Effects of Fuel Injection Pressure on CRDI Diesel Engine Performance and Emissions using CCD

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Abstract - *The influence of injection parameters like injection pressure and injection duration on performance and emission of a common rail direct injection system assisted diesel engine has been evaluated using central composite design (CCD). The tests have been carried out on a four stroke, single cylinder DI diesel engine. The fuel injection system of the diesel engine used was the high pressure common rail direct injection system. From the experiments, it is observed that the brake thermal efficiency (BTE) is improved and fuel consumption reduced due to better atomization. It is also observed that carbon monoxide (CO), unburned hydrocarbons (HC) and smoke emissions are reduced and NOx emissions increased when increasing the injection pressures. This is due to injected fuel droplets find smaller as the injection pressure increases, which leads to improve atomization of the fuel.*

Key Words: Fuel injection pressure, Injection duration, Central composite design, CRDI diesel engine, Performance, Emission.

1. INTRODUCTION

Paragraph Nowadays an automobile engine has to fulfill all the satisfactory environmental constraints, So we have to follow every possible steps to increase the performance and decrease the emission quantity. CI engine is more efficient than spark ignition engine because it takes less fuel than spark ignition engines. Since the diesel engines are used in heavy vehicles because of their fuel efficiency, reliability, and durability. Performance of diesel engine usually depends on many factors like fuel injection pressure, injection duration, injection quantity, injection position, injection angle, nozzle size, air swirling etc. [1-5]. The fuel injection system is the most necessary component in the working of CI engine. In recent diesel engines, a fuel injection system has to be designed to obtain higher injection pressure. Fuel injection pressure plays an important role for better atomization of injected fuel and allows it for complete combustion and to reduce the emission [6]. Fuel injection pressure will be low, fuel particle diameters will become wider and ignition delay period will increase during the combustion and engine performance will decrease and cause CO, HC and smoke emissions and the injection pressure increases than the fuel particle diameter decreases and the mixing of air with fuel becomes better during combustion, this leads to better engine performance and reduces smoke level and HC, CO emissions [7-9]. In this study, effect injection pressure on engine performance and emissions characteristics have been experimentally investigated in single cylinder diesel engine equipped with common rail direct injection (CRDI) fuel injection system.

2. EXPERIMENTAL DESIGN

Central composite design (CCD), is an experimental design used to attain maximal information about a process from a minimal number of experiments [10]. Central composite face centered (CCFC) design was used in this study to determine the optimal conditions and study the effect of injection pressure and injection quantity on seven responses (fuel consumption (gm/kw.h), BTE, HC, CO, NOx, smoke emissions and speed of the engine) of a common rail single cylinder direct injection diesel engine. From the initial experimental results, process variables and their ranges (injection pressure (220-1000 bar), injection quantity (600-1200 μsec)) were determined. After selection of independent variables and their ranges, experiments were established based on a CCFC design with two factors and each independent variable was coded at three levels between -1, 0 and +1. In this study, the total number of 13 experiments (in order to allow the estimation of pure error) was carried out and the total number experiments were calculated from the following equation [11]:

$$N = 2^n + 2n + n_c$$

Where N is the total number of experiments required; n is the number of factors; and c is the number of center points. The experimental progression was randomized with the intention of minimizing the effects of unpredicted variability in the responses due to extraneous factors. A second-order polynomial equation was used with the intention of developing an experimental model which correlated the responses to the independent variables. The general form of the second order polynomial equation is

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j \, X_j + \sum_{j=1}^{k} \beta_{jj} \, X_j^2 + \sum_{i} \sum_{<j=2}^{k} \beta_{ij} \, X_i \, X_j + e_i$$

Where Y is the response; Xi and Xj are variables (i and j range from 1 to k); b0 is the model intercept coefficient; bj, bjj and bij are interaction coefficients of linear, quadratic and the second order terms, respectively; k is the number of independent parameters (k= 4 in this study); and ei is the error [13]. In the present study, two factors at three level central composite, face centered (CCFC) design used to study the influence of process variables such as injection pressure and injection quantity in CRDI system assisted diesel engine. The three dimensional response surface was constructed from the developed models. Response surface plots are graphical representations of a regression equation that illustrate the main and interactive effects of independent variables on a response variable. These graphs are simple to understand and symbolize the interactions between pairs of independent variables on the responses and also accustomed to locating their optimal levels.

3. EXPERIMENTAL SETUP

Paragraph The experiment is performed on a stationary single cylinder, 4 stroke, water cooled, Common rail direct ignition diesel engine. The fuel injected in standard injection timing (23° BTDC) and the fuel used is standard diesel. The fuel injection pressure in standard engines varies from 150-220 bars, but in this investigation pressure varied from 220-1000 bars to analyze the performance and emission on the CRDI diesel engine. This high pressure was achieved by using two pumps. The primary pump was used to increase the fuel pressure up to 5 bar for pump the fuel from the fuel tank to high pressure pump (secondary pump). The secondary pump is used to compress the fuel to very high pressure up to 1000bar.Common rail (accumulator) used to maintain the

pressure of fuel and supply the fuel at high pressure to the injector. The piezo injector is used to inject the fuel at high pressure into the combustion chamber. The engine is coupled to an eddy current dynamometer; the fuel is injected at high pressure with the help of high pressure fuel injection system. The pollutants like NOx, CO and HC are measured using AVL Di-gas analyzer and smoke is measured by using an AVL smoke meter. The technical specification of the tested engine is given in Table 1 and the injector specification is given in Table 2.
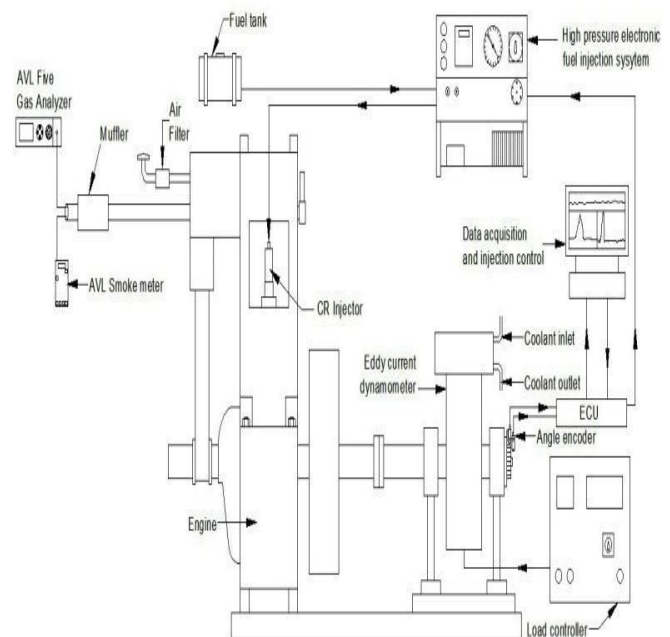

Fig. 1 Engine set up with common rail fuel injection system

Table 1. Engine specification

Type	:	Vertical, water cooled, four stroke
Number of cylinders	:	One
Bore	:	80 mm
Stroke	:	110 mm
Compression ratio	:	17.5:1
Maximum power	:	3.7 kW
Speed	:	1500 rev/min
Dynamometer	:	Eddy current
Injection timing	:	23 (before TDC)
Injection pressure	:	220-1000 kgf/cm²

Table 2. Injector fuel system specifications

Fuel fed	Units	Common rail
Injection pressure	MPa	250-600 MPa
Number of nozzle holes	-	3
Nozzle hole diameter	mm	0.518
Start of injection	-	23º Before top dead center (BTDC)
Injection duration	µsec	750
Fuel injected	g/cycle	0.168 (at full load)

3. EXPERIMENTAL SETUP

The results obtained at different injection pressures and injection durations are analyzed. Based on the output results, the discussions are represented with the help of central composite design (CCD) graphs.

4.1 FUEL CONSUMPTION (FC)

Fuel consumption plays a very important role in analyzing the performance of an engine. By the help of three dimensional response surface for fuel consumption, it is cleared that the injection pressure was increase; the amount of fuel consumption was reduced. So, increasing injection pressure helps in reducing fuel consumption. This is due to increased injection pressure reduces the fuel particle diameter and because of this, atomization occurs properly and causes better combustion.

DESIGN-EXPERT Plot

Fuel conumption
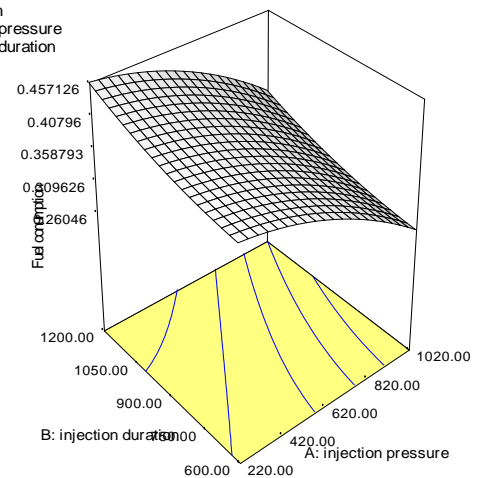X = A: injection pressure
Y = B: injection duration

Fig. 2 Three dimensional response surface for fuel consumption

4.2 BRAKE THERMAL EFFICIENCY (BTE)

Fig. 3 shows the three dimensional response surface for BTE by varying injection pressure and injection duration. From the response surface it is clear that increase in injection pressure results better BTE. BTE was increased up to 5% when the injection pressure was increased from 220bar to 1000 bar. On the other side, increase in injection duration does not seem pretty good for BTE, in comparison to injection pressure. So increase of injection pressure increases BTE better than standard working pressure.

DESIGN-EXPERT Plot

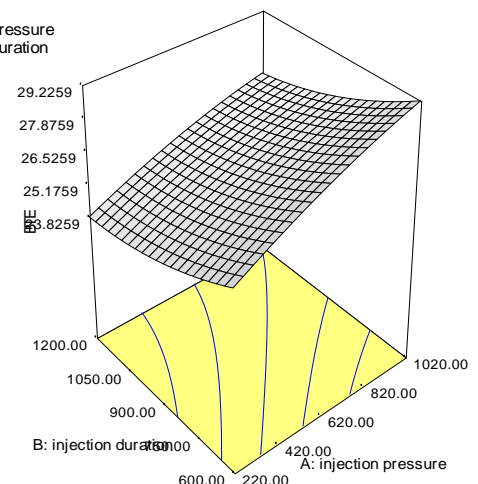BTE
X = A: injection pressure
Y = B: injection duration

Fig . 3 Three dimensional response surface for BTE

4.3 UNBURNED HYDROCARBONS (HC)

Fig. 4 shows the response surface for Unburned Hydrocarbons (HC). From the figure it is clear that the increasing in injection pressure HC emission was reduced, it is due to the high injection pressure increases the rapid atomization and shorter ignition delay period, and this will cause better combustion of fuel. On the other hand increase in injection duration will increase the HC emission. When the HC emission was 90ppm on 220 bar injection pressure and it was 65ppm on 1000 bar injection pressure. So to reduce the HC emission, increase of injection pressure is the best way.
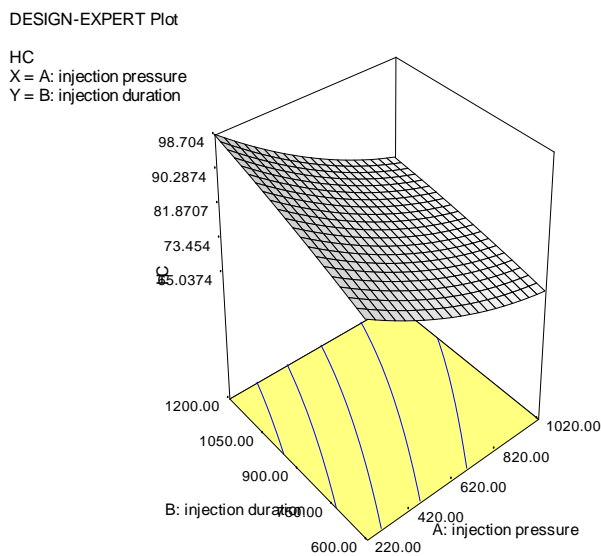

Fig. 4 Three dimensional response surface for HC

4.4 CARBON MONOXIDE (CO)

Fig.5 shows three dimensional response surface for Carbon Monoxide (CO) emission. From the figure it is clear that the increasing the pressure, increases the amount of CO emission. Carbon-monoxide is a by-product of incomplete combustion and it is produced from the partial oxidation of carbon-containing compounds; it forms when there is not enough oxygen to produce carbon dioxide (CO_2). This condition is referred as a rich fuel condition. Since CO emission occurs due to rich mixture and if injection pressure increases, the mixture gets leaner and easily mixes with the air. CO emission was 0.517% (by volume) when injection pressure was 220bar and it was reduced to 0.38% (by volume) on 1000bar. On other side,

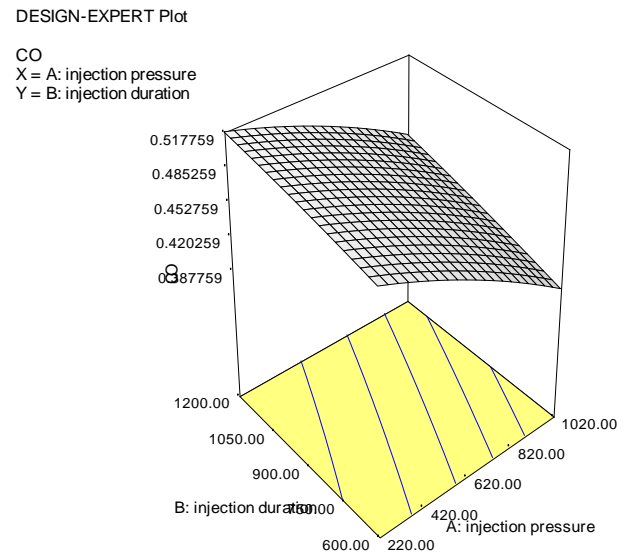increase in injection duration, the mixture gets rich and CO emission was increased.

Fig. 5 Three dimensional response surface for CO

4.5 OXIDES OF NITROGEN (NOX)

Fig. 6 shows three dimensional response surface for NOx emission. NOx emission is caused by lean mixture and if injection pressure was increased, the fuel mixture will be lean and tends to complete combustion. From the figure, it is clear that the NOx emission increases with increasing of pressure. When NOx emission was 740.525 ppm on injection pressure of 220 bar, and 910.489 ppm on 1000 bar. On the other side, the injection duration will not create any major deviation in NOx emission.
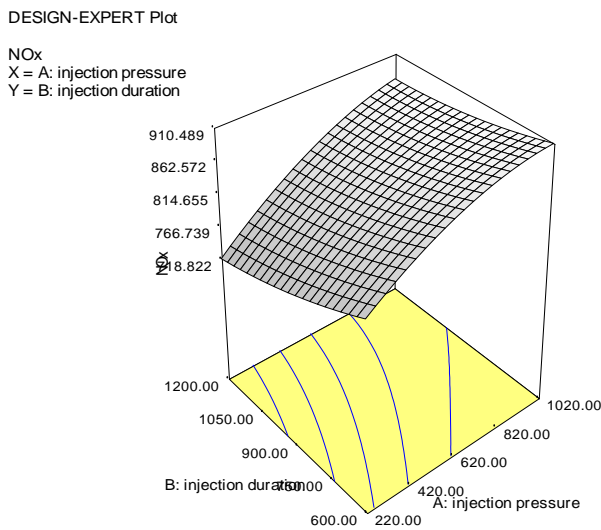
DESIGN-EXPERT Plot

NOx
X = A: injection pressure
Y = B: injection duration

Fig. 6 Three dimensional response surface for NOx

4.6 SMOKE

Fig.7 shows three dimensional response surface for smoke emission. When injection pressure increased the formation of mixing of fuel to air becomes better during ignition delay period and tends to complete combustion. So the injection pressure was increased, smoke emission gets decreased. From the figure, smoke emission was decreased from 64 HSU to 46 HSU by increasing the pressure up to 1000bar. In case of injection duration, smoke emission was dramatically increased.
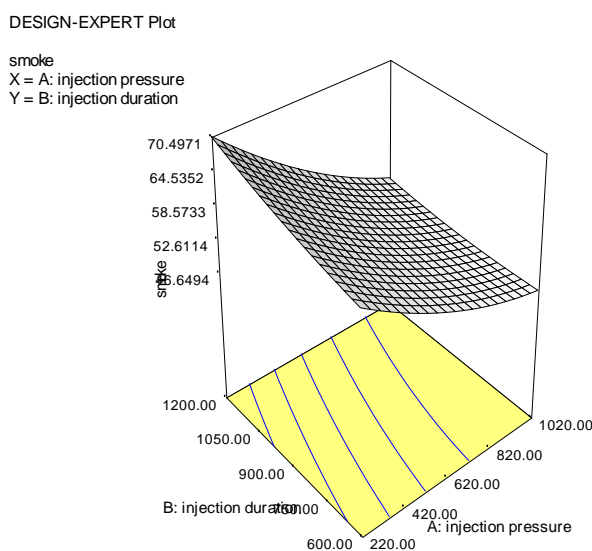

DESIGN-EXPERT Plot

smoke
X = A: injection pressure
Y = B: injection duration

Fig. 7 Three dimensional response surface for smoke

5. CONCLUSION

Increasing the injector pressure i.e. 220 bar to 1000 bar using electronically controlled injection system resulted in a considerable enhancement in performance and emissions with due to better spray formation. The changes noted at maximum engine output were:

1. Brake thermal efficiency increases from 23.8% to 29.2%,

2. Hydrocarbon emission reduced from 90 to 65ppm,

3. NOx emission increases with increasing of injection pressure due to faster combustion and higher temperatures reached in the cycle.

4. Smoke emission reduced from 64HSU to 46HSU. Smoke levels gradually drop with increase in the injector pressure due to better mixture formation owing to well-atomized spray.

Overall a considerable enhancement in the performance and emissions can be realized by appropriately optimizing the injector pressure when a diesel engine.

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