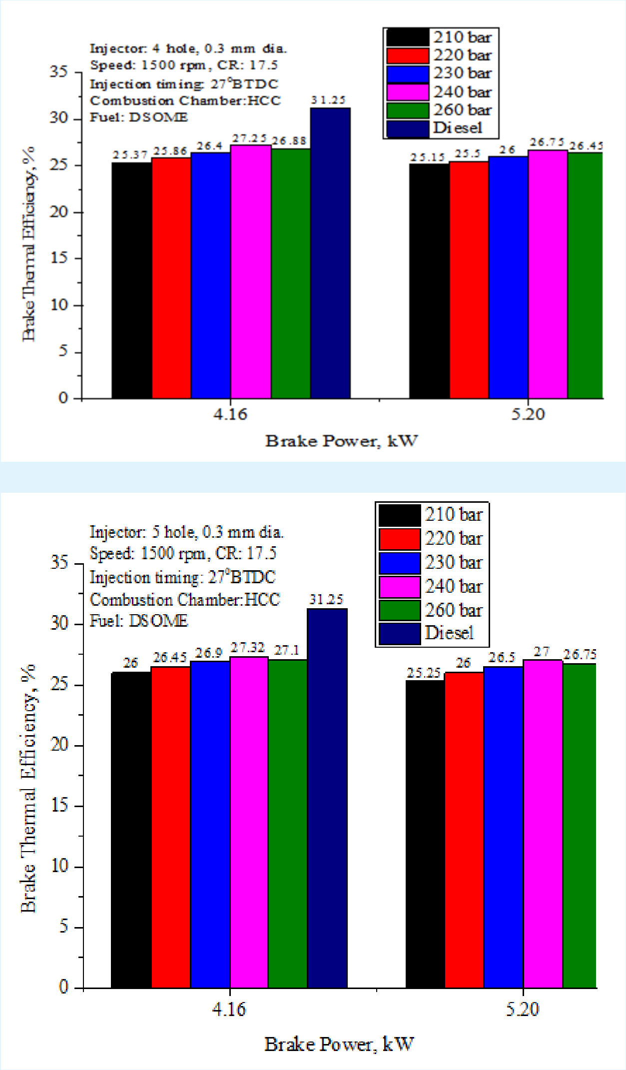


Figure 10: Effect of IOP and Nozzle geometry on Brake Thermal Efficiency.

Effect of IOP and nozzle geometry on smoke opacity: Figure11 shows the effect of IOP and different nozzle geometry on smoke opacity with brake power. Smoke levels decreased with increase in the IOP. Lowest smoke level is seen with the IOP of 240 bar. Too high IOP (260 bar) will lead to delayed injection negating the gain in BTE and hence smoke opacity increased. At 80 % load the smoke level was decreased from 56 HSU to 49 HSU when the IOP was increased from 205 to 240 bar with 3 hole injector. It is seen that increase in number of holes of the injector from 3 to 5 may increase the fuel-air mixing rate and hence ensures improved combustion with reduced smoke emissions.

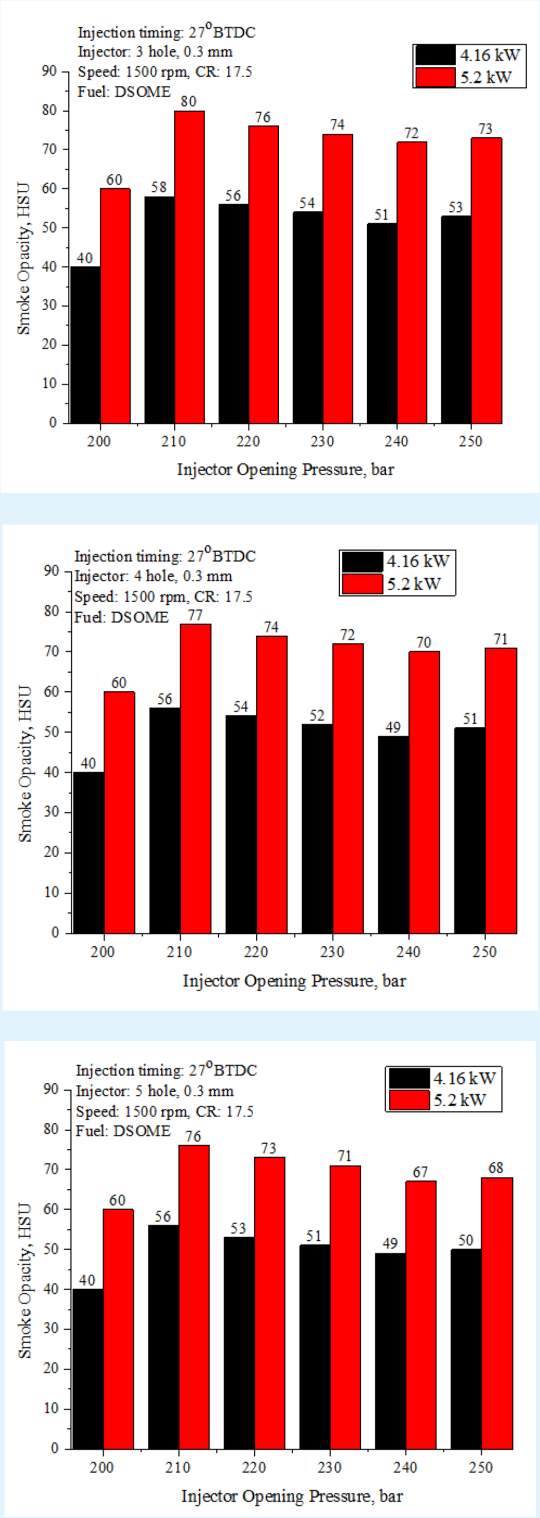
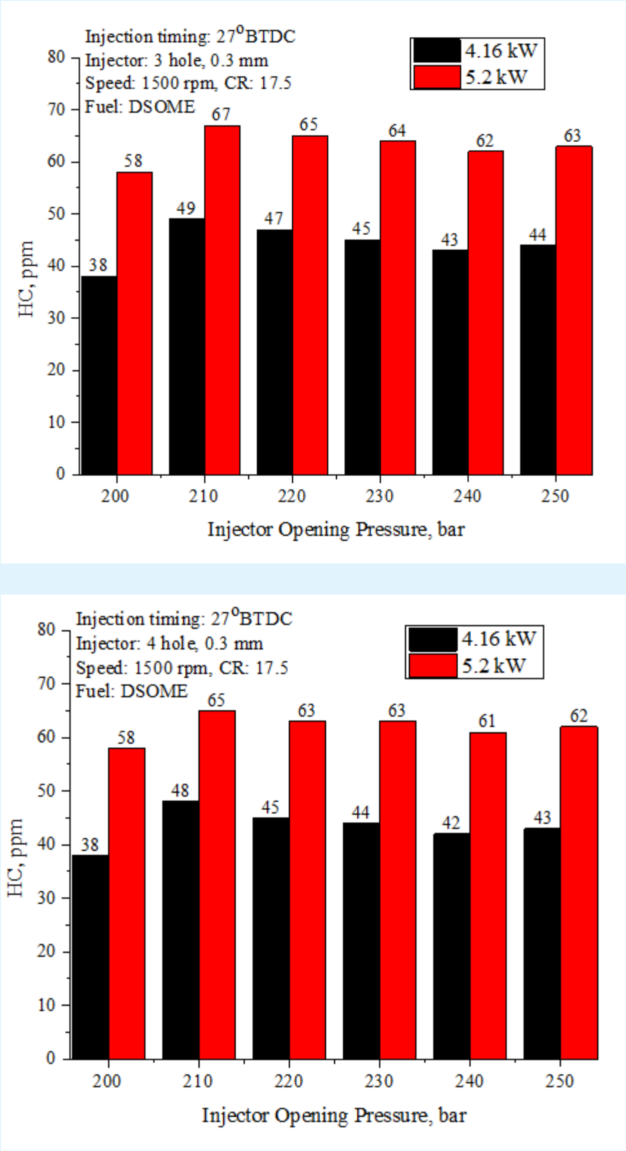


Figure 11: Effect of IOP and Nozzle geometry on Smoke opacity.

Effect of IOP and nozzle geometry on HC emission: Figure 12 shows effect of IOP and nozzle geometry on HC emission with brake power. A significant drop in HC is observed at 240 bar IOP because of better combustion. Enhanced atomization will also lead to a lower ID. This will enhance the performance of the engine with DSOME, which normally have a higher ID on account of their higher viscosity. HC reduced from 47 to 41ppmwhenIOP increasing from 205 to 240 bar at 80% power output. Further HC emissions reduced when injector nozzle holes increased from 3 to 5 at IOP 24MPa. It is concluded that, un-burnt HC were found to be less during the engine operation with 5-hole nozzle and IOP of 24MPa.



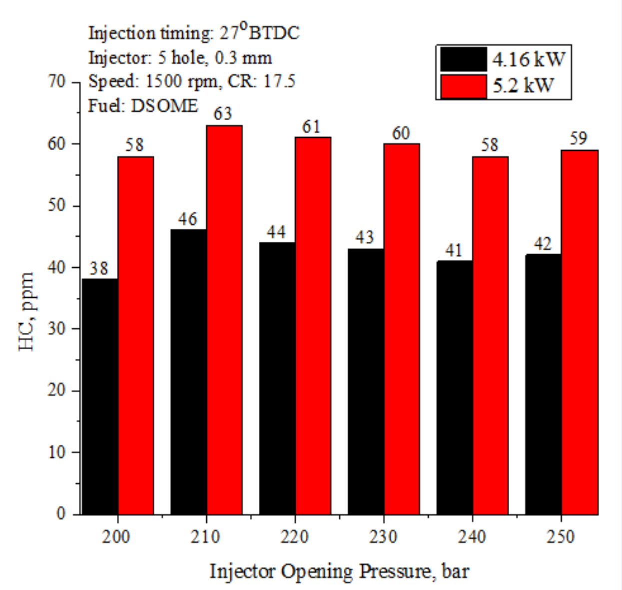
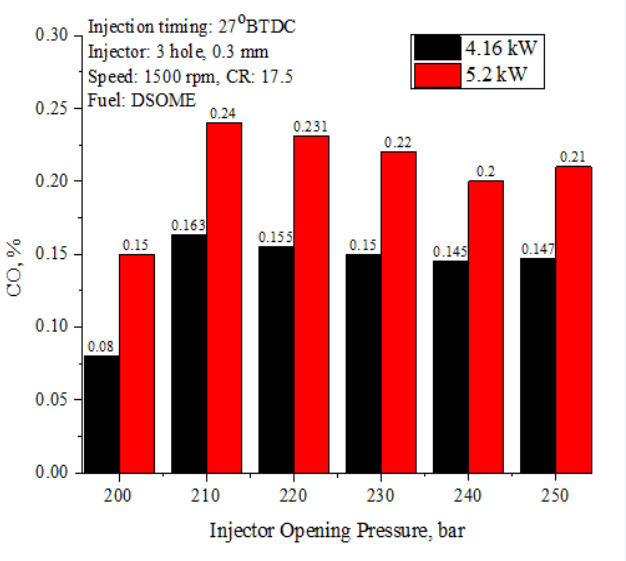


Figure 12: Effect of IOP and Nozzle geometry on Unburned Hydrocarbon Emissions.

Effect of IOP and nozzle geometry on CO emission: Figure 13 shows effect of IOP and nozzle geometry on CO emission with brake power. Observed trends for CO emissions were similar to HC emissions, with lower CO emissions occurring at 240 bar IOP and 5-hole injector.



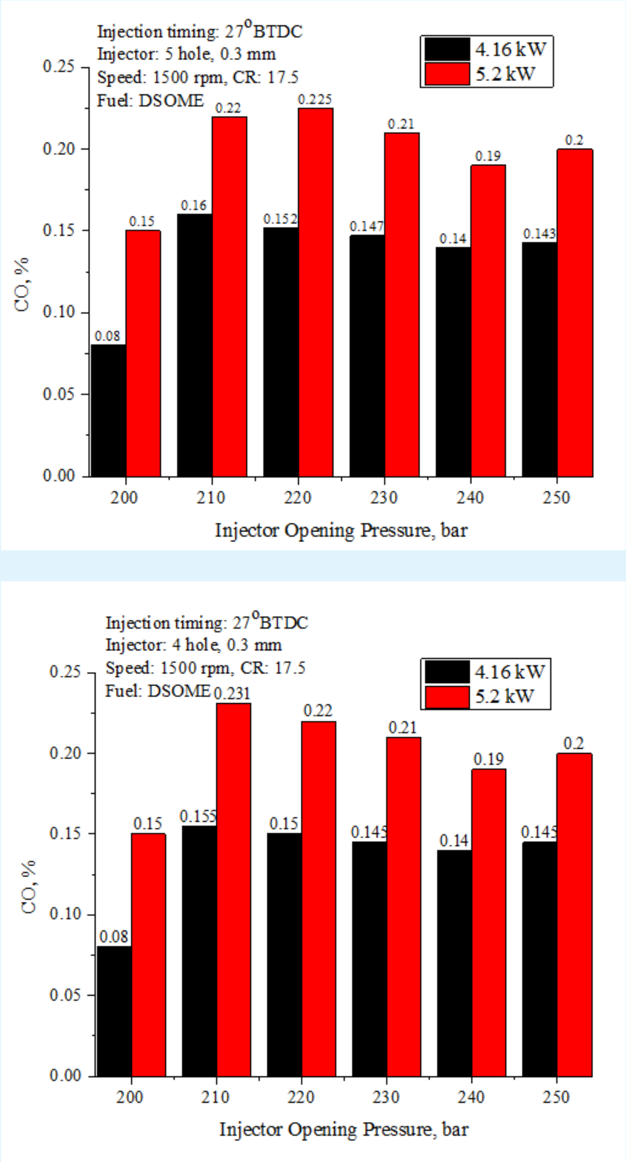


Figure 13: Effect of IOP and Nozzle geometry on Unburned Carbon Monoxide Emissions.

Effect of IOP and nozzle geometry on NOx emission: NOx emissions increased with the increase in IOP which is as shown in Figure 14. Enhanced combustion prevailing inside engine cylinder and higher temperatures reached in the cycle are responsible for increased NOx. For 5-hole nozzle with same orifice size the NOx increased as the BTE is more and higher premixed combustion was observed at these conditions. NOx of 1088 ppm was obtained with a five-hole injector at optimized conditions.

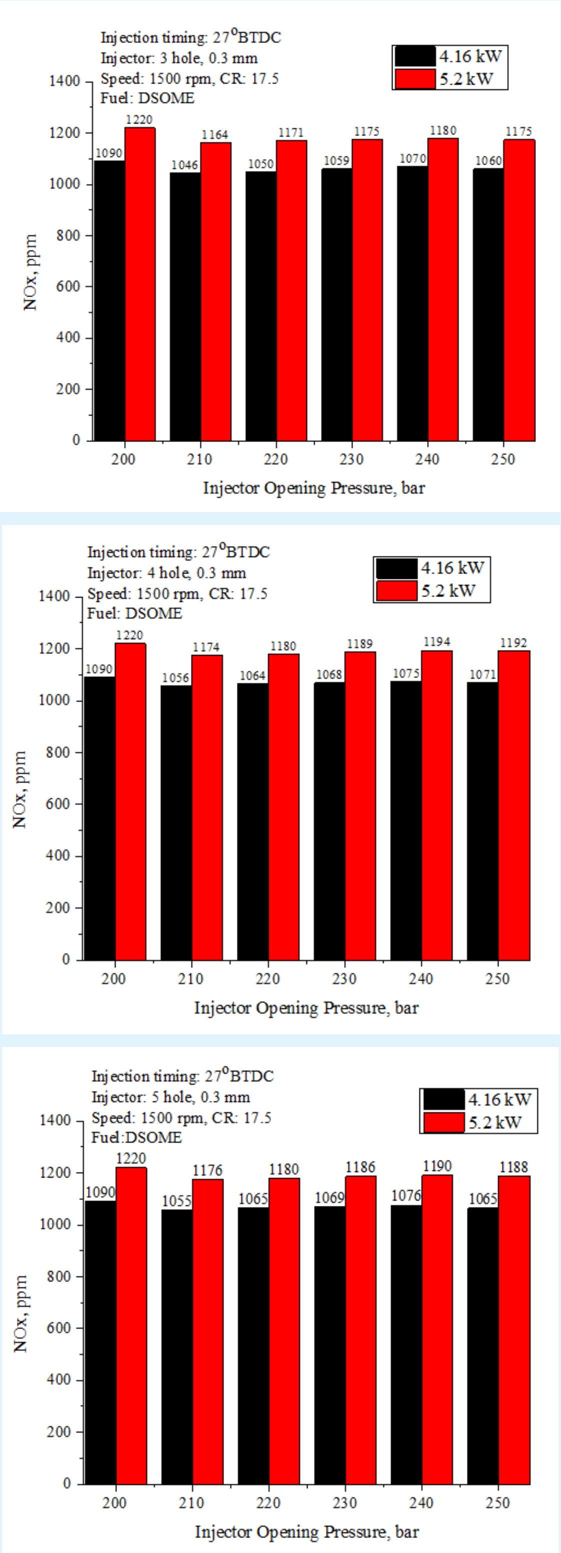


Figure 14: Effect of IOP and Nozzle geometry on NO_x Emissions.

Effect of IOP on peak pressure: Figure 15 shows the effect of IOP on peak pressure with brake power for diesel and DSOME operation respectively using 5-hole injector. Lower peak pressures were resulted with DSOME operation at all Injector opening pressures compared to fossil diesel due to its lower energy content. Throughout the combustion, the peak pressure of DSOME increased with increase in IOP. The increase in peak pressure was observed when the IOP was varied from 21MPa to 24MPa as shown in fig.6. Beyond 24MPa the peak pressure was lowered due to the negation effect. Lower pressure and temperature at the beginning of injection results with the lower IOP and hence the peak pressure lowered.

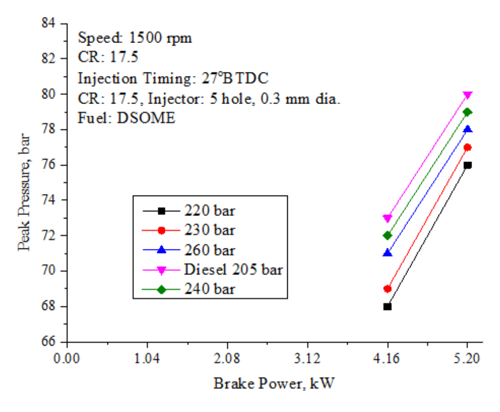


Figure 15: Effect of IOP on Peak Pressure.

Effect of IOP on ignition delay period

Figure 16 shows the effect of IOP on ID with brake power for diesel and DSOME operation respectively using 5-hole injector.ID is calculated based on the static fuel IT. ID decreased with load and increased with biodiesel operation. DSOME showed longer ID as compared to diesel. However, when the IOP is increased the ID decreased as the increased BTE provides improved combustion for DSOME operation.

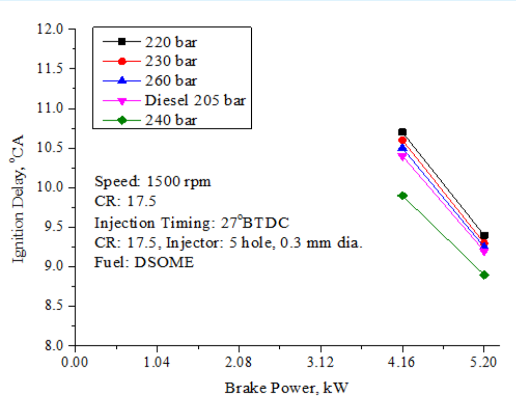


Figure 16: Effect of IOP on Ignition Delay Period.

Effect of IOP on combustion duration: Figure 17 shows the effect of IOP on combustion duration with brake power for diesel and DSOME operation respectively using 5-hole injector. Higher combustion duration is observed with DSOME than diesel due to elongated diffusion combustion phase. With the increased IOP the combustion duration reduced. This could be attributed to the amount of fuel being burnt gets increased.

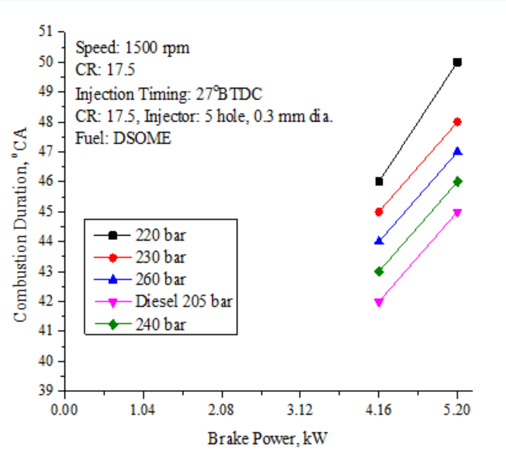


Figure 17: Effect of IOP on Combustion Duration.

Conclusions

The following critical conclusions could be drawn from the experimental results obtained from CI engine operated at engine speed of 1500 rpm and compression ratio of 17.5:

1. The engine powered with DSOME yielded best BTE at fuel IT of 27°BTDC and IOP of 205 bar.
2. Biodiesel showed maximum BTE of 25.6% at fuel IT of 27° BTDC and IOP of 205 bar
3. Against 31.25% for diesel with 3 hole injector.
4. BTE was found to be 28% with 5-hole nozzle and at an IOP of 24 MPaat 80% load.
5. Smoke, HC, CO of 48 HSU, 39 ppm, 0.13 % volume was obtained with five hole injector.
6. NOx of 1088 ppm was obtained which is similar to diesel at same operating conditions.
7. Peak pressure of 73 bar was reported at 80 % load with five hole injector at optimized conditions.

Overall the engine operation was smooth with neat DSOME with no hardware modification. An injector of five holes with 0.3 mm orifice diameter yields better performance when engine powered with BDF at optimized conditions.

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