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Experimental Investigation on Effect of Fuel Injection Pressures in the Performance and Emission of a Single Cylinder DI Diesel Engine

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ABSTRACT

This paper reports the results of the investigation carried out on a single cylinder DI diesel engine for the effects of fuel injection pressure (FIP) on the combustion, performance and emission characteristics. The experiments were conducted at constant speed (1500 rpm) with four different FIPs Viz., 200, 400, 600 and 800 bar are used for the injection of fuel with a fixed start of fuel injection. With increased injection pressure the heat release rate increases and also the peak point is advanced in time. The results reveal that with increase in pressure at the full load condition the brake thermal efficiency increases by 11.8%, smoke density reduces from 86HSU to 70HSU. The HC emissions are reduced from 100 ppm to 50 ppm while the oxides of nitrogen emission increase from 960 ppm to 1160 ppm. The Carbon Monoxide emissions are reduced from 0.21 % by volume to 0.16 while the Carbon-di-Oxide reduced by 5.26 %. The brake thermal efficiency is increased by 12% with apparent reduction in smoke reduction by 18%. The cylinder pressure increases from 64 to 80 bar while Heat release rate increases from 112 to 148 kJ/m^{3}deg. This investigation establishes that switching to higher injection pressure improves fuel economy of diesel engines.

1. Introduction

Direct Injection (DI) Compression Ignition (CI) engines, due to their excellent fuel economy and efficiency, have become more and more popular in automotive applications. This is used for powering the equipments in the various fields such as agriculture, industries, construction and marine. However, emissions from diesel engines have been focused in increasingly stringent emission regimes because of their adverse health impact on humans. In diesel engines, it is rather difficult to lower NOx and PM emissions simultaneously due to soot-NOx trade off. High NOx and PM emissions are still the main obstacle in the development of next generation conventional diesel engines.

Combustion, performance and emission characteristics of diesel engines depend on several factors like FIP, SOI (start of injection), fuel quantity injected, number of injections (post-and pilot-), design of combustion chamber and nozzle spray patterns. High-pressure direct injection (HPDI) seems to be one of the most efficient ways to comply with the stringent global emission norms. FIP for different generation of diesel engines varies from 200 to 2000 bars. Kato et al.[2] demonstrated using high fuel injection pressures as a means to reduce PM emissions without increasing NOx emissions. High FIPs seem to induce a very different spray structure than low FIP sprays used earlier [3].This is mainly due to cavitation created in the nozzles at high FIPs, which results insignificantly faster atomization[4]. Other studies [5,6]showed that higher FIPs improve fuel–air mixing, followed by faster combustion, which directly influences pollutant formation. Diesel spray characterization is usually done for parameters such as spray tip penetration, spray angle, droplet velocities, droplet sizes and distributions, and global spray structure.

A good understanding of these characteristics is essential for increasing the combustion efficiency and reducing the environmental impact. High pressure difference across the injector nozzle is necessary to atomize the liquid fuel into small droplets in order to enable rapid vaporization as well for high jet penetration in the combustion chamber [7,8]. Droplets size distribution of a spray fundamentally affects CI engine combustion. Smaller fuel droplets vaporize rather quickly compared to larger droplets however their penetration is shorter therefore the size distribution needs to be optimized. Chen et al. reported that small droplets and high penetration depth of fuel jet enhances the fuel–air mixture quality, which provides shorter ignition delays and more complete combustion [8,9]. Lower FIPs gives larger droplet diameters, thus increasing ignition delay during combustion [9]. This also leads to higher cylinder pressures, which ultimately results in higher NOx emissions. When FIPs increase, spray droplet diameter distribution reduces. This leads to improved fuel–air mixture formation because of superior mixing during ignition delay, therefore smoke and CO emission reduce [10]. However, if FIP is too high, ignition delay period becomes too short. Hence, possibility of homogeneous mixing decreases and as a result, combustion efficiency reduces [11].

In the present investigation, a single cylinder research engine was used to experimentally evaluate the effect of FIP on performance and emissions.

2. Materials and method

2.1 Engine setup and Measurements

The experimental investigation was carried out on a single cylinder four stroke DI diesel engine under different loads at a constant speed of 1500 rpm. The engine specifications are given in Table 1.

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The schematic diagram of the experimental setup is shown in Fig. 1. The test engine was directly coupled with an Eddy current Dynamometer to apply load on the engine. A duly calibrated standard burette (100 ml volume and 1 ml division) and a digital stop-watch were employed for the fuel flow measurements. Separate fuel tanks were used for supplying fuel to the test engine. The flow rate of air was measured using an orifice plate. The orifice plate created a pressure drop which varied with the flow rate. This pressure drop was measured by means of an inclined manometer. A damping tank was used for the reducing air pulsation.

The Bosch fuel injection pump (9410031021) and Bosch fuel injector (9430031258E) were used to inject the fuel into the combustion chamber.

Table 1. Engine Specification

TYPE	**FOUR STROKE WATER COOLED OHV, CRDI ASSISTED DIESEL ENGINE**
Make	Kirloskar AV-1
No. of Cylinders	1
Bore X stroke	80 x 110 mm
Displacement Volume	553 cc (0.553liters)
Compression Ratio	12:1 to 21:1
Combustion Chamber	Hemisphere open type piston flat bowl in piston
Injection	Multiple injection at compression stroke
Injector	Inward swirl 6 hole injector
Nominal power / speed	3.7 kW / 1500 rpm
Connecting rod Length	231 mm

Base line engine reading with standard injection pressure is conducted. The fuel input for this obtained from the base line reading. Finally experiment at the standard speed with a fuel injection pressure of 800 bar is conducted.

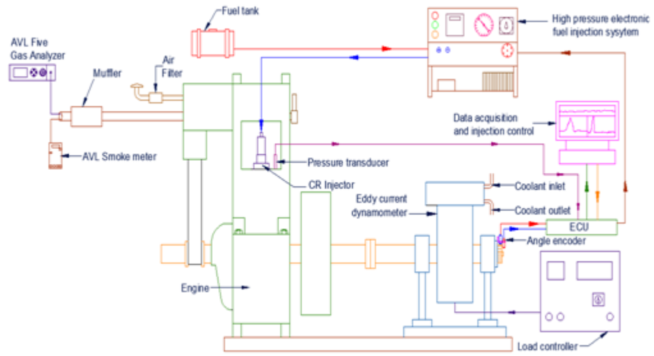

Fig 1. Experimental Setup

2.2. Error analysis

Experimental error analysis is the study and evaluation of uncertainty in an experiment. It is required in analysing the results from an experiment. Errors and uncertainties in the experiments may occur due to the selection of instruments, working conditions, calibration, environment, observation and method of conduct of the tests [12, 13]. Uncertainty analysis is needed to prove the accuracy of the experiments. Experiments were carried out in the research work using single cylinder diesel engine including gas analyzer and smoke meter from M/s. Legion Brothers, Bangalore and M/s. AVL Pvt. Ltd., Chennai. All the instruments used in the experimental setup were calibrated. In this present work, using the percentage uncertainties of various instruments given in Table 2, percentage uncertainties of various parameters like total fuel consumption, brake power, specific fuel consumption, brake thermal efficiency were calculated and they are presented in Table 3.

Table 2. Percentage uncertainties of various instruments

Sl.No	**Instruments**	**Percentage Uncertainties**
1.	Pressure pick up	± 1.0
2.	Crank angle encoder	± 0.2
3.	Exhaust gas analyser	
	NOx	± 0.2
	CO	± 0.2
	HC	± 0.2
4.	Smoke intensity	± 1.0
5.	Manometer	± 1.0
6.	Digital stop watch	± 0.2
7.	Burette for fuel measurement	± 1.5
8.	Load indicator	± 0.5

Table 3. Percentage uncertainties of calculated parameters

Sl.No	**Parameters**	**Percentage Uncertainties**
1.	Brake power	± 0.5
2.	Brake specific fuel consumption	± 1.5
3.	Brake thermal efficiency	± 1.0

3. Results and Discussion

3.1. Performance characteristics

3.1.1. Effect of fuel injection pressures on specific fuel consumption

The variation of Specific fuel consumption (SFC) for different injection pressures is shown in Fig. 2. The SFC for all Fuel injection pressures decreases with increasing load. The lowest SFC of 0.24 kg/kWh were noted at an fuel injection pressure of 800 bar at 100% load condition, which is 14.28 % lower than the fuel injection pressure of 200 bar at same load condition. The reduction in SFC is due to the increase in fuel injection pressure which leads to proper mixing of fuel and air.

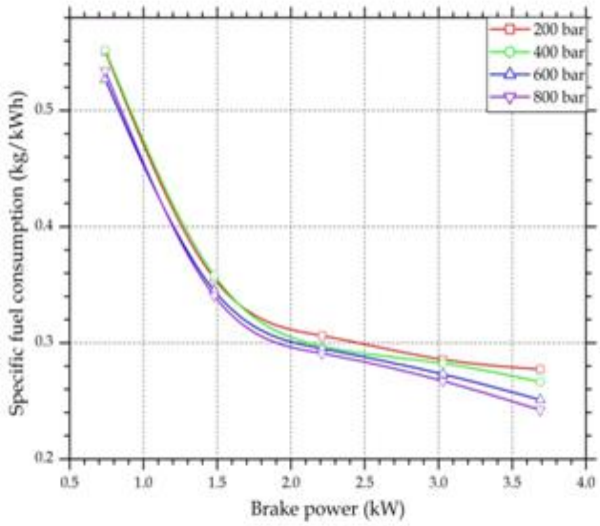

Fig 2. Variation of SFC for different fuel injection pressures

3.1.2. Effect of fuel injection pressures on Brake thermal efficiency

The variation of Brake thermal efficiency for different injection pressures is shown in Fig. 3. The brake thermal efficiency for all the Fuel injection pressures increases with increasing load. Maximum brake thermal efficiency of 33% was observed at fuel injection pressure of 800 bar at 100% load condition, which is 11.8% higher than the fuel injection pressure of 200 bar at same load condition. The increase in brake thermal efficiency is due to better combustion as a result of proper atomization due to the increase in the fuel injection pressure.

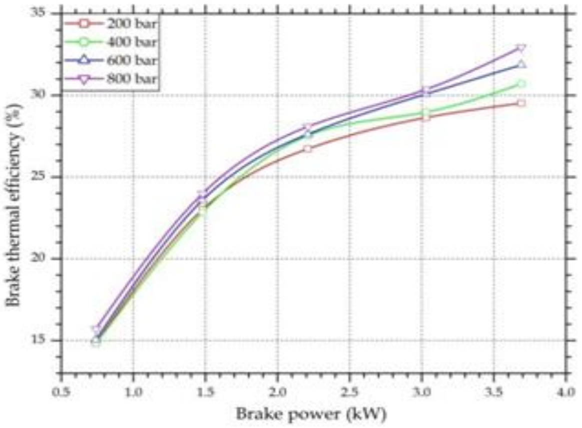

Fig 3. Variation of Brake thermal efficiency for different fuel injection pressures

3.2. Emission characteristics

3.2.1. Effect of fuel injection pressures on Smoke density

The comparison of Smoke density for different injection pressures is shown in Fig. 4. For all the fuel injection pressures used the Smoke density increases with increasing load. The corresponding results for each load range showed that the smoke density level decreased with the increase of fuel injection pressure. Maximum smoke density of 86 HSC was observed at fuel injection pressure of 200 bar at 100% load condition, compared to 70 HSC (18.6% lower) at fuel injection pressure of 800 bar at same load condition. The decrease in Smoke density is due to higher fuel injection pressure leads to longer duration and fine fuel droplets during the expansion stroke in which oxidation of the soot particles occurs.

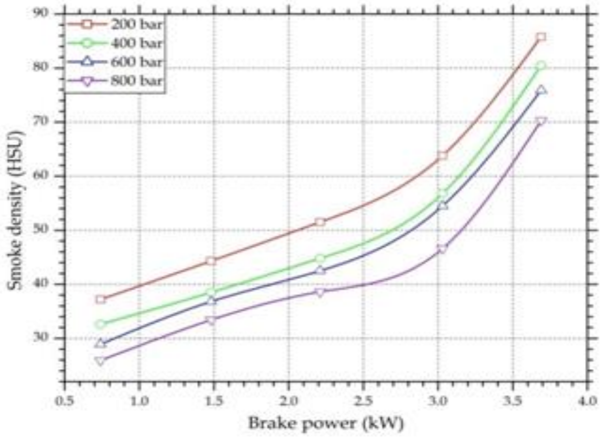

Fig 4. Comparison of Smoke density for different fuel injection pressures

3.2.2. Effect of fuel injection pressures on Oxides of nitrogen

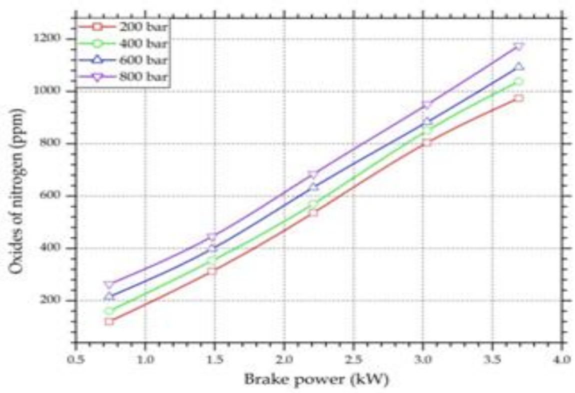

Fig 5. Comparison of Oxides of nitrogen for different fuel injection pressures

The comparison of Oxides of nitrogen (NOx) for different injection pressures is shown in Fig. 5. The NOx formation depends upon the in-cylinder temperature, oxygen concentration and residence time for the reaction [15–17]. The NOx emission level increases with increasing fuel injection pressure; this is because of faster combustion and higher cylinder gas temperature occurred as a result of peak pressure at earlier crank angles [18]. For all the Fuel injection pressures used the Oxides of nitrogen increases with increasing load. Maximum NOx emission of 1160 ppm (20.83 % higher) was observed at fuel injection pressure of 800 bar at 100% load condition, compared to 960 ppm at fuel injection pressure of 200 bar at same load condition.

3.2.3. Effect of fuel injection pressures on Hydrocarbon

The comparison of Hydrocarbon for different injection pressures is presented in Fig. 6. For all the Fuel injection pressures used the Hydrocarbon increases with increasing load. The highest emission of 100 ppm was observed with Fuel injection pressures of 200 bar at 100% load condition, compared to 50 ppm (50 % lower) at fuel injection pressure of 800 bar at same load condition.

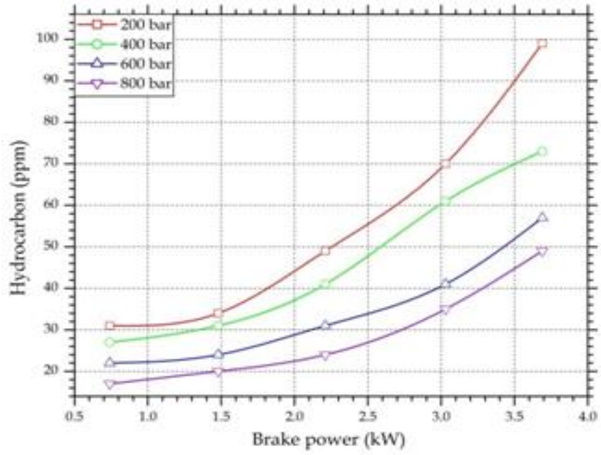

Fig. 6 Comparison of Hydrocarbon for different fuel injection pressures

3.2.4. Effect of fuel injection pressures on Carbon monoxide

The comparison of Carbon monoxide for different injection pressures is presented in Fig. 7. The highest emission of 0.21 % by volume was observed with Fuel injection pressures of 200 bar at 100% load condition, compared to 0.16 % by volume (23.80 % lower) at fuel injection pressure of 800 bar at same load condition.

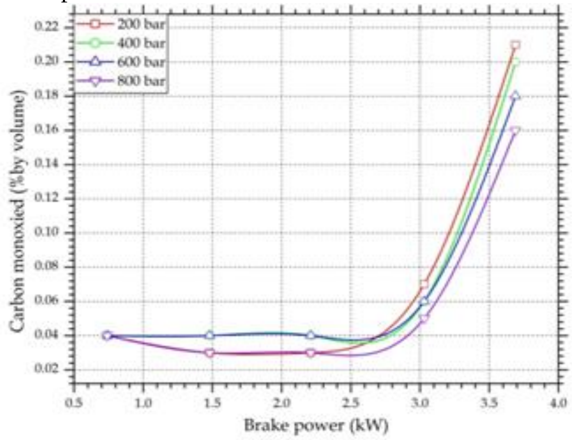

Fig 7. Comparison of Carbon monoxide for different fuel injection pressures

3.2.5. Effect of fuel injection pressures on Carbon dioxide

The comparison of Carbon dioxide for different injection pressures is presented in Fig. 8. For all the Fuel injection pressures used the Carbon dioxide increases with increasing load. The highest emission of 7.6 % by volume was observed with Fuel injection pressures of 200 bar at 100% load condition, compared to 7.2 % by volume (5.26 % lower) at fuel injection pressure of 800 bar at same load condition.

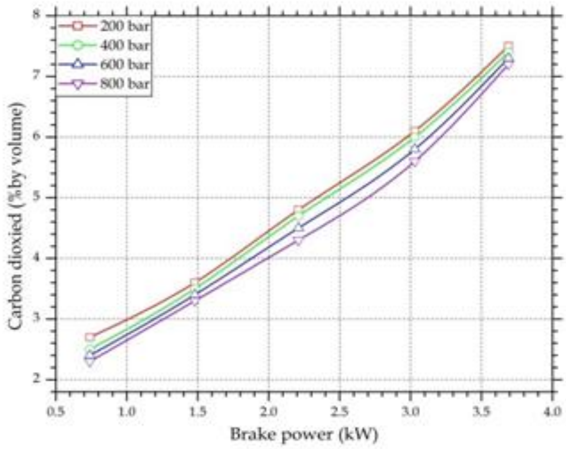

Fig 8. Comparison of Carbon dioxide for different fuel injection pressures

3.3. Combustion characteristics

3.3.1. Effect of fuel injection pressures on Exhaust gas temperature

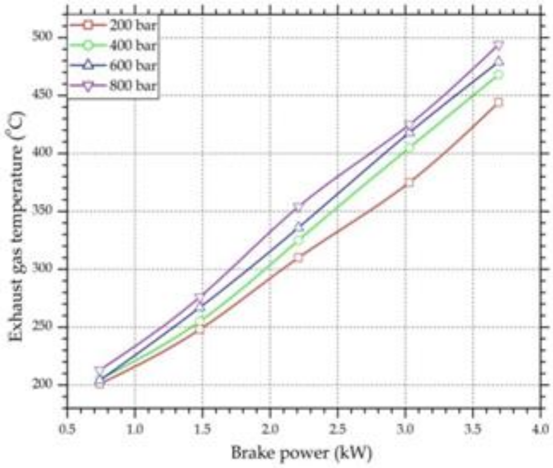

Fig 9. Variation of Exhaust gas temperature for different fuel injection pressures

The variation of Exhaust gas temperature for different injection pressures is shown in Fig. 9. For all the Fuel injection pressures used the Exhaust gas temperature increases with increasing load. Maximum Exhaust gas temperature of 49^{o}C (12.5% higher) was observed at fuel injection pressure of 800 bar at 100% load condition, compared to 440^{o}C at fuel injection pressure of 200 bar at same load condition. The increase in Exhaust gas temperature is due to better combustion as a result of proper atomization due to the increase in the fuel injection pressure.

3.3.2. Effect of fuel injection pressures on Cylinder Pressure

The variation of Cylinder Pressure for different injection pressures is shown in Fig. 10. Maximum Cylinder Pressure of 80 bar (25% higher) was observed at fuel injection pressure of 800 bar at 100% load condition, compared to 64 bar at fuel injection pressure of 200 bar at same load condition.

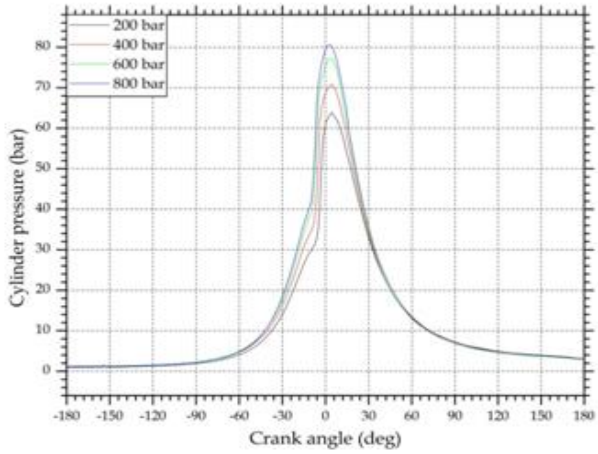

Fig 10. Variation of Cylinder Pressure for different fuel injection pressures

3.3.3. Effect of fuel injection pressures on Heat release rate

The variation of Heat release rate for different injection pressures is shown in Fig. 11. Maximum Heat release rate of 148 kJ/m^{3}deg (32.15% higher) was observed at fuel injection pressure of 800 bar at 100% load condition, compared to 112 kJ/m^{3}deg at fuel injection pressure of 200 bar at same load condition.

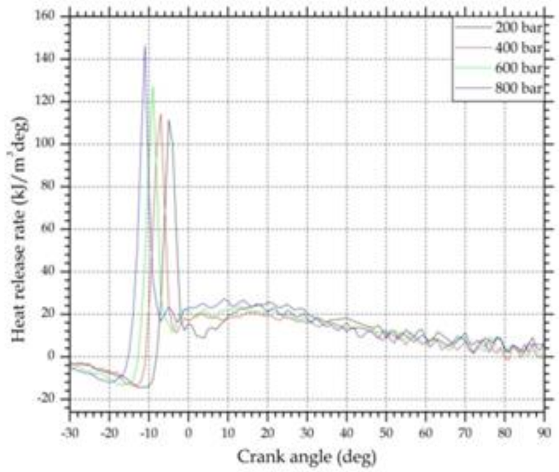

Fig 11. Variation of Heat release rate for different fuel injection pressures

4. Conclusion

Based on the significant improvement in performance, combustion and reduction in emission characteristics, optimum condition was found to be 800 bar fuel injection pressure. From the experimentations carried out, the following conclusions can be made:

(i) Significant improvement in brake thermal efficiency by 11.8% and reduction in SFC by 14.28% was observed for FIP 800 bar when compared to FIP 200 bar.

(ii) Reduction in smoke density, CO, CO_2 and HC by 18.6%, 23.8%, 5.26% and 50% respectively was observed with FIP 800 bar when compared to FIP 200 bar. Significant increase in NOx emission (20.83%) was also noted with FIP 800 bar when compared to FIP 200 bar.

(iii) Significant increase in Exhaust gas pressure, cylinder gas pressure and Heat release rate by 12.5%, 25% and 32.15% respectively was observed with FIP 800 bar when compared to FIP 200 bar.

There is a lot of scope for further development on this experiment to reduce NOx emission further and to enhance the combustion. Besides, the optimization of engine parameter using Artificial Neural Network (ANN) approach can be used to predict the engine performance, emission and combustion characteristics for obtaining more accurate data for such complex and multivariate problems.

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