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Combustion Analysis of CI Engine under the Influence of two different Injecting Nozzles

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Abstract: *The combustion process taking place inside the engine cannot be directly visualized for the analysis purpose but the same can be possible by performing the experiment and listing the data into graphical form and by the curves of graphs we can conclude the main core of the experiment. Generally combustion is divided into three major parts pressure-crank angle study, pressure-volume study & fuel-line pressure. This paper includes the study of combustion of CI engine when it is experimented by two different types of nozzles. The study gives a brief idea of the amount of pressure and volume attained inside the combustion chamber of CI engine.*
Keywords: *CI engine, Combustion analysis, pressure, volume, fuel line, nozzle*

I. Introduction

The combustion taking place inside the engine cylinder is heterogeneous form. The CI engine is having higher thermal efficiency as compared to SI engine. The Thermal efficiency thus depends on the combustion taking place inside the engine cylinder. This paper gives the general idea about the pressure and volume at the respective crank angle. When the combustion is taking place inside the engine cylinder the pressure rises at maximum level near its combustion phenomenon. This rate of rise in pressure is predicted in the pressure-crank angle study by the graphical method [10].

This study also gives the general idea of the change in the volume created by the piston movement inside the cylinder. The exact volume at the respective crank angle along with the rate of pressure is depicted on the pressure-volume study by the graphical method. When the piston moves from TDC to BDC during the suction stroke the volume of combustion chamber increases thereafter when the piston moves from BDC to TDC for the compression stoke the volume is reduced, then after the completion of compression stoke the piston moves from TDC to BDC for the power stoke and during that time the volume increases rapidly and at last at the time of removal of exhaust gases the volume is again reduced to its minimum level by travel of piston from BDC to TDC [3, 5].

The pressure inside the fuel line is also an important aspect of study of combustion process. The Fuel line pressure indicated the amount of pressure inside the fuel line at the time of injection of fuel. This study plays an important role when the focus is made on both the nozzles. For both the nozzles the pressure might be different [1]. The amount of pressure inside the fuel line also relates the fuel consumption of the engine. By the overall study of pressure, volume and fuel line pressure the complete combustion analysis is achieved in a most proper and efficient manner [2]. The Pressure and volume of combustion differs from time to time due to the continuous movement of the piston inside the engine cylinder [4, 8]. The graph also shows the start of combustion and the start of injection of fuel inside the engine. This study helps to get the general working of the engine itself and also the engine with respect to the nozzles.

This Study is further helpful for the design purpose for designing the cylinder of combustion chamber. The inappropriate design may leads to the explosive accidents during the working conditions. The proper material selection phase is also done by this analysis [6].

II. Experimental Setup

The setup consists of single cylinder, four stroke, multi-fuel, research engine connected to eddy type dynamometer for loading and DC five gas analyzer connected measures five emission gases, including Hydrocarbons (HC), Carbon Monoxide (CO), Carbon Dioxide (CO2), Oxygen (O2) and Oxides of Nitrogen (NOX) [11]. The operation mode of the engine can be changed from diesel to Petrol of from Petrol to Diesel with some necessary changes [9]. The specification of the research engine is given in table-3. The operation mode of the engine can be changed from diesel to petrol of from petrol to diesel with some necessary changes. In both modes the compression ration can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement [7]. The injection point and spark point can be changed for research tests. Setup is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements. These signals are interfaced with computer for pressure crank angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The set-up has stand-alone panel box consisting of air box, two fuel flow measurements, process indicator and hardware interface. Rota meters are provided for cooling water and calorimeter water flow measurement [12]. A battery, starter and battery charger is provided for engine electric start arrangement. The setup enables study of VCR engine performance for brake power, indicated power, frictional Power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio. Laboratory view based engine performance analysis software package "Engine soft" is provide for performance of experiment. Figure 2.1 shows the experimental set-up [13].

Fig.1: Experimental setup [14]

Table 1: Technical specification of the engine.[15]

No. of cylinder	Single cylinder
No. of stroke	4
Cylinder dia.	87.5 mm
Stroke length	110 mm
C.R. length	234 mm
Orifice dia.	20 mm
Dynamometer arm length	185 mm
Fuel	Diesel
Power	3.5 kW
Speed	1500 rpm
C.R. range	12:1 to 18:1
Inj. Point variation	0 to 25 BTDC

III. Experimental Procedure

- First of all the water flow for the cooling of engine is turned on and then the engine is cranked with the handle and started.
- During this testing the two-hole nozzle having two holes for the fuel supply is fitted in the engine assembly along with the injector.
- Then the fuel line in the filled with the diesel and allowed to stable.
- The knob for the load is set at load 1 and the pressure is set at the high level by adjusting the pressure adjusting screw on the injector.
- Then the "Enginesoft" software is attached to the engine setup and the start of reading is done.

- The software takes 60 seconds for taking the reading of any specific reading.
- Then the load and pressure is adjusted as per the table and 21 readings were taken as per table and individual software files are saved.
- Then the engine is stopped and the injector bolts are loosen and the nozzle with two holes is removed from injector and nozzle with single hole is fitted in the injector and the engine is again started.
- The same procedure is followed again for the single-hole nozzle having the single hole for the fuel supply.[16]

IV. Observation

Table 2: Observation Table for Two-hole nozzle

Ex. No	Injection Pressure	Load	Speed rpm	FC cc/min	Air mmwc	O_2 %	CO_2%	HC ppm	CO %	No_x ppm
1	High	1	1534	8	59.17	19.28	0.9	10	0.07	88
2	High	3	1529	10	58.49	19.23	1.1	25	0.05	184
3	High	5	1496	12	55.81	18.66	1.3	27	0.03	321
4	High	7	1468	14	53.74	18.13	1.7	34	0.03	535
5	High	9	1468	16	53.17	17.98	1.8	45	0.03	769
6	High	11	1453	18	51.89	17.52	2	29	0.02	837
7	High	13	1456	21	51.22	17.33	2.1	54	0.03	992
8	Medium	1	1544	8	59.94	18.87	1	25	0.06	119
9	Medium	3	1527	10	58.5	18.91	1.1	27	0.04	201
10	Medium	5	1517	12	57.65	18.66	1.3	32	0.03	339
11	Medium	7	1462	13	53.39	18.14	1.6	41	0.03	531
12	Medium	9	1472	16	53.16	18	1.8	49	0.02	795
13	Medium	11	1460	18	52.06	17.48	2	36	0.02	874
14	Medium	13	1461	20	51.57	17.31	2.1	65	0.03	1050
15	Low	1	1554	8	60.54	19.27	1	26	0.05	137
16	Low	3	1551	10	59.92	18.87	1.1	29	0.04	222
17	Low	5	1485	11	55.79	18.56	1.4	20	0.04	333
18	Low	7	1497	14	55.99	18.44	1.5	34	0.03	539
19	Low	9	1493	16	54.94	17.98	1.8	48	0.02	830
20	Low	11	1467	18	52.67	17.57	1.9	45	0.02	904
21	Low	13	1449	21	50.85	17.27	2.1	73	0.03	1066

Table 3: Observation Table for Single-hole nozzle

Ex. No	Injection Pressure	Load	Speed rpm	FC cc/min	Air mmwc	O_2 %	CO_2%	HC ppm	CO %	No_x ppm
1	High	1	1503	12	56.88	19.47	1	37	0.15	12
2	High	3	1505	10	56.97	18.92	1.3	31	0.04	256
3	High	5	1406	11	51.43	18.22	1.4	33	0.03	387
4	High	7	1442	14	53.79	18.17	1.6	38	0.03	460
5	High	9	1462	16	52.37	17.66	1.8	33	0.02	542
6	High	11	1464	18	51.85	17.45	1.9	45	0.02	807
7	High	13	1454	21	51.12	17.14	2.1	50	0.02	951
8	Medium	1	1484	11	55.45	19.26	1	22	0.06	80
9	Medium	3	1486	10	55.63	18.72	1.1	26	0.05	123
10	Medium	5	1414	12	49.55	18.29	1.3	32	0.04	275
11	Medium	7	1458	14	52.24	17.98	1.6	37	0.03	455
12	Medium	9	1455	16	52.25	17.69	1.8	37	0.02	612
13	Medium	11	1468	18	52.06	17.43	2	48	0.02	853
14	Medium	13	1458	20	51.38	17.18	2.1	56	0.02	983
15	Low	1	1504	8	57.48	19.23	1	28	0.08	67
16	Low	3	1498	10	56.52	18.76	1.1	28	0.05	117
17	Low	5	1460	11	53.43	18.41	1.4	35	0.04	279
18	Low	7	1454	14	52.47	17.99	1.6	41	0.03	480
19	Low	9	1464	16	52.55	17.71	1.8	41	0.02	644
20	Low	11	1459	18	51.77	17.47	1.9	51	0.02	856
21	Low	13	1477	20	52.56	17.2	2	59	0.02	990

Table 4: Nozzle specifications

Two Hole Nozzle	Single Hole Nozzle
	
Nozzle 1	Nozzle 2
Two fuel Holes One Leak-off port	Single fuel Hole One Leak –off port

V. Result And Discussion

Discussions of results for Pressure-Crank Angle

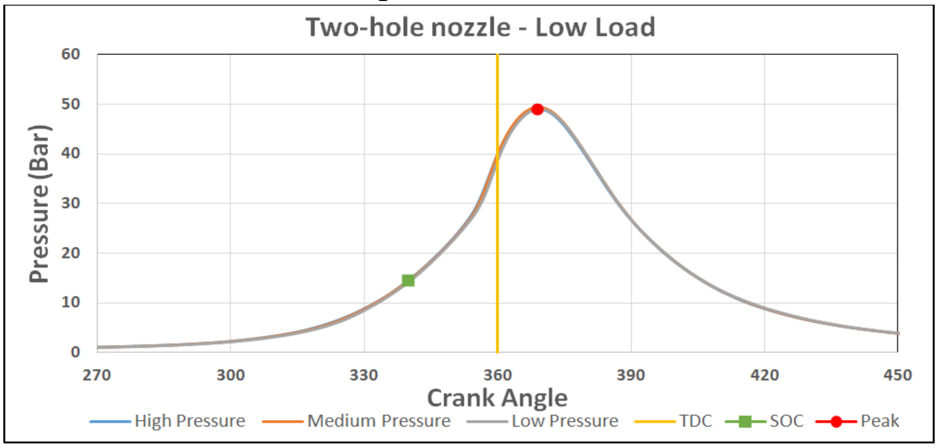

Fig.2: Pressure V/S Crank Angle (P-θ) graph for Low Load with two-hole nozzle

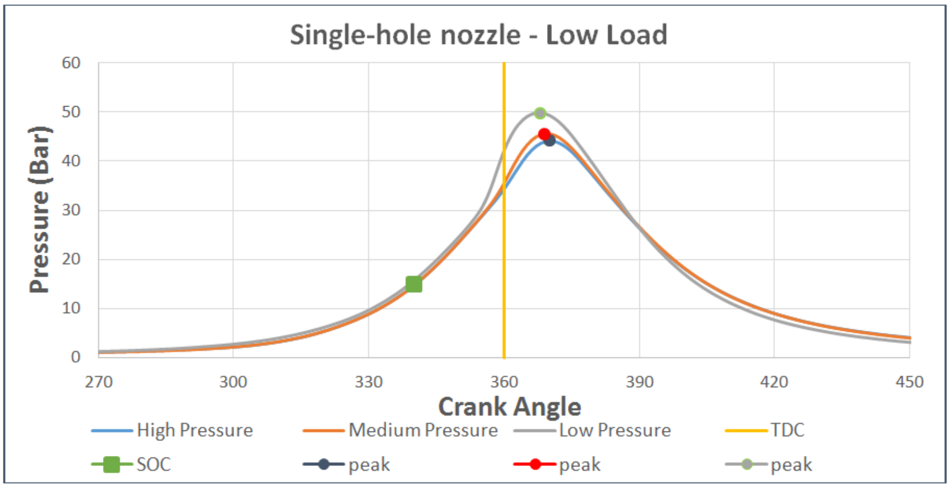

Fig.3: Pressure V/S Crank Angle (P-θ) graph for Low Load with single-hole nozzle

Figure 2 and Figure 3 shows Pressure – Crank Angle (P-θ) graph the graph for low load including all the injection pressures. From graph we can conclude that the pressure created by the combustion for all the injection pressure is same for two-hole nozzle whereas different at all the injection pressure for single-hole nozzle. The pressure created by the combustion is at peak level of 50 bar for all injection pressure in two-hole nozzle, while in single-hole nozzle also peak of 50 bar for low injection pressure only.

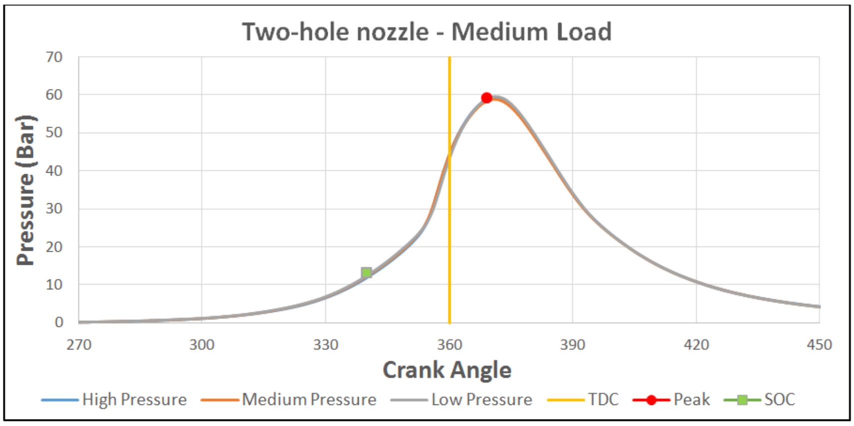

Fig.4: Pressure V/S Crank Angle (P-θ) graph for Medium Load with two-hole nozzle

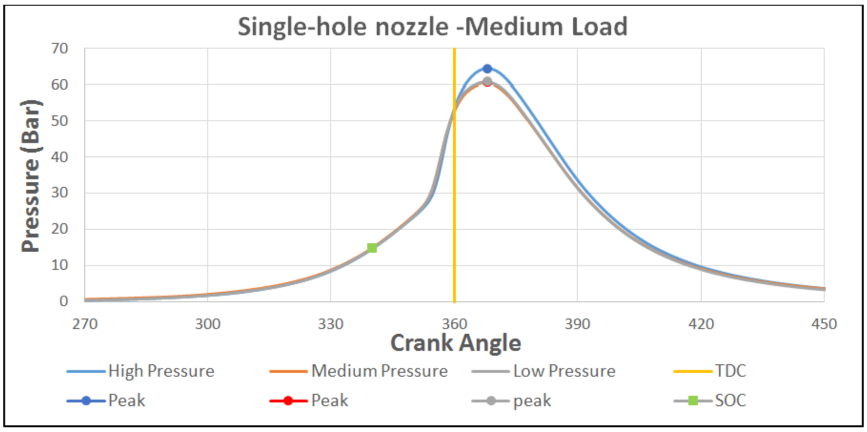

Fig.5: Pressure V/S Crank Angle (P-θ) graph for Medium Load with single-hole nozzle

Figure 4 and Figure 5 shows Pressure – Crank Angle (P-θ) graph the graph for medium load including all the injection pressures. From graph we can conclude that the pressure created by the combustion for all the injection pressure is same for two-hole nozzle whereas different at all the injection pressure for single-hole nozzle. The pressure created by the combustion is at peak level of 60 bar for all injection pressure in two-hole nozzle, while in single-hole nozzle also peak of 65 bar for high injection pressure only.

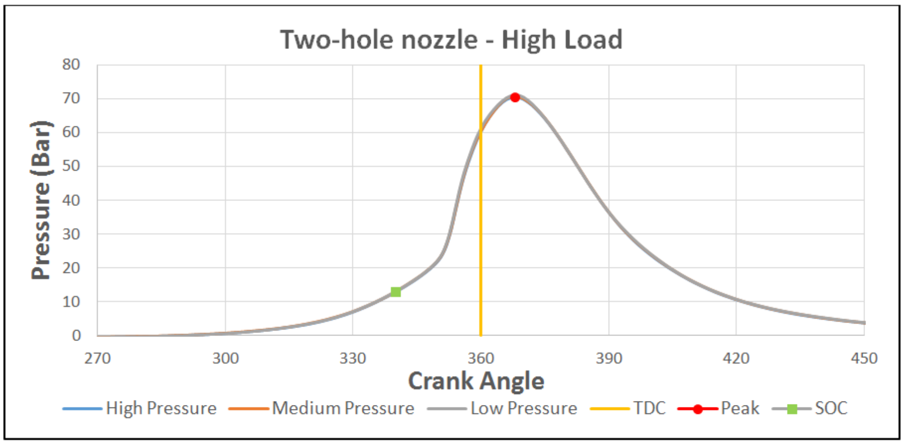

Fig.6: Pressure V/S Crank Angle (P-θ) graph for High Load with two-hole nozzle

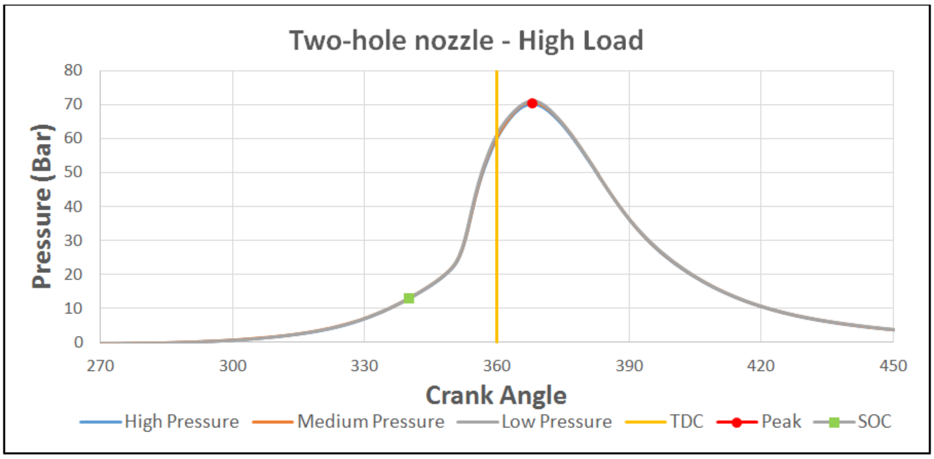

Fig.7: Pressure V/S Crank Angle (P-θ) graph for High Load with single-hole nozzle

Figure 6 and Figure 7 shows Pressure – Crank Angle (P-θ) graph the graph for high load including all the injection pressures. From graph we can conclude that the pressure created by the combustion for all the injection pressure is same for two-hole nozzle and also same for all the injection pressure for single-hole nozzle.

The pressure created by the combustion is at peak level of 71 bar for all injection pressure in two-hole nozzle, and for single-hole nozzle also peak of 70 bar for all injection pressure.

Discussions of results for Pressure-Volume

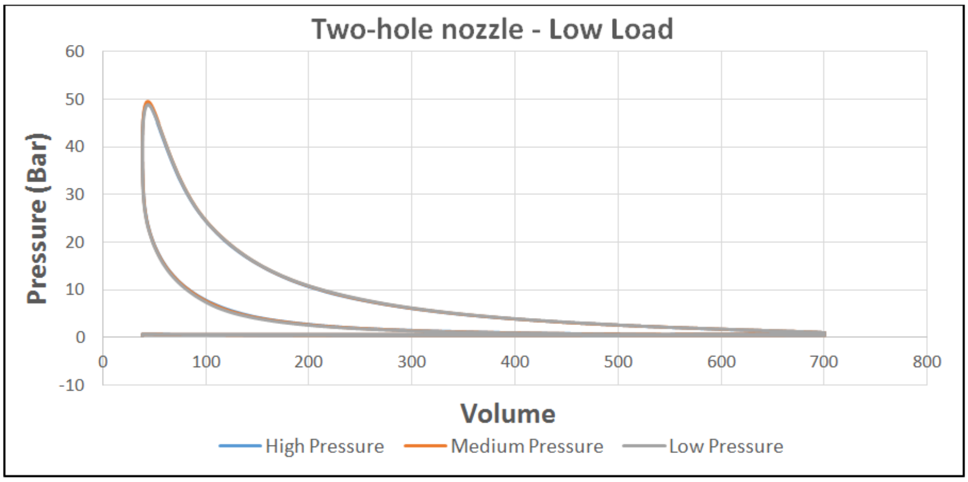

Fig.8: Pressure V/S Volume (P-V) graph for Low Load with two-hole nozzle

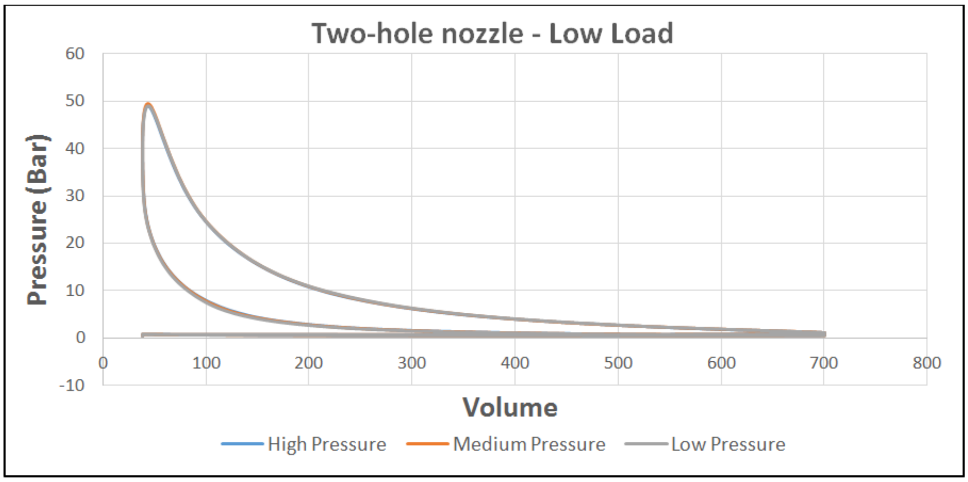

Fig.9: Pressure V/S Volume (P-V) graph for Low Load with single-hole nozzle

Figure 8 and Figure 9 shows Pressure – Volume (P-V) graph the graph for low load including all the injection pressures. From graph we can conclude the changes in volume & pressure in the system by the combustion for all the injection pressure is same for two-hole nozzle and it varies at all injection pressure for single-hole nozzle.

The volume at various pressure created by the combustion is at peak level of 50 bar for all injection pressure in two-hole nozzle, and for single-hole nozzle also peak of 50 bar for low injection pressure and peak at 47 bar for high and medium injection pressure.

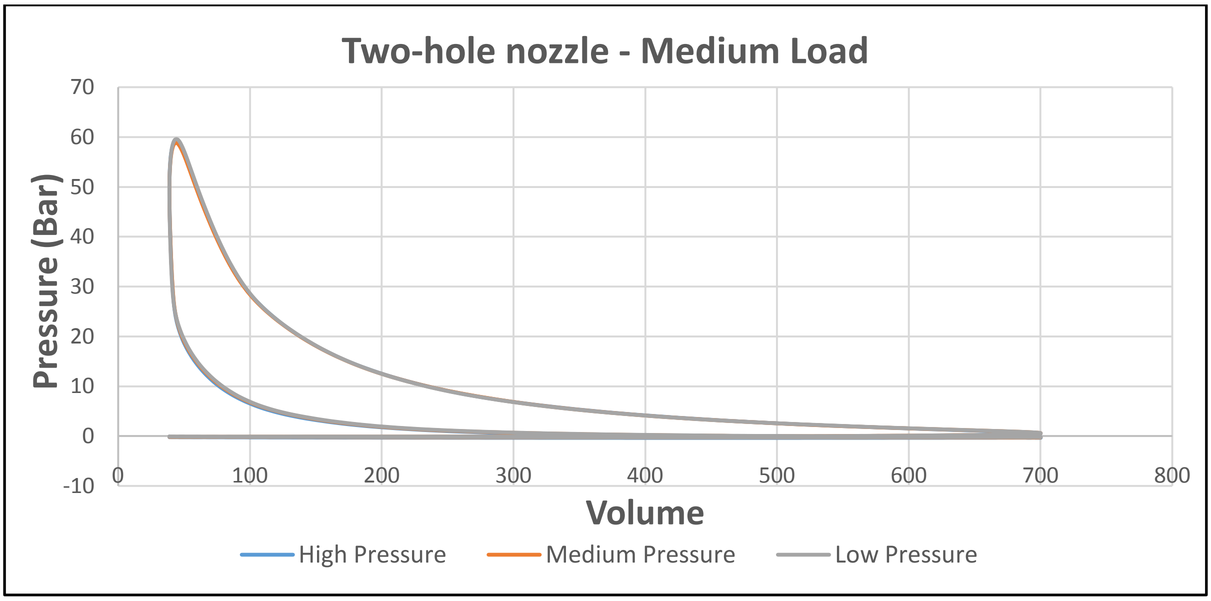

Fig.10: Pressure V/S Volume (P-V) graph for Medium Load with two-hole nozzle

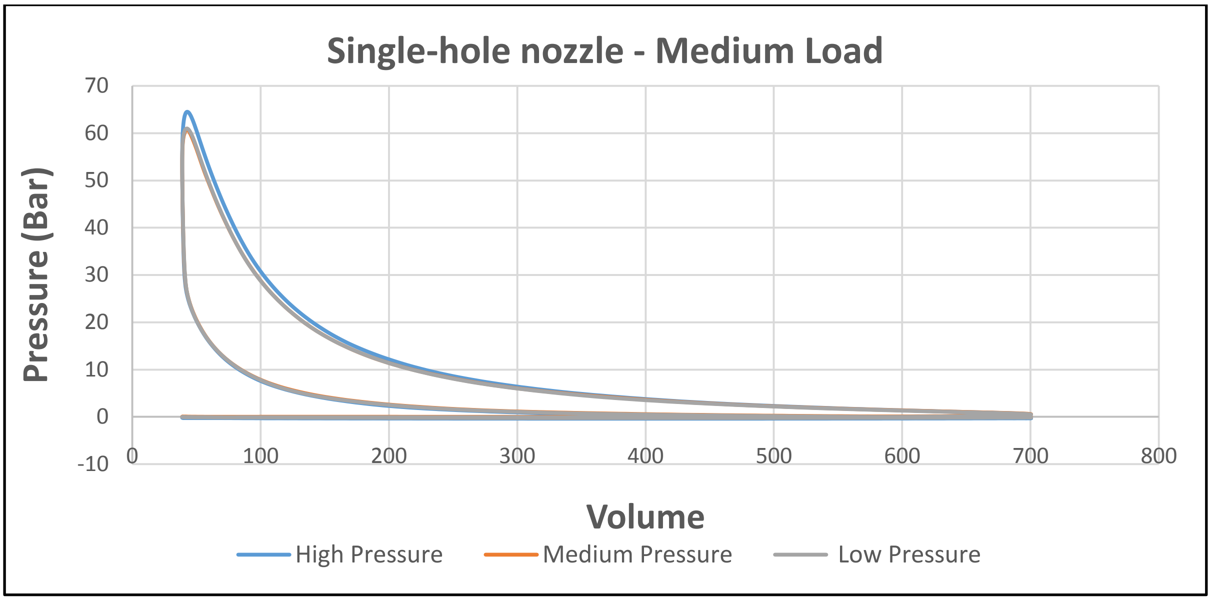

Fig.11: Pressure V/S Volume (P-V) graph for Medium Load with single-hole nozzle

Figure 10 and Figure 11 shows Pressure – Volume (P-V) graph the graph for medium load including all the injection pressures. From graph we can conclude the changes in volume & pressure in the system by the combustion for all the injection pressure is same for two-hole nozzle and it varies for at various injection pressure for single-hole nozzle.

The volume at various pressure created by the combustion is at peak level of 60 bar for all pressure in two-hole nozzle, and for single-hole nozzle also peak of 65 bar for high injection pressure.

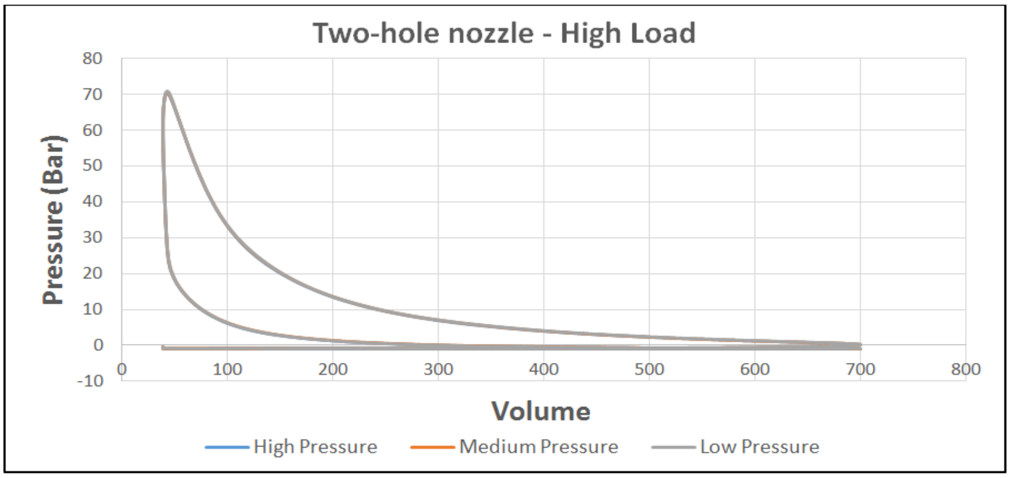

Fig.12: Pressure V/S Volume (P-V) graph for High Load with two-hole nozzle

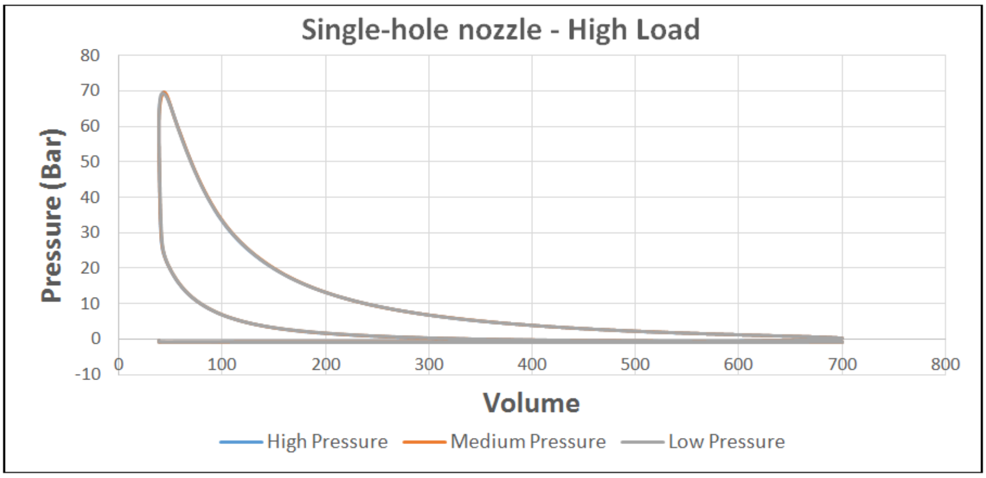

Fig.13: Pressure V/S Volume (P-V) graph for High Load with single-hole nozzle

Figure 12 and Figure 13 shows Pressure – Volume (P-V) graph the graph for high load including all the injection pressures. From graph we can conclude the changes in volume & pressure in the system by the combustion for all the injection pressure is same for two-hole nozzle and same also for the all injection pressure for single-hole nozzle.

The volume at various pressure created by the combustion is at peak level of 70 bar for all pressure in two-hole nozzle, and for single-hole nozzle also peak of 68 bar for all injection pressure.

Discussions of results for Fuel-Line Pressure

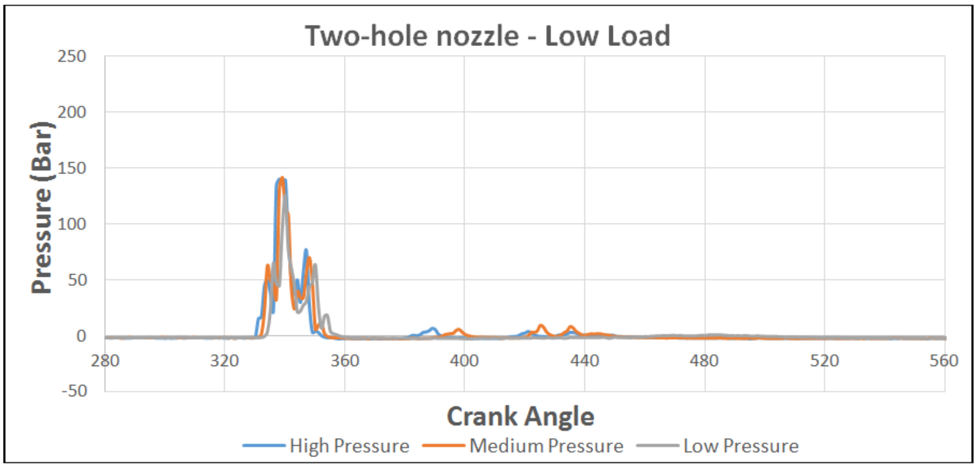

Fig.14: Fuel Line Pressure V/S Load graph for Low Load with two-hole nozzle

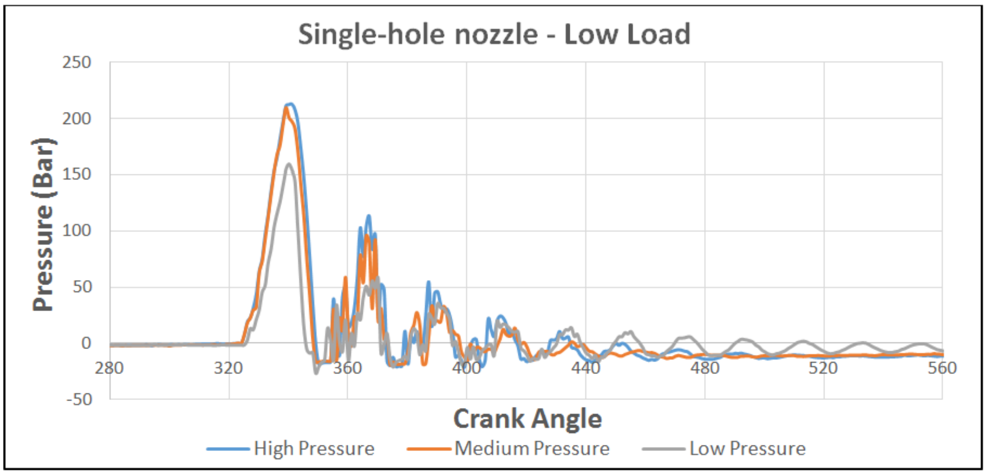

Fig.15: Fuel Line Pressure V/S Load graph for Low Load with single-hole nozzle

Figure 14 and Figure 15 shows Fuel line pressure V/S Load graph for low load including all the pressures. From graph we can conclude that in two hole nozzle the pressure of the fuel line is maximum about 140 bar at time of injection and it comes to steady state uniformly after 20° crank angle, while in single-hole nozzle the pressure of fuel line is maximum about 210 bar at the time of injection but the disturbance is created in single hole nozzle. The amplitude of disturbance within specific range of crank angle is less as compared to the others. The unsteadiness comes to normal condition quickly with the approach of crank angle.

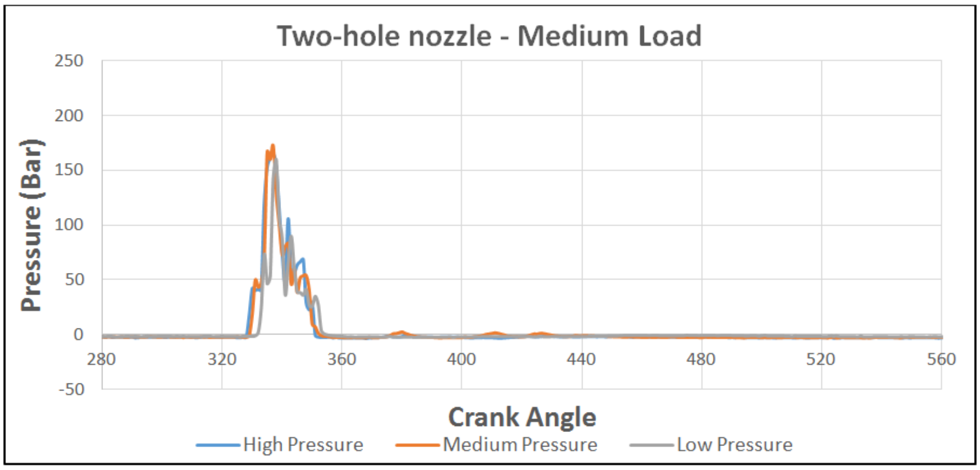

Fig.16: Fuel Line Pressure V/S Load graph for Medium Load with two-hole nozzle

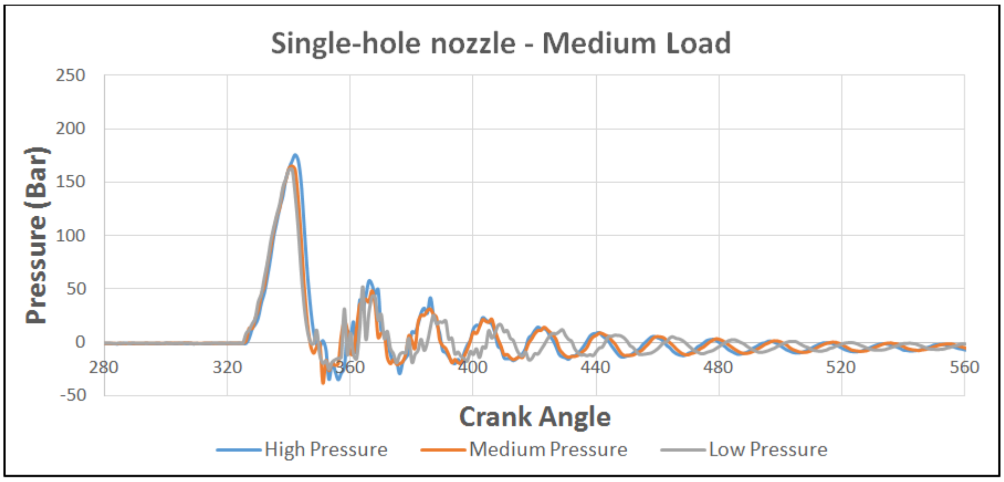

Fig.17: Fuel Line Pressure V/S Load graph for Medium Load with single-hole nozzle

Figure 16 and Figure 17 shows Fuel line pressure V/S Load graph for low load including all the pressures. From graph we can conclude that in two hole nozzle the pressure of the fuel line is maximum about 155 bar at time of injection and it comes to steady state uniformly after 20° crank angle, while in single-hole nozzle the pressure of fuel line is maximum about 162 bar at the time of injection but the disturbance is created in single hole nozzle. The amplitude of disturbance within specific range of crank angle is more as compared to low load condition. The unsteadiness comes to normal condition within little time with the approach of crank angle.

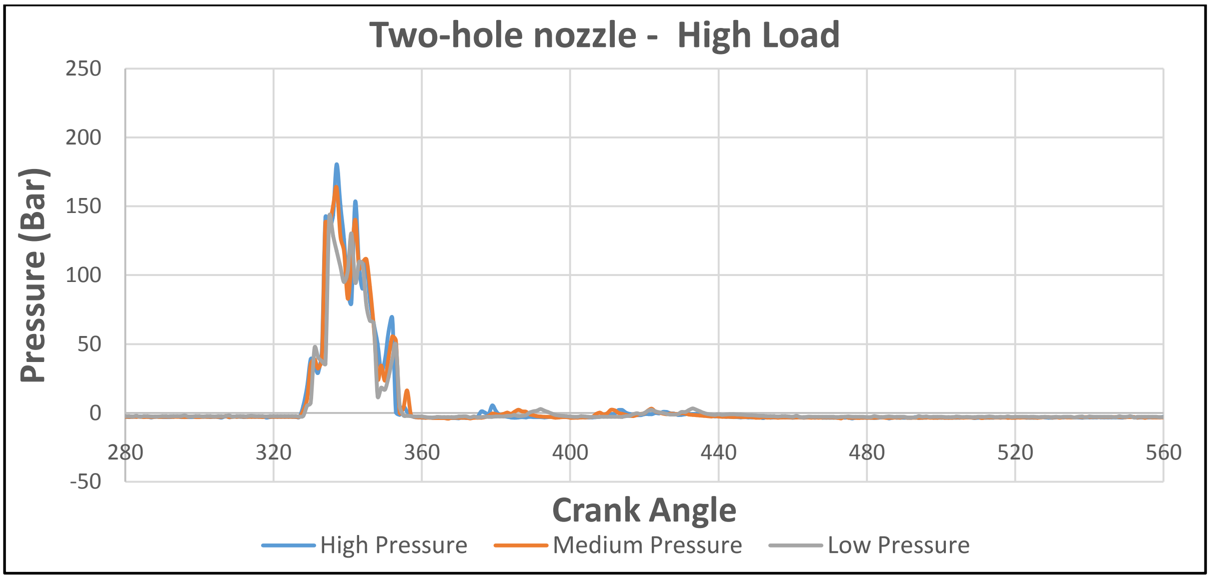

Fig.18: Fuel Line Pressure V/S Load graph for higher load with two-hole nozzle

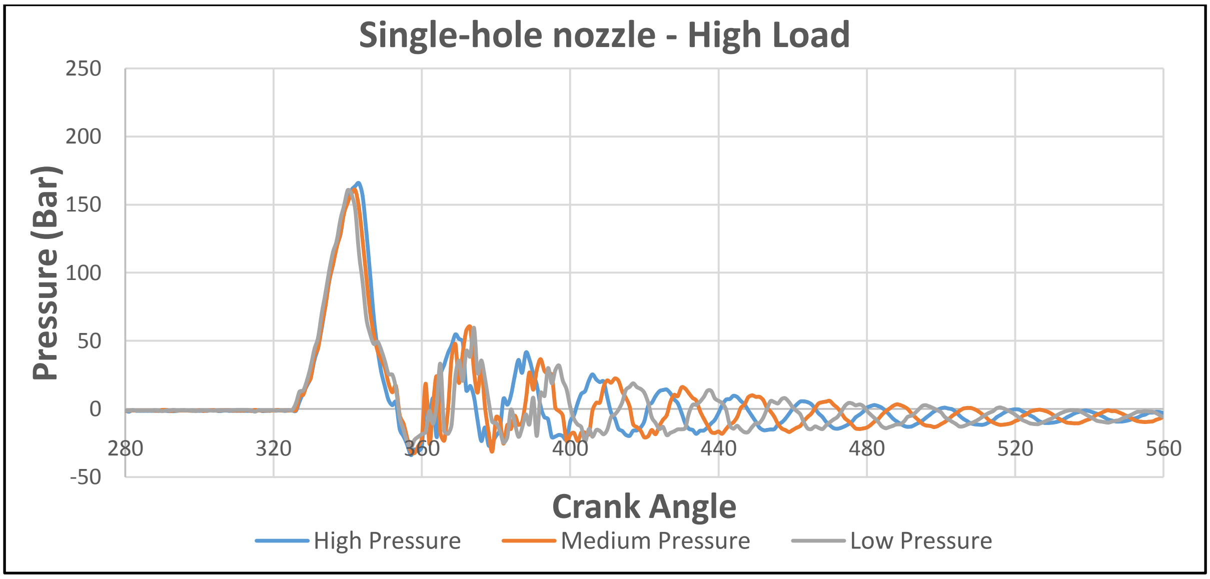

Fig.19: Fuel Line Pressure V/S Load graph for high load with Single-hole nozzle

Figure 18 and Figure 19 shows Fuel line pressure V/S Load graph for low load including all the pressures. From graph we can conclude that in two hole nozzle the pressure of the fuel line is maximum about 160 bar at time of injection and it comes to steady state uniformly after 20° crank angle, while in single-hole nozzle the pressure of fuel line is maximum about 165 bar at the time of injection but the disturbance is created in single hole nozzle. The amplitude of disturbance within specific range of crank angle is more as compared to low and medium load condition. The unsteadiness comes to normal condition within long time with the approach of crank angle.

VI. Conclusion

- The value of pressure at the time of combustion is increasing with the increase in load for both the nozzles.
- The pressure inside the cylinder at the time of combustion is same for all the injection pressure in case of two-hole nozzle, while in case of single-hole nozzle the pressure inside the cylinder vary for all the injection pressure.
- The volume of combustion taking place inside the engine cylinder is increasing with the increase in load.
- The volume of combustion taking place inside the engine cylinder is same at all the injection pressure for two-hole nozzle, while in case of single-hole nozzle the volume inside the engine cylinder vary for all the injection pressure.
- The fuel line pressure is very less for two-hole nozzle while for single-hole it is at extreme level and becomes stable over a large range of crank angle.
- The working of single-hole nozzle tries to work similar as two-hole nozzle as there is increase in load.

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