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Effect of Injection Timing & Injector Opening Pressures on the Performance of Diesel Engine Fuelled With Ceiba Pentandra Oil Methyl Ester

S.B. Nagesh[1], T.K. Chandrashekhar[2], N.R. Banapurmath[3*], S.V. Khandal[4]
[1, 2, 3]Department of Mechanical Engineering,
[1]Channabasaveshwara institute of Technology, Gubbi, Karnataka, India
[2]Mangalore institute of technology, mudibidri-574227,Karnataka, India
[3,4]B.V.B. College of Engineering and Technology, Hubli, Karnataka, India
***Corresponding author: nr_banapurmath@rediffmail.com**

Abstract
Experiments were carried out on a compression ignition (CI) engine to study its performance at different injection timings (IT), injector opening pressures (IOP) and nozzle holes. The Ceiba Pentandra oil methyl ester (CPOME) was selected to check its suitability as CI engine fuel. The engine was operated at 1500 rpm keeping hemispherical combustion chamber (HCC) shape and compression ratio of (CR) of 17.5. IT of 27^0BTDC, IOP of 240 bar and injector of 5 holes yielded better performance. Maximum BTE for CPOME found to be 27.25, 27.6 and 28 % respectively for 3, 4 and 5 holes injector at 80% load against 31.25% for diesel with 3 holes injector and 0.3 mm orifice size. Smoke, HC, NOx and CO emissions for CPOME powered diesel engine were found to be 46 HSU, 39 ppm,1088 ppm and 0.13 % volume respectively for 5 holes injector at optimized conditions. ID, CD, PP and HRR were 9.8 ^{o}CA,40 ^{o}CA, 73 bar and 81 J/^{o}CA respectively for 5 holes injector. Finally it could be concluded that CPOME powered engine operation with optimum engine operating parameters like IT of 27^0 BTDC, IP of 240 bar, and 5 holes injector showed overall better engine performance in terms of higher BTE with reduced emissions.

Key Word and Phrases
Ceiba Pentandra Oil Methyl Ester (CPOME), Injection Strategies, Performance, Emission Characteristics.

1. Introduction

Use of biodiesel and different methods of using them in normal diesel enginecould be seen in the literature [1]-[6]. 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 [7].

Ignition delay (ID), combustion and emission characteristics of diesel engine fueled with biodiesel were reported when engine was fuelled with bio-fuel. It was reported that fuel burning starts early and showed shorter ID [8]. The properties of Ceiba Pentandra methyl ester were well within the recommended biodiesel standard ASTM D6751 and it can be a possible source for biodiesel production [9]. There are more than 350 oil-bearing crops identified as potential sources for biodiesel production around the globe [10]. Biodiesel derived from unrefined Jatropha, Karanja and Polanga seed oil could suit as CI engine fuel and Polanga biodiesel (PB100) gives maximum cylinder pressure but ID were consistently shorter for JB100 [11]. Degummed jatropha of 20% with diesel yielded better results at high loads when IT was at 45˚ BTDC [12]. In the experimental studies using tyre pyrolysis oil (TPO) was blended with Jatropha oil methyl ester (JOME) showed combustion and emission behavior different after 20% TPO in the blend. BTE reduction was revealed with 30%, 40% and 50% TPO in the blend at full load [13]. Shorter ID and higher peak cylinder pressure were observed with JOME and its emulsions with WPO. Smoke opacity decrease was also reported whenemulsions with WPO was increased in comparison with diesel at full load [14]. A review work on the research in last decade was highlighted in the literature toget clean and efficient combustion in diesel engines [15]. It was reported that the biodiesel types have no impact on peak cylinder pressure and BSFC.

Higher in-cylinder pressure and HRR were observed with biodiesel but BSFC for the engine was higher. Biodiesel's physical properties affect the performance of the engine much [16]. Review work provides potential guideline that enhances engine performance using different biodiesels and their blends [17]. The effect of CC shapes & injection strategies on the performance of Uppage oil methyl ester (UOME) powered CI engine was studied and results showed that toriodal CC (TCC) yielded better engine output measurable at fuel IT of 19^o bTDC. Injector used had 6 hole and 0.18 mm diameter each [18]. Biodiesel fuelled engine suffers due to poor cold flow properties and higher viscosity and yields higher nitric oxide (NO) [19], [20]. The work on production of biodiesel with different feed stock was discussed [21]-[24]. However, seeds availability discouraging the use of biodiesel for engine applications [25]. Production of pyrolysis oil by different reactors and upgrading using catalyst has reported [26]. Desulfurized tyre oils with low percentages can be used as an alternative fuels in diesel engine with HC and smoke emission were slightly higher than neat diesel [27]. At high CR of 18.5, it has been reported a reduction in CO, HC and smoke were observed [28]. Operation of engine with 20% of tyre oil or more lead to deteriorated the engine combustion character [29]. By varying intake air flow rate and optimizing to 170 g/hr resulted in NOx emission reduction by 5% when engine is operated with TPO-DEE, simultaneously increasing in HC, CO and smoke emission by 2%, 4.5% and 38% respectively [30]. Specific fuel consumption (SFC) of plastic oil blends was higher than the diesel and CO_2, CO and NOx were also found higher [31]. NOx, CO and unburned HC were decreased, while CO_2 and smoke increased when the IT was 140 BTDC fueled with plastic oil [32].

From the detailed literature review carried out, it was found that CPOME suitability for CI engine and the subsequent effect of different IT, IOP and nozzle hole combinations on the this biodiesel fueled engine was scarcely reported. Hence the objective of the present experimental work is to study the performance, combustion and emission characteristics of CI engine powered with CPOME with different IT, IOP and nozzle hole combinations.

2. Materials and Methods

2.1. Fuels used in Present Study

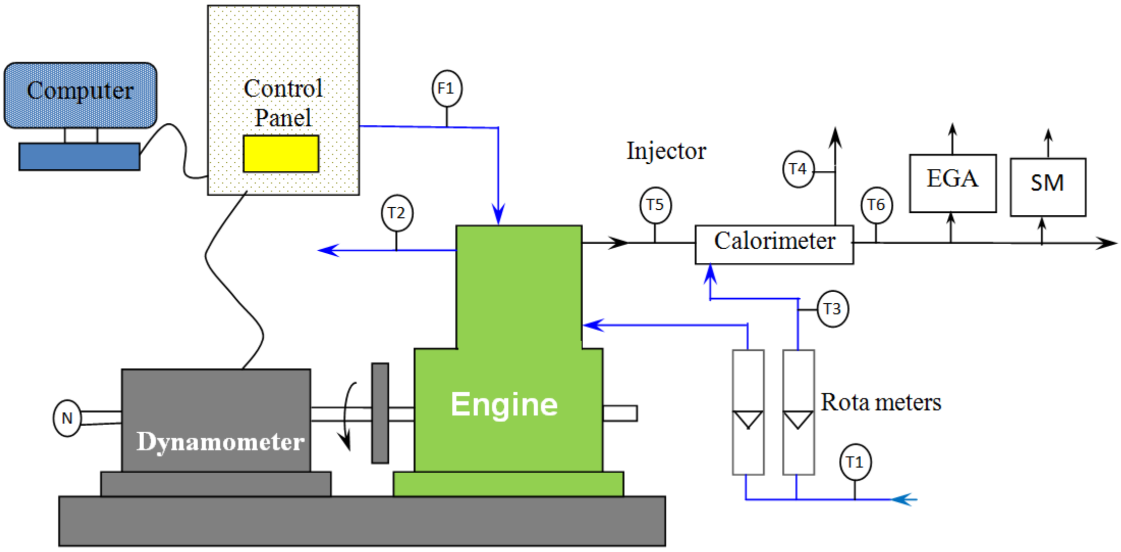
Ceibapentandra L also called as kekabu and kapok belongs to the Malvaceae family. It is a non-edible oil and used for biodiesel production. This is abundantly available in India and other Asian country. The seeds of Ceibapentandra contains about 28-30% oil. It contains high fiber and can be used for ethanol production. The physicochemical and fatty acid composition of Ceibapentandra and its effect on the biodiesel production were investigated by several investigators [10], [33]. Ceibapentandra has comparatively better oxidation stability. The biodiesel was derived from the seeds of Ceibapentandra through well-established transesterification process called as CeibaPentandra Oil Methyl Ester (CPOME) and the properties of the same were measured at Bangalore Test House Laboratory, Bengaluru, India. Tables 1 summarize the properties of fuels used in the current investigation.

Table 1 Properties of various fuels

Sl. No.	Properties	Diesel	CPOME
1	Chemical Formula	$C_{13}H_{24}$	-
2	Density (kg/m^3)	840	884.4
3	Calorific value (kJ/kg)	43,000	39,790
4	Viscosity at 40^{o}C (cSt)	2-5	4.3
5	Flash point (^{o}C)	75	202.5
6	Cetane Number	45-55	42.4
7	Carbon Residue (%)	0.1	0.06
8	Cloud point	-2	3
9	Pour point	-5	5

2.2. Experimental Set-up and Methodology

Experimental setup use for the current investigation is depicted in Fig.1. Initially the experimental tests were carried out on CI engine to optimize IT, at different loading conditionsand IT of 19^0,23^0,27^0 and 31^0BTDC with diesel and CPOME. The engine was always operated at 1500 rpm. The CR of 17.5 was used with hemispherical combustion chamber and injector of 3 holes and 0.3 mm orifice size. The readings recorded only after engine attained stable condition. Further experiments were conducted to optimize IOP with 4 and 5 hole injector, keeping optimized IT. 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. HRR value was calculated [34], [35]. ID is the time lag between the start of fuel injection and the start of ignition. The start of injection was obtained based on the static fuel IT. The experimental set up of the CI engine is shown in Fig. 1. The specifications of the engine are provided in Table 3. Exhaust gas composition during the steady-state operation was measured by employing a Hartridge smoke meter shown in Fig. 2 and five-gas analyzers (A DELTA 1600 S-non dispersive infrared analyzer) shown in Fig 3.



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

Fig. 1 Experimental setup

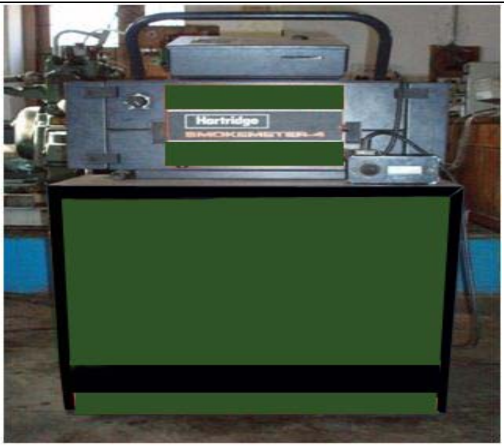


Fig. 2 Hartridge Smoke meter

Fig. 3 Exhaust Gas Analyzer (EGA)

Table 2 Specifications of the CI engine

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

2.3 Uncertainty Analysis

The uncertainties in the calculated parameters of the current investigation are provided in the Table 3. In order to minimize the errors of measurements,four readings were recorded and averaged out results are only presented for the analysis.

Table 3 The accuracies of the measurements and the uncertainties in the calculated parameters

Measured variable	**Accuracy (±)**
Load, N	0.1
Engine speed, rpm	1
Temperature, ^oC	1
Fuel consumption, g	0.1
HFFR, kg/h	0.001
Measured variable	**Uncertainty (%)**
HC	±1.2
CO	±2.5
NOx	±2.3
Smoke	±2.0
Calculated parameters	**Uncertainty (%)**
BTE (%)	±1.2
HRR (J/^{o}CA)	±1.3

3. Results and Discussions

3.1 Optimization of Injection Timing (IT)

In the first part, studies on the performance, emission and combustion characteristics of a single cylinder diesel engine when fueled with diesel, and CPOME were carried out. At the rated speed of 1500 rev/min, variable load tests were conducted at fourITs of 19^o, 23^o, 27^o and 31^o BTDC keeping IOPconstant at 205 bar. Based on the averaged out results from four readings at each of the conditions specified, optimum IT was determined.

3.1.1 Effect of IT on BTE

The effect of IT on BTE for single fuel operation with diesel, and CPOME at fourITs is shown in Fig. 3.1. The highest BTE is obtained with diesel at a fuel IT of 23^o BTDC. BTE values were lower for CPOME as compared to diesel for all four ITs. The decrease in BTE for TPOME could be due to lower energy content of the fuel. Due to higher viscosity of CPOME the formation of the mixture and subsequent burning were poorer than diesel. The maximum BTE at 23^o BTDC is 25.25% as compared to 31.25 % for diesel. However, by advancing the IT by 4^oCA, improvement in BTE was obtained. It is about 26.32%at an IT of 27^o BTDC. Based on the magnitudes of BTE the optimum IT for TPOME could be taken as27^oBTDC.

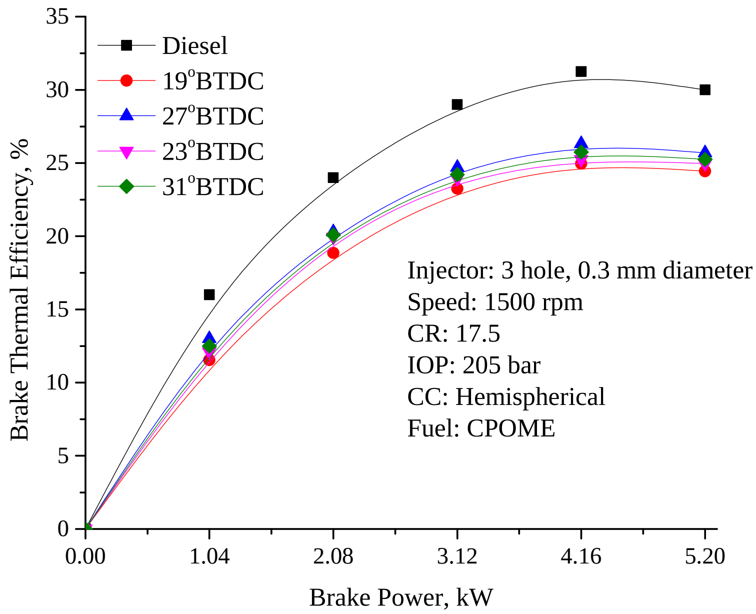


Fig. 3.1 Effect of injection timing on BTE

3.1.2 Effect of IT on Smoke Opacity

The effect of IT on smoke emission for diesel, and CPOME is shown in Fig 3.2. Smoke opacity for both fossil diesel and renewable fuel CPOME increased with increased brake power. Increased quantity of both pilot fuels injected in the engine cylinder results into increased smoke emissions. The greater smoke opacity observed with CPOME compared to diesel fuel could be mainly due to emission of higher molecules of hydrocarbons and particulate associated. Comparatively heavier molecular structure of CPOME 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 CPOME elevated with the retarded IT. The smoke emission with CPOME is found to be minimal for retarded IT of 27° BTDC as shown in Fig. 3.2. It is a clear indication of relatively better combustion of fuel air mixture. The reasons for incomplete combustion are incorrect air-fuel ratio and improper mixing. It is seen that with CPOME the smoke level falls when the IT is advanced to 27° BTDC from 19 and 23°BTDC. However, with the further increase in IT to 31° BTDC the smoke level is observed to increase due to fall in BTE, which leads to increased fuel input at a given power output. The smoke level with CPOME operation was found to be minimum at 27° BTDC compared to other ITs. Smoke emission values were 63, 60, 56 and 58 HSU for IT 19^0,23^0,27^0 and 31^0BTDC respectively at 80 % load.

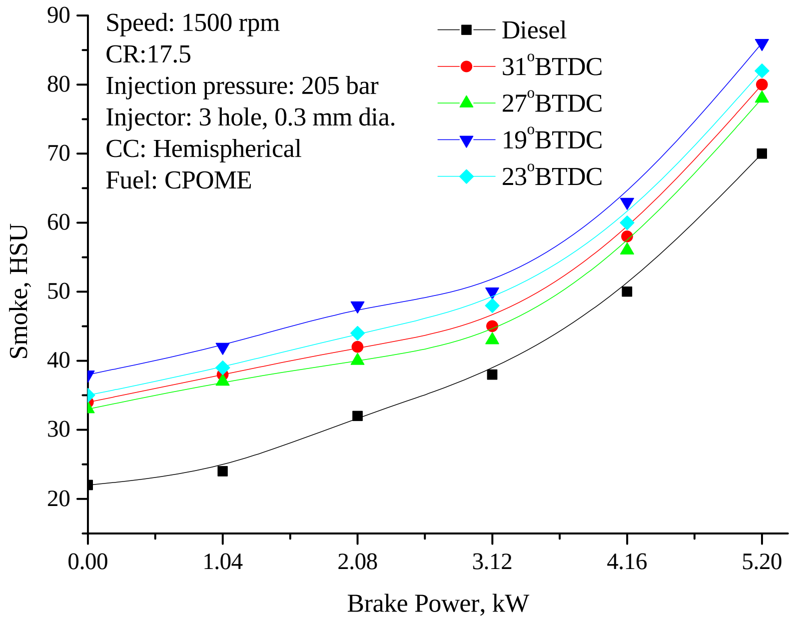


Fig. 3.2 Effect of injection timing on Smoke opacity

3.1.3 Effect of IT on the HC and CO

Figure 3.3 and 3.4 demonstrates the effect of IT on HC and CO emissions for diesel, and CPOME.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.

Increased HC and CO emissions for CPOME are observed as compared to diesel for all four IT, this result could be due to decreased combustion efficiency on account of poor spray characteristics of CPOME and the injected biodiesel resulting in wall wetting. The HC emission values at 80% load are 52 ppm, 48 ppm 44 ppm and 46 ppm for 19^0,23^0,27^0 and 31^0BTDC IT respectively. Lowest HC levels are found at the optimum IT of 27^0BTDC.

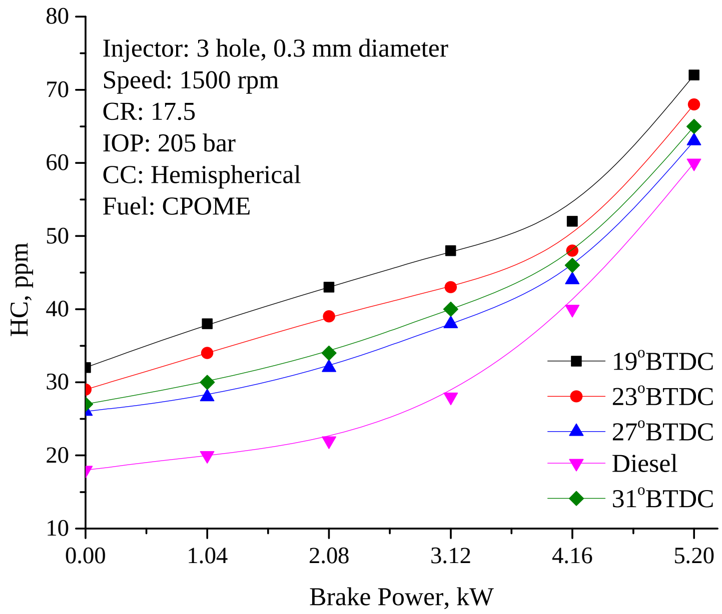


Fig. 3.3 Effect of injection timing on Unburned Hydrocarbon Emissions

Carbon Monoxide Emissions

CO is a toxic by-product on account of incomplete combustion of the pre-mixed mixture prevailing inside the engine cylinder. CO emission found decreased at part loads and increased at higher loads. CPOME showed comparatively higher CO emissions for the probable reasons explained in HC emissions. The amount of CO at full load is 0.153% vol., 0.18% vol., 0.2% vol. and 0.3% vol. for 19^0,23^0,27^0 and 31^o BTDC injection timings respectively. Lowest CO levels are found at the optimum injection timing of 27^0 BTDC. HC and CO emissions were also lowest at 27^o BTDC as compared to other IT with CPOME as fuel.

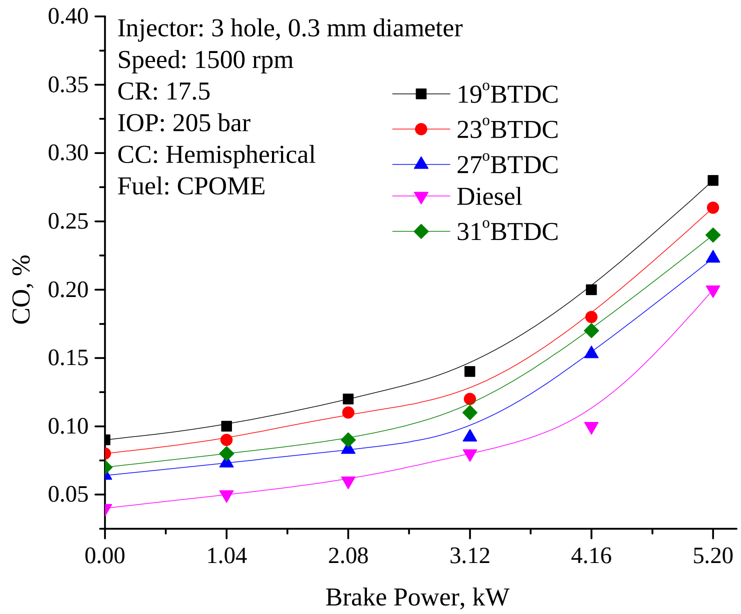


Fig. 3.4 Effect of injection timing on Carbon Monoxide Emissions

3.1.4 Effect of IT on NOx Emissions

The effect of IT on emissions of nitrogen oxides with brake power for diesel, CPOME is depicted in Fig. 3.5. With CPOME NOx emissions were lower compared to diesel fuel at all the ITs. 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. Retarded IT showed substantial reduction in NOx emissions due to retarded combustion and lower temperature. NOx levels are 960 ppm, 1056 ppm, 1068 ppm and 1072 ppm respectivelywith CPOME operation at 80% load andIT of 19^o, 23^o, 27^o and 31^{o}BTDC as they lead to a sharp premixed heat release due to longer ID.

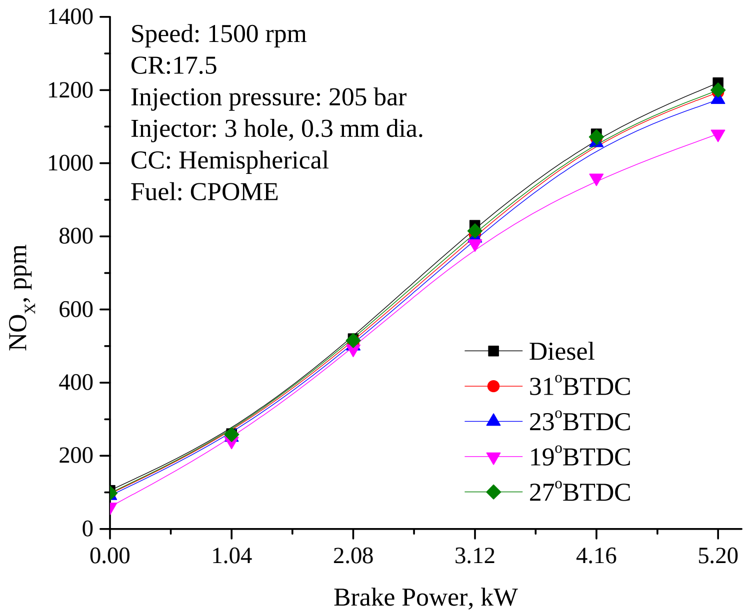


Fig. 3.5 Effect of injection timing on NO_x Emissions

3.1.5 Effect of IT on Combustion Parameters

Peak Pressure

Figure 3.6 illustrates the effect of IT on peak pressure with brake power for CPOME. Lower peak pressures were resulted with CPOME operation at all the IT compared to fossil diesel due to its lower energy content, slower burning nature and longer ID. However, when the IT is advanced the peak pressure increased as the delay period also increasedfor CPOME operation. For the retarded IT, ID redces and the engine operation was found to be noiseless and smooth. Lower pressure and temperature at the beginning of injection results with theretarded IT and hence the peak pressure lowered. PP values at 80% load are 68 bar, 70 bar, 71 bar and 70 bar for 19^0,23^0,27^0 and 31^{0}BTDC IT respectively. Highest PP levels are found at the IT of 27^{0}BTDC.

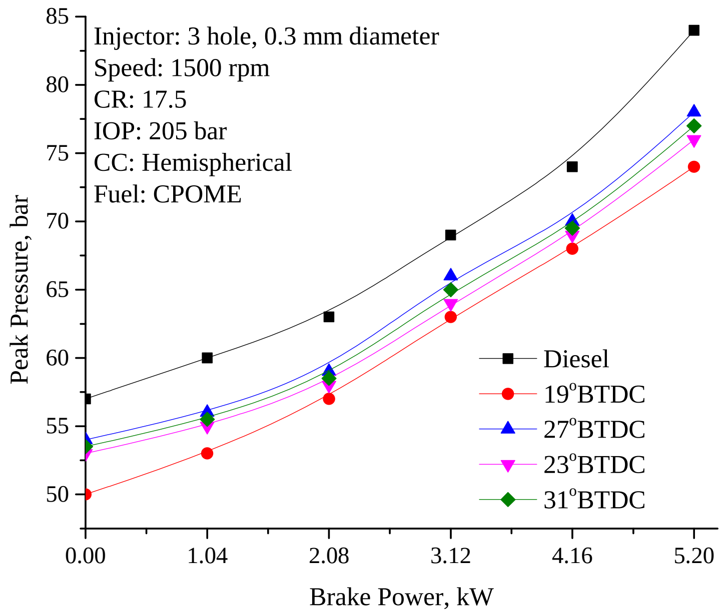


Fig. 3.6 Effect of injection timing on Peak Pressure

Ignition Delay

The effect of ITon IDwith brake power is depicted in Fig. 3.7. The ID is calculated based on the static IT. ID decreased with load and increased with biodiesel operation.CPOME showed longer ID as compared to diesel. However, when the IT is advanced the ID decreased as the increased BTEprovides improved combustion for CPOME operation.ID values at 80% load are 10.5 ^{0}CA, 10.2 ^{0}CA, 10.1 ^{0}CA and 10.21 ^{0}CA for 19^{0},23^{0},27^{0} and 31^{0}BTDC ITs respectively. Lower ID is found at the IT of 27^{0}BTDC.

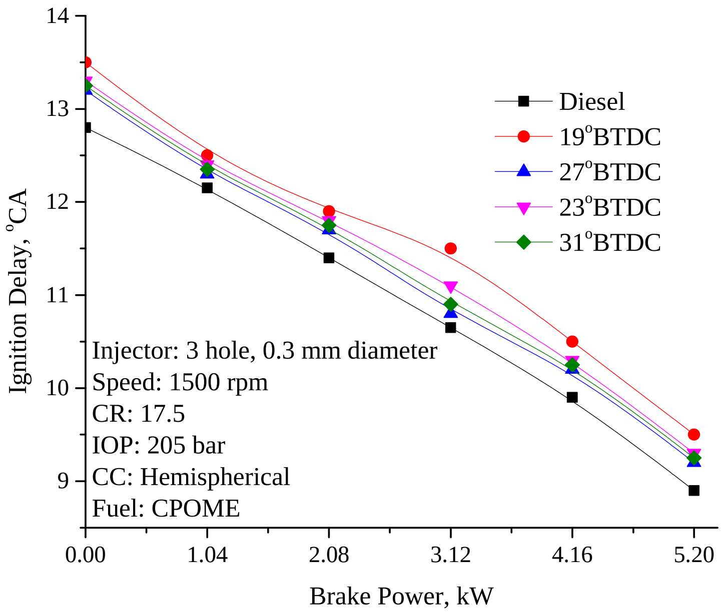


Fig. 3.7 Effect of injection timing on Ignition Delay Period

Combustion Duration

The combustion duration (CD) shown in Fig. 3.8 was calculated based on the duration between the SOC and 90% cumulative heat release. CD increased with increase in the power output with both fuels and IT as well. Longer CD is observed with CPOME than diesel due to longer diffusion combustion phase. It could be due to longer time for mixing and hence resulting in incomplete combustion with longer diffusion combustion phase. With the advanced IT the CD reduced. This could be attributed to the amount of fuel being burnt inside the cylinder gets increased. CD values at 80% load are 43 ^{0}CA, 41 ^{0}CA, 40 ^{0}CA and 41.5 ^{0}CA for 19^0,23^0,27^0 and 31^{0}BTDC ITs respectively. Lower CD are found at the IT of 27^{0}BTDC.

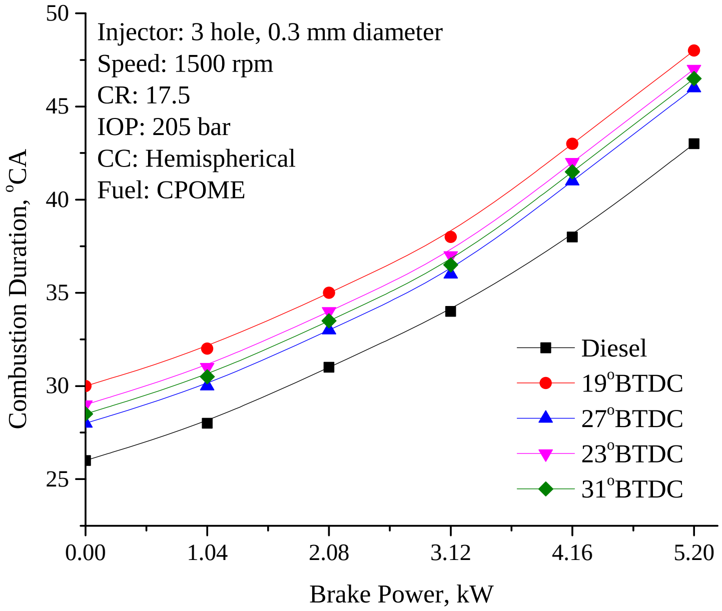


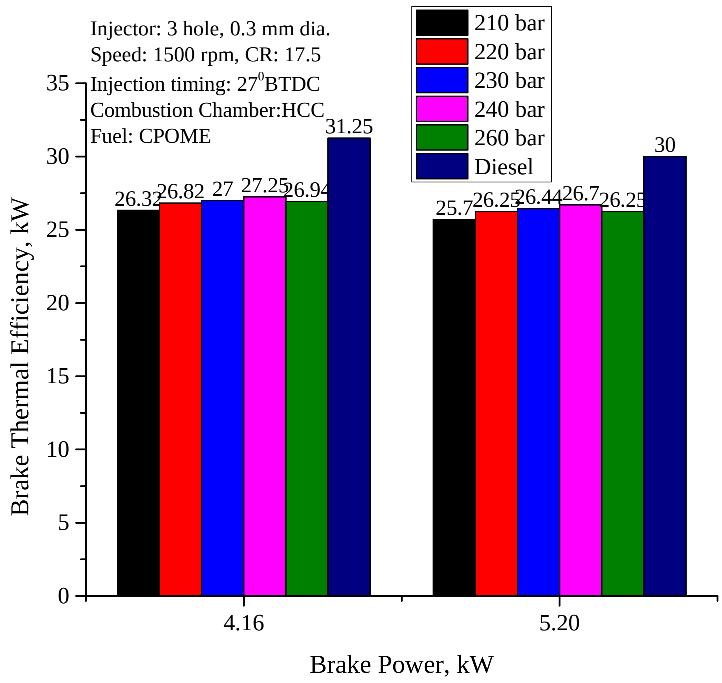
Fig. 3.8 Effect of injection timing on Combustion Duration

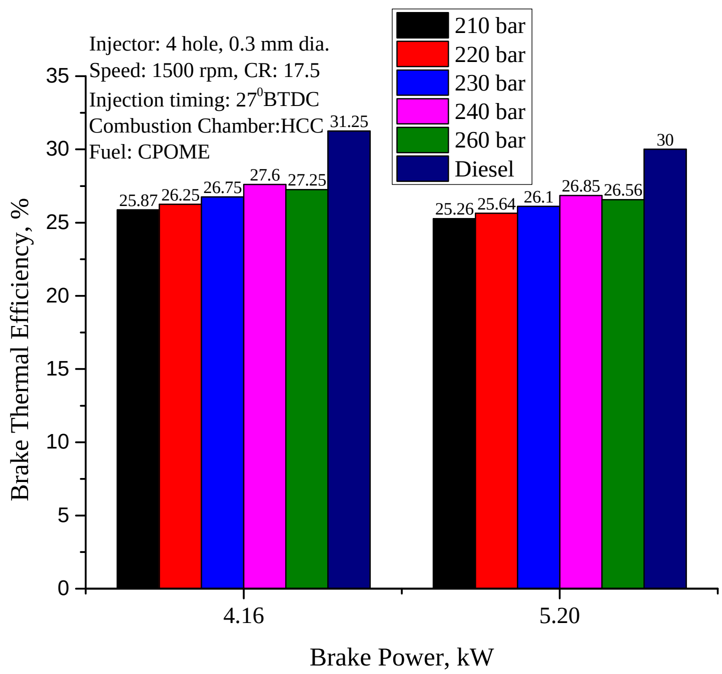
3.2 Optimization of IOP

In the second part, studies on thec performance and emission characteristics of the engine were carried out on the normal diesel engine using CPOME at different IOP. The IOPs were varied from 210 bar to 260 bar. Variable load tests were conducted at these selected IOP operating with optimized IT of 27°BTDC. Based on the results, the optimum IOP was identified for CPOME. Subsequently performance, emission and combustion parameters with the CPOME were compared.Engine was operated only at manufacturer specified injector opening pressure (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 is presented in the following graphs.

3.2.1 Effect of IOP and different nozzle geometry on BTE

The effect of different IOP and different nozzle geometry on BTE with brake power is demonstrated in Fig. 3.9. Amongst all the IOPs tested, the highest BTE was observed at IOP of 240 bar which could be due to better atomization, spray characteristics and mixing with air. Highest BTE found to be 28% at 80% load with 5-hole nozzle and at an IOP of 24MPa. However, BTE for 3-hole and 4-hole nozzles were found to be 27.25% and 27.6% respectively at 24MPa. Based on the results, BTE was found to be high with 5-hole injector nozzle geometry and IOP of 24MPa.


Injector: 3 hole, 0.3 mm dia.
Speed: 1500 rpm, CR: 17.5
Injection timing: 27⁰BTDC
Combustion Chamber:HCC
Fuel: CPOME
210 bar
220 bar
230 bar
240 bar
260 bar
Diesel
26.32
26.82
27
27.25
26.94
31.25
25.7
26.25
26.44
26.7
26.25
30
Brake Thermal Efficiency, kW
Brake Power, kW
4.16
5.20


Injector: 4 hole, 0.3 mm dia.
Speed: 1500 rpm, CR: 17.5
Injection timing: 27⁰BTDC
Combustion Chamber:HCC
Fuel: CPOME
210 bar
220 bar
230 bar
240 bar
260 bar
Diesel
25.87
26.25
26.75
27.6
27.25
31.25
25.26
25.64
26.1
26.85
26.56
30
Brake Thermal Efficiency, %
Brake Power, kW
4.16
5.20

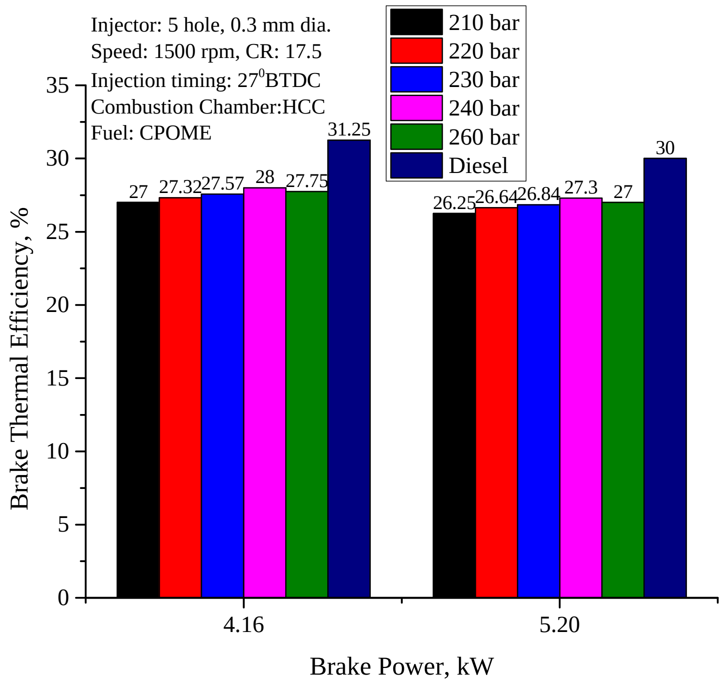
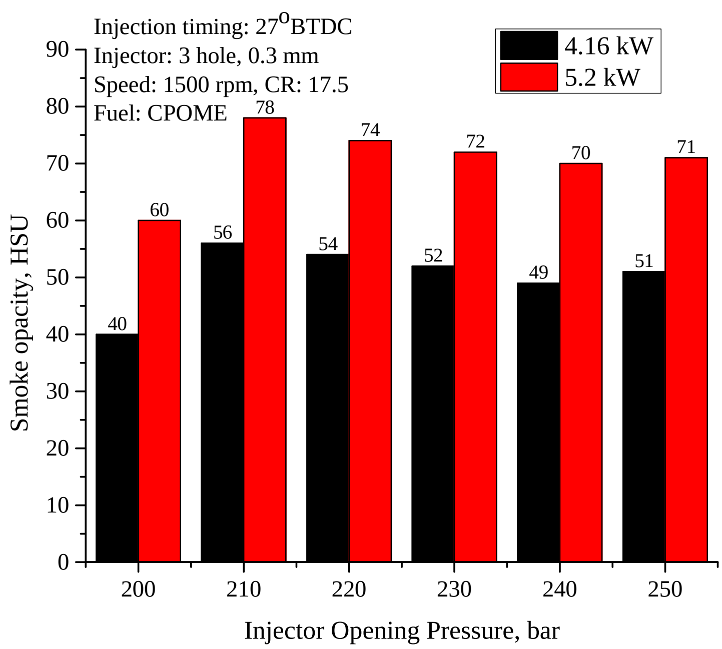
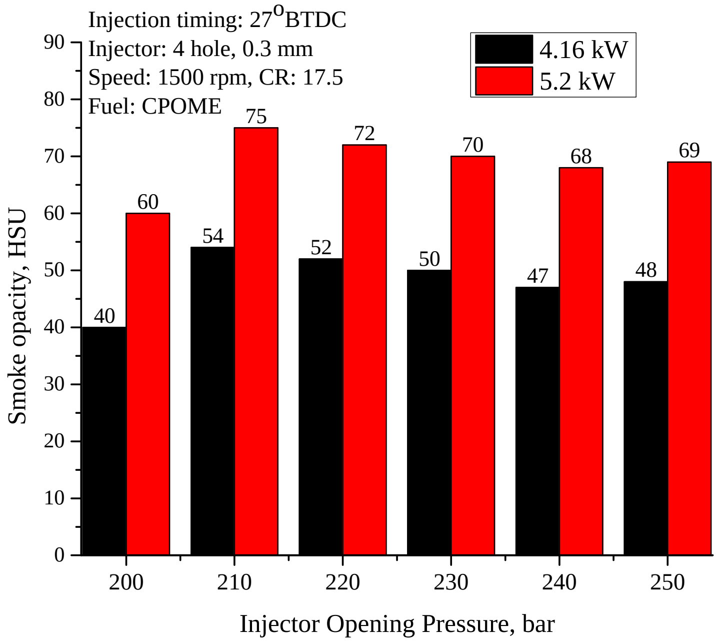


Fig. 3.9 Effect of IOP and Nozzle geometry on BTE

3.2.2 Effect of IOP and Nozzle Geometry on Smoke Opacity

Figure 3.10 shows the effect of IOP and different nozzle geometry on smoke opacity with brake power. Smoke levels were observed to fall with IOP as mixture formation improved. Lowest smoke level is seen with the IOP of 240 bar. At 80 % load the smoke level was observed to fall from 53HSU to 46 HSU when the IOP was increased from 210 to 240 bar with 5 holes injector. These values reported were higher than diesel operation. It is seen that 5 hole injector increased the fuel-air mixing rate and hence ensures improved combustion with reduced smoke emissions.





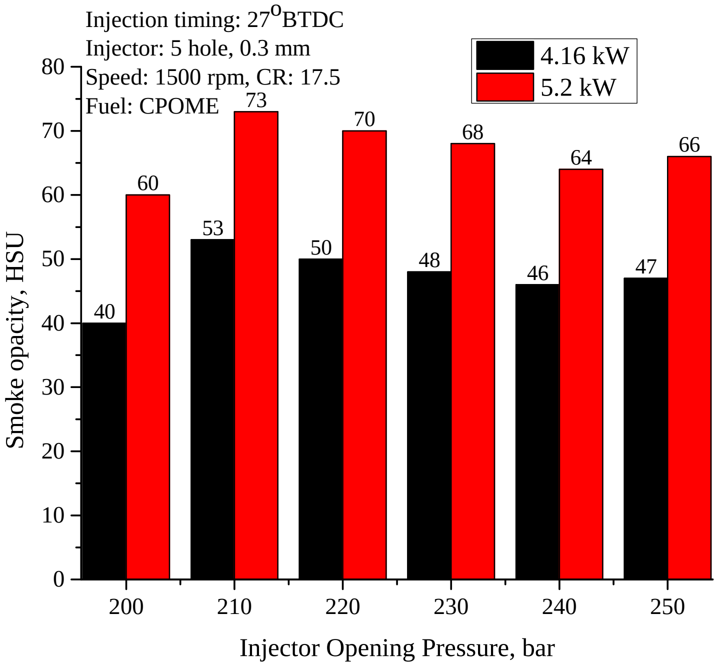
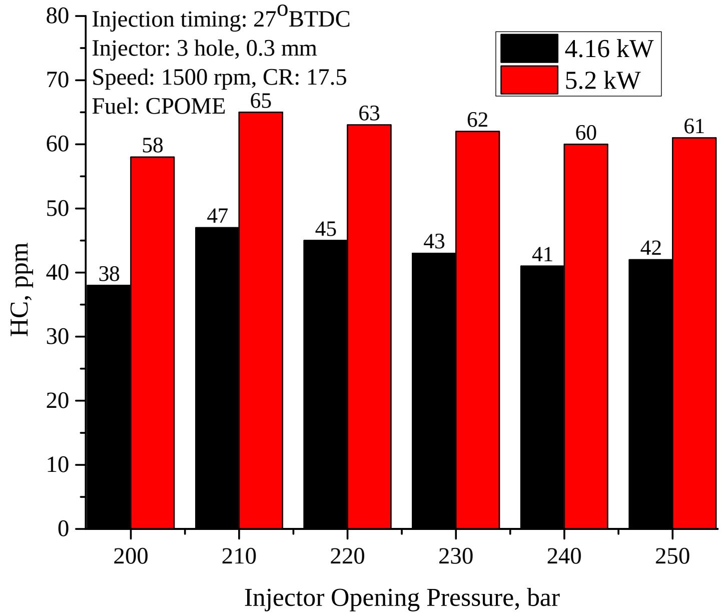
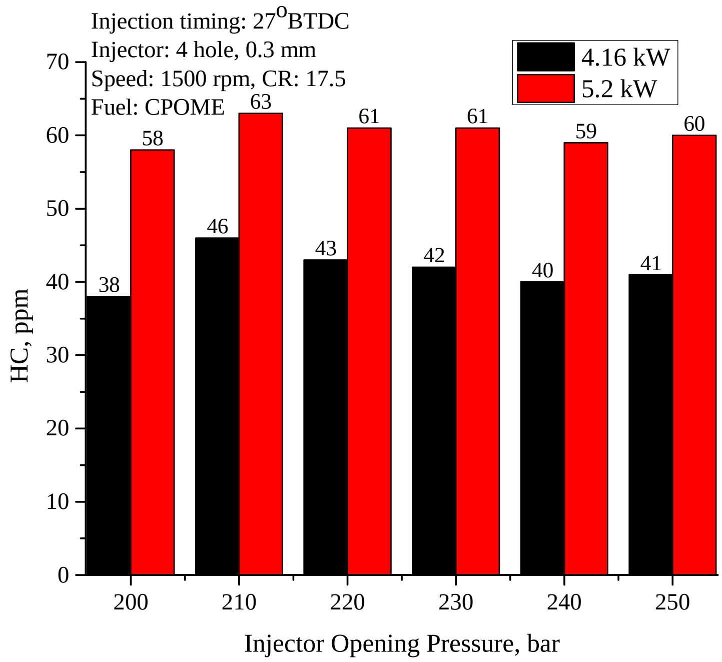


Fig. 3.10 Effect of IOP and Nozzle geometry on Smoke opacity

3.2.3 Effect of IOP and Nozzle Geometry on HC Emission

Figure 3.11 depicts the effect of IOP and nozzle geometry on HC emission with brake power. A drop in HC was observed at 240 bar IOP because of better combustion on account of enhanced atomization. HC reduced from 44 to 39 ppm after increasing the IOP from 210 to 240 bar at 80% power output with 5 holes injector. The highest IOP of 260 bar leads to an increase in the HC level probably because it leads to a reduction in the BTE. Higher IOP led to a considerable portion of the combustion occurring in the diffusion phase on account of the short ID. It is concluded that, unburnt hydrocarbons were found to be less during the engine operation with 5-hole nozzle and IOP of 24MPa.


Injection timing: 27^{o}BTDC
Injector: 3 hole, 0.3 mm
Speed: 1500 rpm, CR: 17.5
Fuel: CPOME
4.16 kW
5.2 kW
HC, ppm
Injector Opening Pressure, bar
0
10
20
30
40
50
60
70
80
200
210
220
230
240
250
38
58
47
65
45
63
43
62
41
60
42
61


Injection timing: 27^{o}BTDC
Injector: 4 hole, 0.3 mm
Speed: 1500 rpm, CR: 17.5
Fuel: CPOME
4.16 kW
5.2 kW
HC, ppm
Injector Opening Pressure, bar
0
10
20
30
40
50
60
70
200
210
220
230
240
250
38
58
46
63
43
61
42
61
40
59
41
60

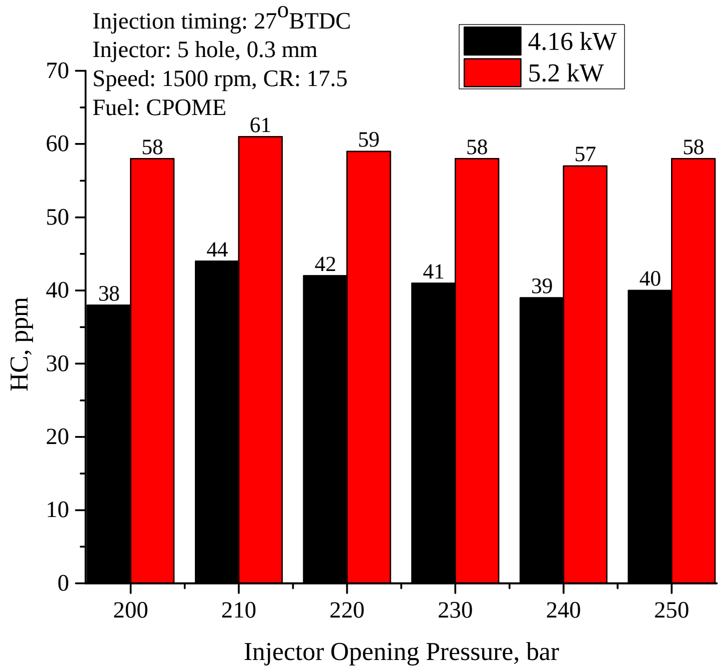
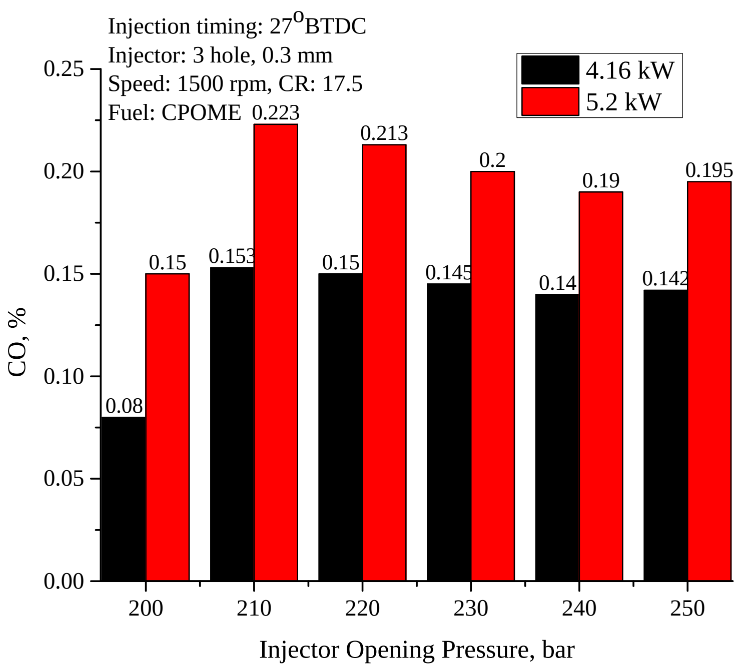


Fig. 3.11 Effect of IOP and Nozzle geometry on Unburned Hydrocarbon Emissions

CO Emission

Figure 3.12 illustrates the effect of IOP and nozzle geometry on CO emission with brake power. Both CO and HC emissions were similar and lower CO emissions found at 240 bar IOP and 5 hole injector as usual. The lower penetration distance of fuel with 5 hole injector due to decreased mass flow rate per hole enhanced fuel air mixing rate and better combustion. This could be the reason for lower CO emission. At 80% load with 5 holes injector and 240 bar IOP, CO level was 0.13 % volume which is higher than CI mode value of 0.08 % volume.



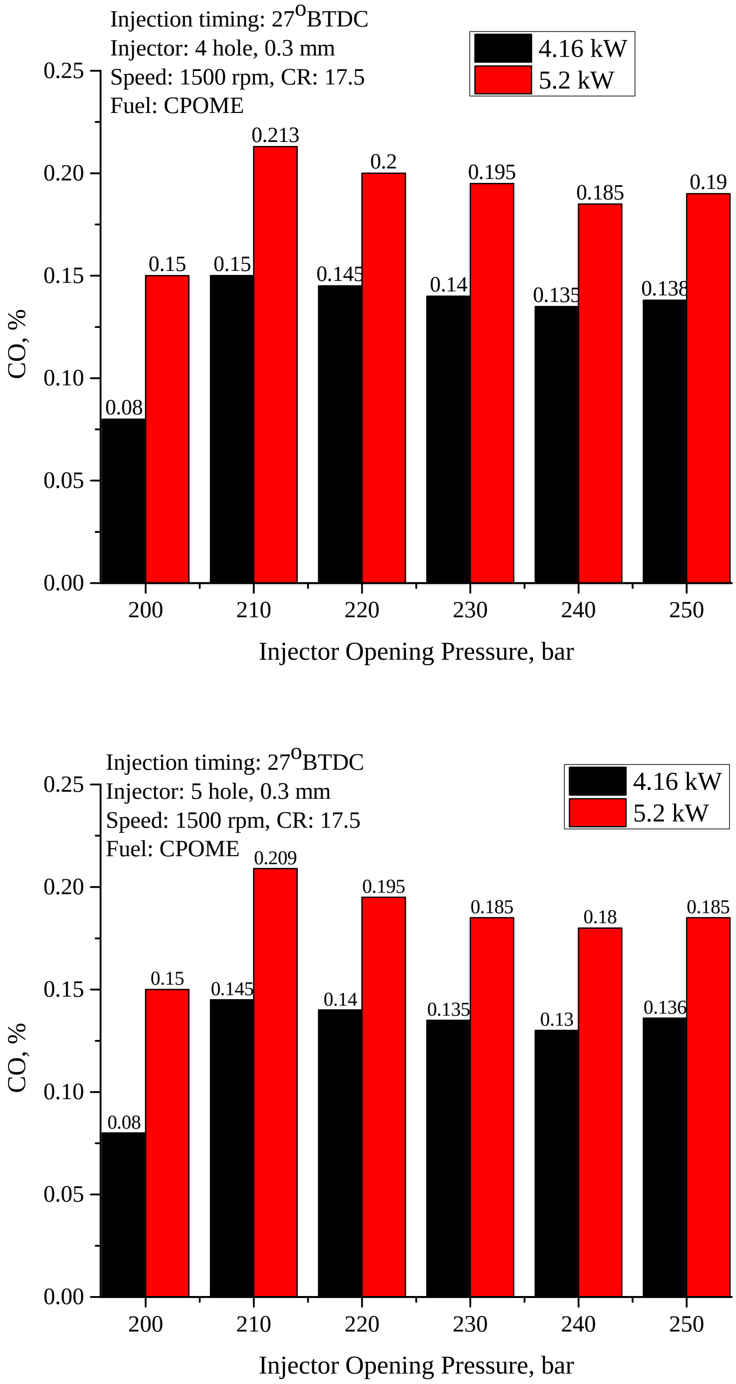
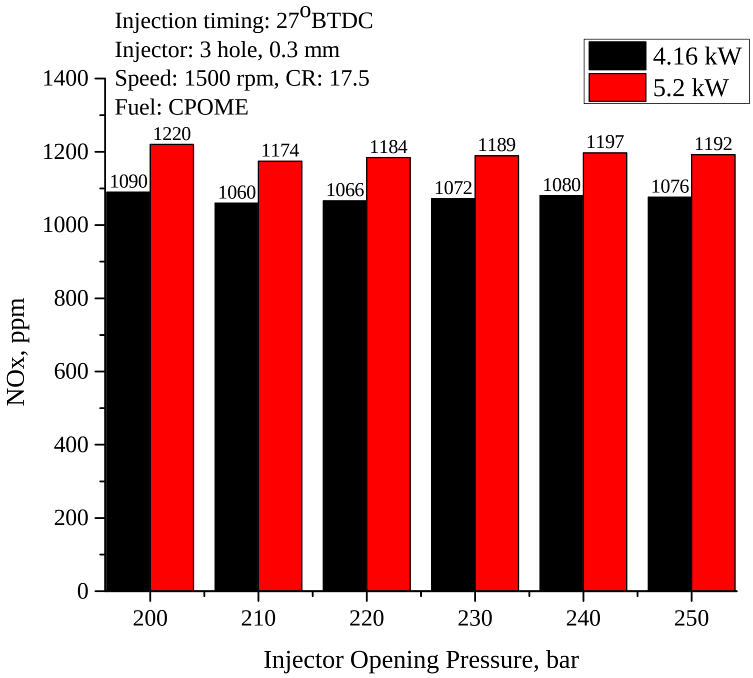
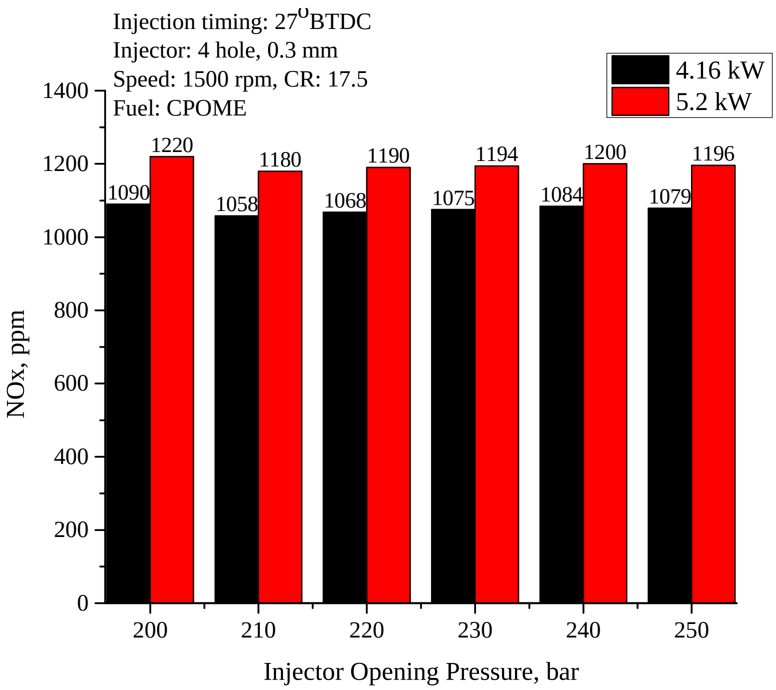


Fig. 3.12 Effect of IOP and Nozzle geometry on Carbon Monoxide Emissions

3.2.4 Effect of IOP and Nozzle Geometry on NOx Emission

NOx emissions increased with the increase in IOP due to faster burning and higher temperatures reached in the cycle as shown in Fig. 3.13. 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. At 80% load with 5 holes injector and 240 bar IOP, NOx level was 1088 ppm. This value reported was close to one obtained with CI mode.


Injection timing: 27°BTDC
Injector: 3 hole, 0.3 mm
Speed: 1500 rpm, CR: 17.5
Fuel: CPOME
4.16 kW
5.2 kW
1090
1220
1060
1174
1066
1184
1072
1189
1080
1197
1076
1192
NOx, ppm
Injector Opening Pressure, bar
0
200
400
600
800
1000
1200
1400
200
210
220
230
240
250


Injection timing: 27°BTDC
Injector: 4 hole, 0.3 mm
Speed: 1500 rpm, CR: 17.5
Fuel: CPOME
4.16 kW
5.2 kW
1090
1220
1058
1180
1068
1190
1075
1194
1084
1200
1079
1196
NOx, ppm
Injector Opening Pressure, bar
0
200
400
600
800
1000
1200
1400
200
210
220
230
240
250

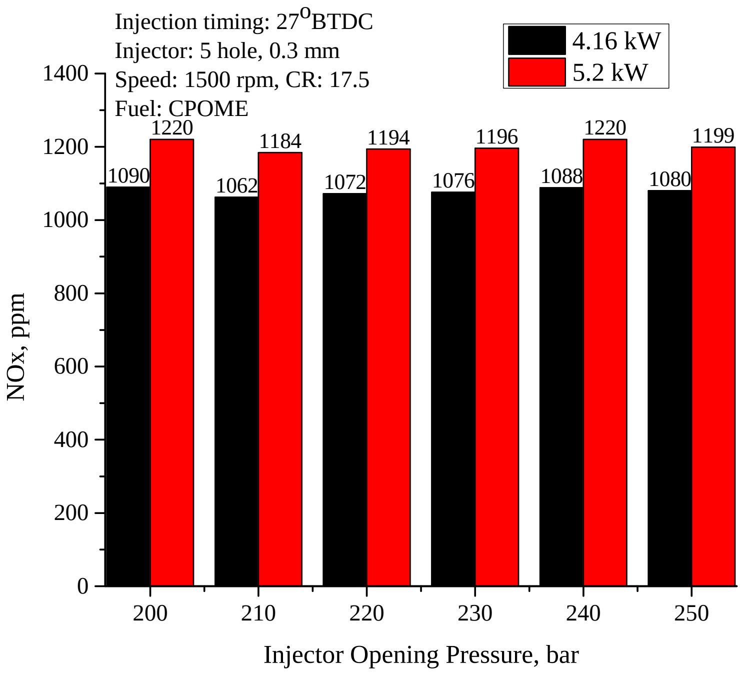


Fig. 3.13 Effect of IOP and Nozzle geometry on NO_x Emissions

3.2.5 Combustion Characteristics

Effect of IOP on Peak Pressure

Figure 3.14 depicts the effect of IOP on peak pressure with brake power for CPOME operation. Lower peak pressures were resulted with CPOME operation at all IOPs as compared to fossil diesel due to its lower calorific value and longer ID. Throughout the combustion, the peak pressure of CPOME increased with increase in fuel IOP. The increase in peak pressure was observed when the IOP was varied from 21MPa to 24MPa as shown in Fig.3.14. Beyond 24MPa the peak pressure was lowered.PP reported was73 bar at 80% load with 5-hole nozzle and at an IOP of 24MPa. However, PP for 3-hole and 4-hole nozzles were found to be 71 bar and 72 bar respectively at 24MPa. Based on the results, PP was found to be high with 5-hole injector nozzle geometry and IOP of 24 MPa.

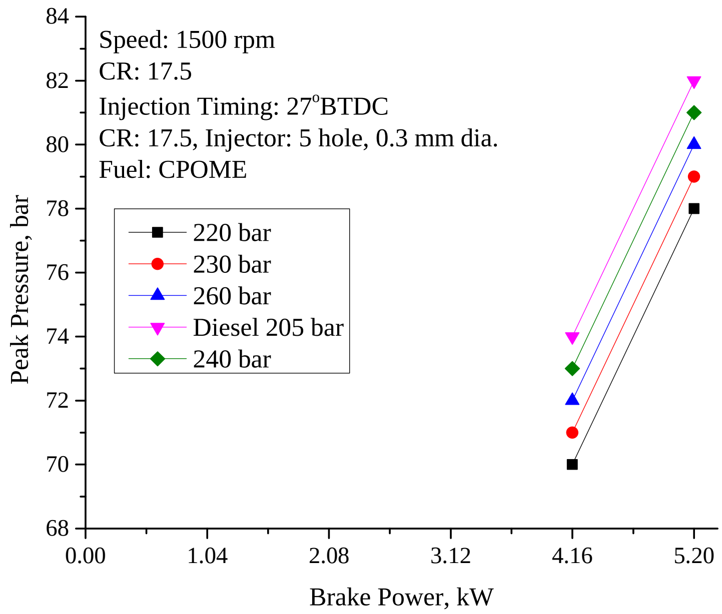


Fig. 3.14 Effect of IOP and Nozzle geometry on Peak Pressure

Ignition Delay

Figure 3.15 shows the effect of IOP on ID Period with brake power for CPOME operation. ID is calculated based on the static IT. ID decreased with load and increased with biodiesel operation. CPOME showed longer ID as compared to diesel. However, when the IOP is increased the ID decreased as the increased BTE provides improved combustion for CPOME operation. ID reported was9.8 ^{0}CA at 80% load with 5-hole nozzle and at an IOP of 24MPa. However, ID for 3-hole and 4-hole nozzles were found to be 10 ^{0}CA and 9.9 ^{0}CA respectively at 24MPa.

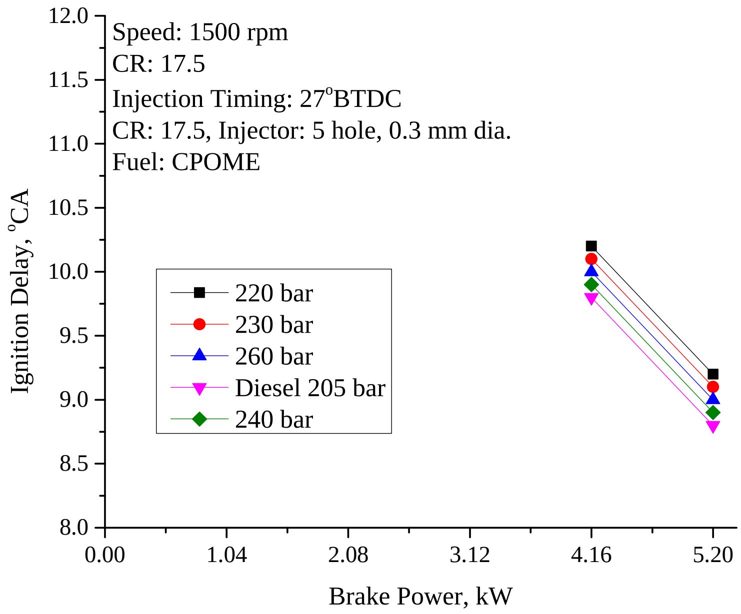


Fig. 3.15 Effect of IOP and Nozzle geometry on ID Period

Combustion Duration

Figure 3.16 shows the effect of IOP on CD with brake power for diesel and CPOME operation respectively. The combustion duration shown in Fig.3.16 was calculated based on the duration between the SOC and 90% cumulative heat release. CD increased with increase in the power output with both fuels and IOP as well. Longer CD was observed with CPOME than diesel due to longer diffusion combustion phase. With the increased IOP, the CD reduced. This could be attributed to the amount of fuel being burnt inside the cylinder gets increased. CD reported was 40 ^{0}CA at 80% load with 5-hole nozzle and at an IOP of 24MPa. However, CD for 3-hole and 4-hole nozzles were found to be 42 ^{0}CA and 41 ^{0}CA respectively at 24MPa.

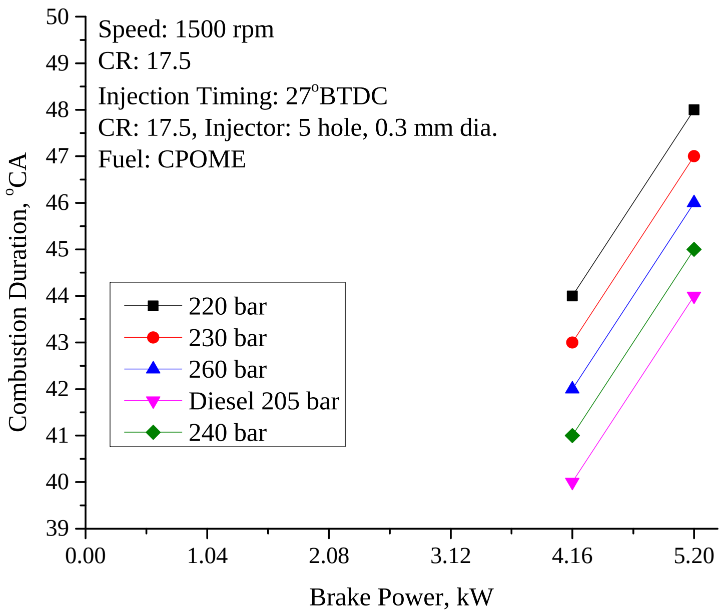
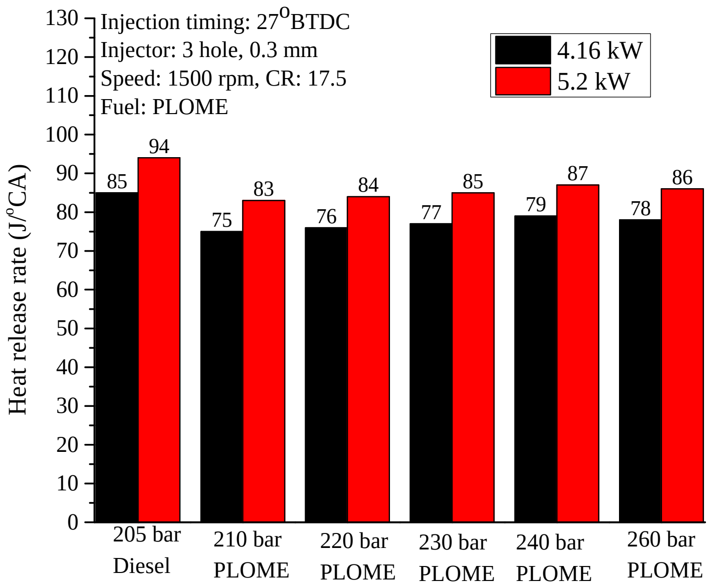
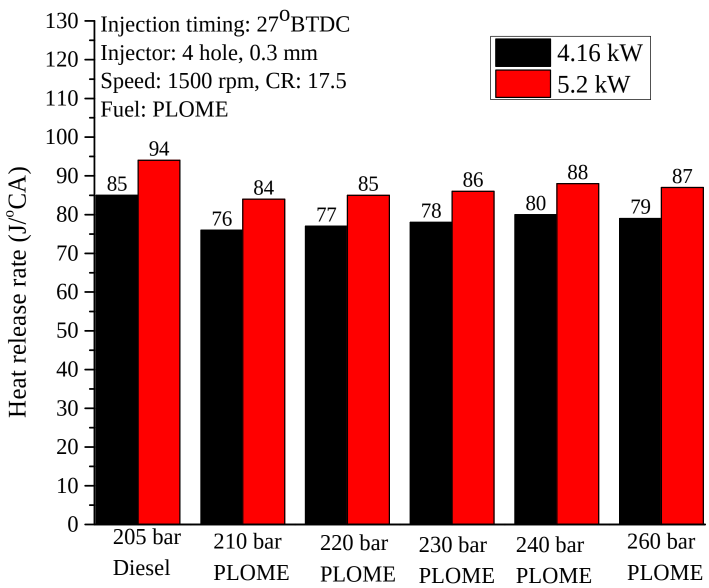


Fig. 3.16 Effect of IOP and Nozzle geometry on Combustion Duration

Heat Release Rate

Figure 3.17 depicts the effect of IOP on HRR with brake power for diesel and CPOME operation respectively. CPOME powered CI engine operation resulted into higher HRR with injector of 5 holes. Better air fuel mixture, better combustion, higher cylinder gas temperature and pressure prevailed might be the reason for the higher HRR. CPOME showed lower HRR compared to mineral diesel due to their poor combustion qualities. The HRR for CPOME found to be 79, 80 and 81 J/^{o}CA respectively for 3, 4 and 5 holes injector against 85 J/^{o}CA for diesel with 3 holes injector and 0.3 mm orifice size.


Injection timing: 27^{O}BTDC
Injector: 3 hole, 0.3 mm
Speed: 1500 rpm, CR: 17.5
Fuel: PLOME
4.16 kW
5.2 kW
Heat release rate (J/°CA)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
85
94
75
83
76
84
77
85
79
87
78
86
205 bar
Diesel
210 bar
PLOME
220 bar
PLOME
230 bar
PLOME
240 bar
PLOME
260 bar
PLOME


Injection timing: 27^{O}BTDC
Injector: 4 hole, 0.3 mm
Speed: 1500 rpm, CR: 17.5
Fuel: PLOME
4.16 kW
5.2 kW
Heat release rate (J/°CA)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
85
94
76
84
77
85
78
86
80
88
79
87
205 bar
Diesel
210 bar
PLOME
220 bar
PLOME
230 bar
PLOME
240 bar
PLOME
260 bar
PLOME

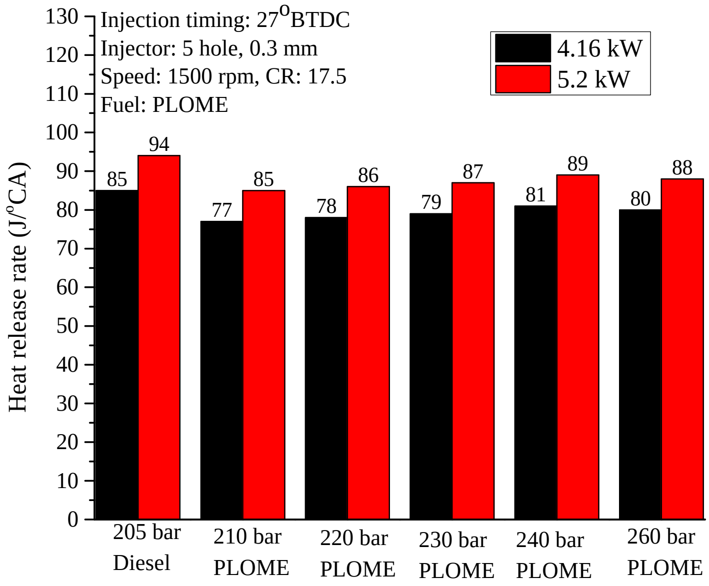


Fig. 3.17 Effect of IOP and Nozzle geometry on HRR

4. Conclusions

From the exhaustive experimental tests conducted on CPOME powered diesel engine running with 17.5 compression ratio and 1500 rpm the following conclusions were drawn:

At IOP of 240 bar, IT of 27 ^{0}BTDC, CR of 17.5, 3 hole injector and engine speed of 1500 rpm following are concluded,
At IOP of 205 bar, CR of 17.5, engine speed of 1500 rpm and load of 80% following were reported,

- CPOME can be used as substitute to diesel for CI engine with small compromise in BTE.
- Fuel IT of 27 ^{0}BTDC yielded better performance in terms of higher BTE and lower emissions.
- BTE of 24.96, 25.25, 26.32 and 25.75 % were achieved withIT of 19^o, 23^o,27^o and 31^{o}BTDC respectively.
- HC emissions of 52, 48, 44 and 46 ppm were revealed withIT of 19^o, 23^o,27^o and 31^{o}BTDC respectively.
- NOx emissions of 960, 1056, 1068 and 1072 ppm were found withIT of 19^o, 23^o,27^o and 31^{o}BTDC respectively.
- PP of 68, 70, 71 and 70 bar were found withIT of 19^o, 23^o,27^o and 31^{o}BTDC respectively.
- ID of 10.5, 10.2, 10.1 and 10.21^{0}CA were obtained withIT of 19^o, 23^o,27^o and 31^{o}BTDC respectively.
- CD of 43, 41, 40 and 41.5 ^{0}CA bar obtained withIT of 19^o, 23^o,27^o and 31^{o}BTDC respectively.

At IOP of 240 bar, IT of 27 ^{0}BTDC, CR of 17.5,and engine speed of 1500 rpm following were reported,

- Maximum BTE for CPOME found to be 27.25, 27.6 and 28 % respectively for 3, 4 and 5 holes injector at 80% load against 31.25% for diesel with 3 holes injector and 0.3 mm orifice size.
- Smoke for CPOME found to be 49, 47 and 46 HSU respectively for 3, 4 and 5 holes injector at 80% load against 40 HSU for diesel.

- HC for CPOME found to be 41, 40 and 39 ppm respectively for 3, 4 and 5 holes injector against 38 ppm for diesel.
- NOx for CPOME found to be 1080, 1084 and 1088 ppm respectively for 3, 4 and 5 holes injector against 1090 ppm for diesel.
- ID for CPOME found to be 10, 9.9 and 9.8 ^oCA respectively for 3, 4 and 5 holes injector against 9.8^oCA for diesel.
- CD for CPOME found to be 42, 41 and 40 ^oCA respectively for 3, 4 and 5 holes injector against 38 ^oCA for diesel.
- PP for CPOME found to be 71,72 and 73bar respectively for 3, 4 and 5 holes injector against 74 bar for diesel.
- HRR for CPOME found to be 79, 80 and 81 J/^oCA respectively for 3, 4 and 5 holes injector against 85 J/^oCA for diesel.

On the whole, CPOME powered engine operation with optimum engine operating parameters like IT of 27^0 BTDC, IP of 240 bar, and 5 holes injector showed overall better engine performance in terms of higher BTE with reduced emissions.

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