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STUDY OF FUEL INJECTION PRESSURE AND INJECTION TIMING EFFECT ON A DIESEL ENGINE PERFORMANCE AND EMISSION

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ABSTRACT

Diesel engine combustion quality is based on the formation of fuel-air mixture. Enormous efforts have made to reduce the harmful diesel engine emissions. High engine noise, Particulate matter (PM) and NOx production are the results of improper combustion process and considered as the major constraints. The performance and emission characteristics of diesel engines depend on many parameters. Precise control over the fuel injection process is one of the most important factors and plays a very important role in combustion to increase the engine performance with minimal exhaust emission. The injection system must satisfy high pressure capability, injection pressure control, flexible timing control, and injection rate control. The purpose of this study is to find the performance and exhaust emission of diesel engines by implementing the combination of various high injection pressures and variable injection timings. Present paper is concentrated towords optimization of the best combination of high pressure injection with suitable injection timing in a diesel engine fueled with pure diesel, to reduce the emission and fuel consumption with increased engine power.

Keywords: *Diesel Engine, Performance, Emission control, Injection pressure, Injection timing;*

INTRODUCTION

In the last few decades of global scenario, internal combustion engines utilisation numbers in automoblie tranportation and stationary sector, increased tremendously with an unavoidable spectre of environmental deterioration. Combustion of fuels has led to widespread release of pollutants such as CO, UBHC, NO_X, PM and many other harmful compounds in the environment, resulting in deterioration of air quality with health effects.

NOx is the main component in the formation of photochemical smog, while PM emissions causes increased cardiovascular mortality rates, impaired lung development in children, and a host of other health impacts. Result of this, emission control regulatory bodies have legislated substantial reductions in PM and NOx emissions from diesel engines, which made great difficulties for the diesel engine manufacturers to provide a quite efficient engine to satisfy the consumers. PM, NOx production and engine noise are purely depends on the combustion process [9]. Therefore precise control over the fuel injection, spray atomization and fuel-air mixing is essential in making improvements to the combustion process. Injection pressure with right injection timing will play an important role in combustion process, which influences the performance, noise and exhaust emission of diesel engine. High injection pressure contributes reduced sized fuel droplet with very fine atomization and improved combustion, resulting in reduction of smoke emission [3, 8]. Low injection pressure is required to reduce noise at idling and in the very low load range. Proper injector opening pressure and injection timing a substantial improvement in the performance and emissions can be obtained [4].

G.R. Kannan et al [1], varied the injection pressure and timing, and found that the combined effect of higher injection pressure of 280 bar and an advanced injection timing of 25.5°**B**TDC had substantial improvement in the brake thermal efficiency, cylinder gas pressure and heat release rate with decrease in nitric oxide and smoke emission. Kiplimo et al. [2], found that reduced NO emissions and increased UBHC, smoke and CO emissions were obtained when the injection timing was advanced, meanwhile smoke, UBHC and CO were low with Higher injection pressure. Murari Mohon Roy [3], found that shortest ignition delay and minimal emissions were lower at high Injection pressures (60–80 MPa). K. M. Mrityunjayaswamy et al [4], found that, with the proper injector opening pressure and injection timing (200 bar and 30°BTDC) a substantial improvement in the performance and emissions can be obtained. N.Venkateswara Rao et al [5], concluded that, injection timing advance and increase in injector opening pressure will reduce exhaust emissions from an engine with biodiesel operation. Venkatraman et al [6], stated that, the combined increase of compression ratio, injection timing and injection pressure increases the BTE and reduces BSFC. Meyyappan Venkatesan [7], found through experiments that, CNG - JOME can be used as fuel with better performance for higher pressure and advanced injection timing. Srinath Pai et al [8,9], suggested that; an increase in injection pressure will improve the combustion, which in turn improves the performance parameters and emission reduction they also observed that, smoke opacity gets reduced with increase in injection pressure for all loads.

A. *Effect of injection prresure on diesel engine performance*

The engine performance, power output, fuel economy and emissions are greatly depends on combustion processes. At the end of compression stroke, fuel is injected in to the combustion chamber and atomize into very fine droplets. These droplets vaporize due to heat transfer from the compressed air and also from an air-fuel mixture. Continued heat transfer from hot air to the fuel yields the temperature to reach a value higher than its self- ignition temperature and makes the fuel to ignite spontaneously. By atomizing the fuel into very fine droplets, it increases the surface area of the fuel droplets resulting in better mixing and subsequent combustion. Atomization is done by forcing the fuel through a small orifice under high pressure. For low fuel injection pressure, fuel particle diameters and ignition delay period during the combustion will increase, results in increased pressure and the decrease in engine performance.

Increase in the injection pressure leads to reduce the fuel particle diameter, the mixing of fuel and air becomes better during ignition period. The fuel injection pressure in a standard diesel engine is in the range of 200 to 1700 atm depending on the engine size and type of combustion system employed [10]. The fuel penetration distance become longer and the mixture formation of the fuel and air was improved when the combustion duration became shorter as the injection pressure became higher. The effects of high injection pressure benefits are;

- Improved fuel atomization producing finer fuel droplets.
- The smaller fuel droplets evaporate at a faster rate resulting in rapid fuel-air mixing.
- Shorter injection duration.
- With shorter injection duration injection timing may be retarded.

- Fuel may be injected closer to TDC in hotter air giving shorter ignition delay, resulting in emission control.
- Higher spray penetration and better air utilization.

The high injection pressure effect on PM-NOx trade off is shown on Figure1. The width of band on the shown Figure1 relates to the contribution of the particulate emissions. As the injection pressure increases the PM-NOx trade-off curve moves closer to origin indicating reduction both in the PM and NOx.

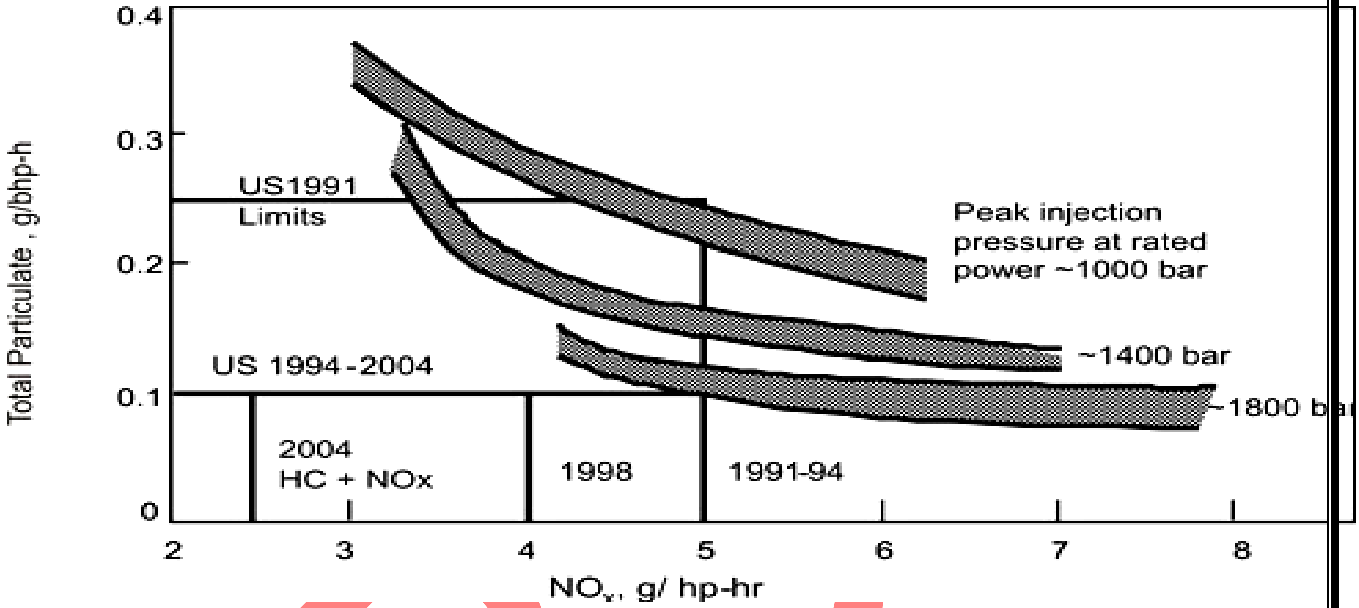

Figure 1. Effect of high injection pressure on PM-NOx trad-off for a DI diesel engine.

B. *Diesel Timing importance*

According to literature review rightist timing results in lowering emissions of nitrogen oxides (NOx) [2,3]. Lower timing is best for NOx levels, increase in carbon monoxide; hydrocarbon levels and brake specific fuel consumption. In addition to this lowered timing decreases cylinder pressure and reduces peak flame temperature (since the fuel is injected once the piston has past TDC and is already on its way back down the cylinder in the power stroke).

Literatures also suggest that advancing the timing results in increased cylinder pressures and higher peak flame temperatures which leads to a more complete burn of the fuel injected and the effect on emissions is significant [1, 4 - 7]. In the mean while, the NOx level increases drastically past just a few degrees of advance, while hydrocarbons increase and carbon monoxide decreases. Brake specific fuel consumption drops off quickly as well.

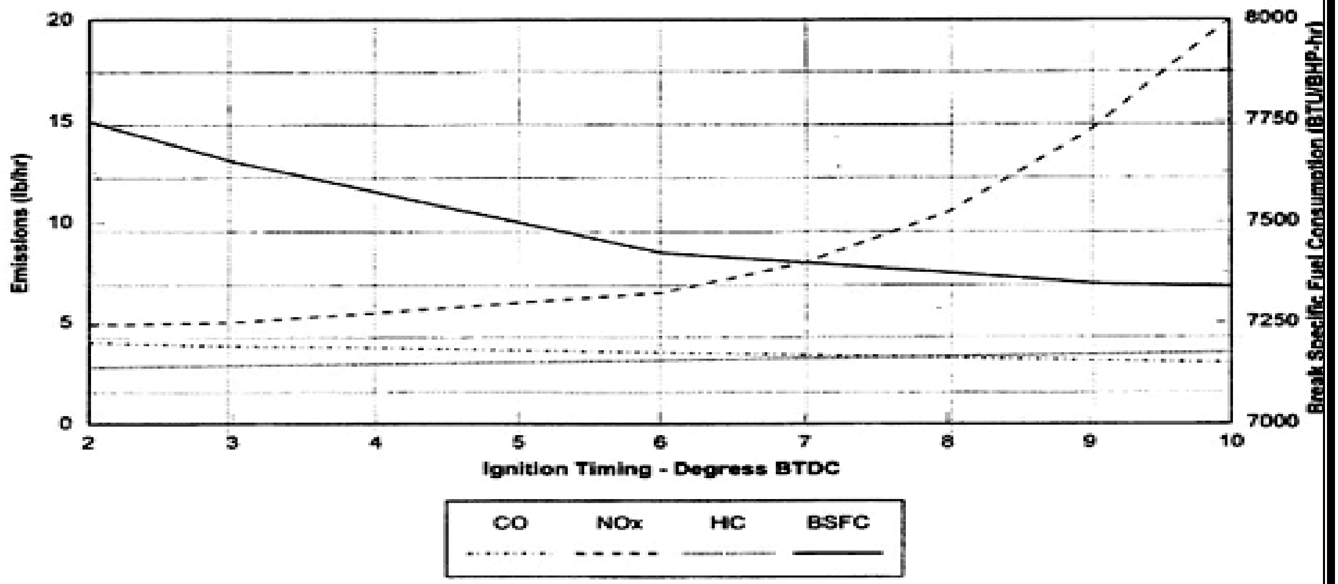

Figure 2. Effect of injection timing on emissions.

It is clear from Figure 2, that results were favoring the proper ignition timing should be managed to obtain the fuel economy with minimum emissions.

EXPERIMENTAL SET UP AND TEST PROCEDURE

Experiments were carried on a Kirloskar make TV1 model single cylinder, four stroke, water cooled 7 hp (5.2 kW) capacity diesel engine coupled to an eddy current dynamometer for loading purpose. The engine is provided with temperature sensors for the measurement of jacket water, calorimeter water, and calorimeter exhaust gas inlet and outlet temperature and also provided with pressure sensors for the measurement of combustion gas pressure and fuel injection pressure. An encoder is fixed and used for crank angle record.

The engine specifications are given below. To measure the air flow rate, an orifice tank is used. The pressure difference between the inside of the cylinder during suction and atmosphere is measured by a manometer fitted to the tank. By noting the difference in water level in the two limbs of manometer the air flow rate can be calculated. The rate of fuel consumption is measured by recording the time taken for consumption of 10 cc of fuel using a graduated burette.The engine is directly coupled to an eddy current dynamometer. The dynamometer has the capacity to absorb the maximum power that can be produced by the engine at all normal speeds. The brake power produced by the engine is measured by the dynamometer. The engine specification is shown in Table-1.

Table I. Engine Specificaton.

Engine Type	*Kirloskar Make (TV1Model)*
Number of cylinders	*1*
Number of strokes	*4*
Rated power	*5.2KW (7 HP) @1500RPM*
Cylinder diameter	*87.5mm*

Stroke length	***110mm***
Compression ratio	***17.5:1***
Cubic Capacity	***661cc***
Dynamometer	***Eddy current type***
Load Measurement	***Strain gauge load cell***
Speed Measurement	***Rotary encoder***
Temperature Indicator	***Digital, PT-100 type temperature sensor***
Fuel Injection Pressure Measurement	***Piezo Sensor, range 5000 Psi***

Table II. Nomenclature.

BTDC: Before top dead center
BTE: Brake thermal efficiency, (%)
BSFC : Brake specific fuel consumption, (g/kWh)
PM : Particulate matter
CO: Carbon monoxide
CO_2 : Carbon dioxide
NOx : Nitrogen oxides

The experiment is carried out on a single cylinder, four stroke diesel engine with pure diesel. The experiment is carried out for the combination of injection pressures (180 bar, 190 bar, 200 bar, 210 bar and 220 bar), and injection timings (15.5°, 20.5°, 23° and 25.5°BTDC) at compression ratio 17.5:1, with a constant speed of 1500 rpm for 0% to 100% load.

Initially the injection timing of the engine was set to 23° BTDC (as set by the manufacturer). For this injection timing, the injection pressure was varied from 180 bar to 220 bar in steps of 10 bar and performance, emissions and combustion characteristics were recorded from 0% to 100% load in steps of 25% with a constant speed of 1500 rpm. The experiment was repeated for different injection timings of 15.5°, 20.5°and 25.5°**B**TDC. Cooling of the engine was carried out by circulating water through the jackets of the engine block and the cylinder head. The injection pressure was varied by changing the spring tension of the injector and the timing was varied by varying the shim thickness at the connection point between the pump and the engine. Reducing the shim thickness by 0.3 mm advances the injection timing by 2.5° crank angle. The results obtained were compared.

Figure 3. View of test rig.

RESULTS AND DISCUSSIONS

The results obtained from the experiments are represented in form of charts and are discussed as follows

A. *Performance Parameters*

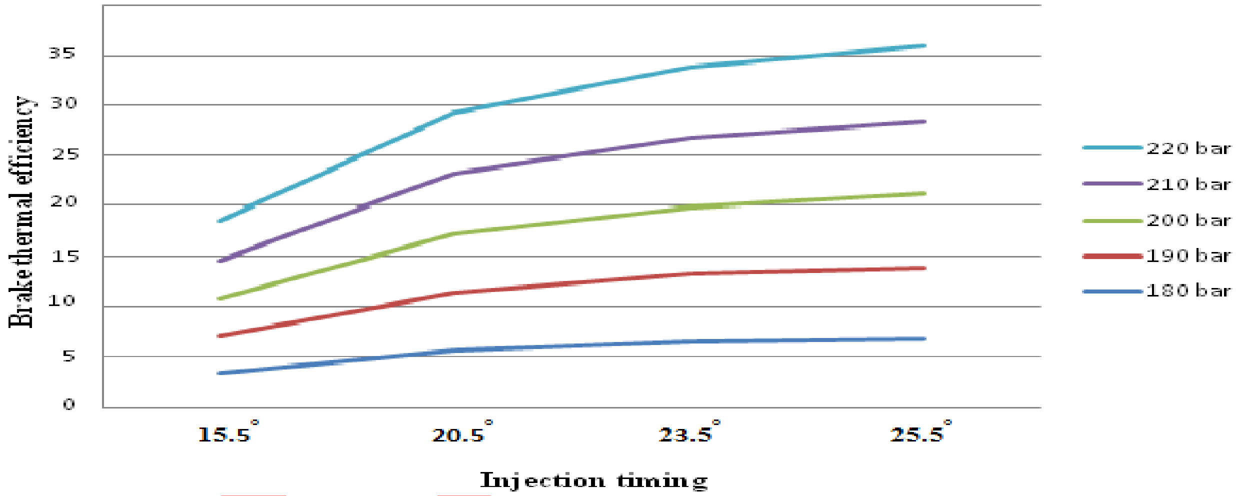

Figure 4. Brake thermal efficiency Vs Injection timing for various injection pressures.

The comparison of brake thermal efficiencies for different injection pressures and timings are shown in Figure 4. For all the injection pressures and timings used the brake thermal efficiency increases with increasing load. Maximum brake thermal efficiency of 36.5% was observed at an injection pressure of 220 bar and an injection timing of 25.5° BTDC at 100% load condition. The increase in brake thermal efficiency is due to proper combustion as a result of better atomization owing to the increase in the injection pressure. When injection pressure is increased, the fuel particle diameters will become small and also proper injection timing leads to improved and better mixing of fuel to air during ignition period, hence engine performance will increase. It is observed from Figure 4 that, for the combination of increasing injection pressure with improved injection timings, the brake thermal efficiency starts increasing. It leads to improvement in engine performance.

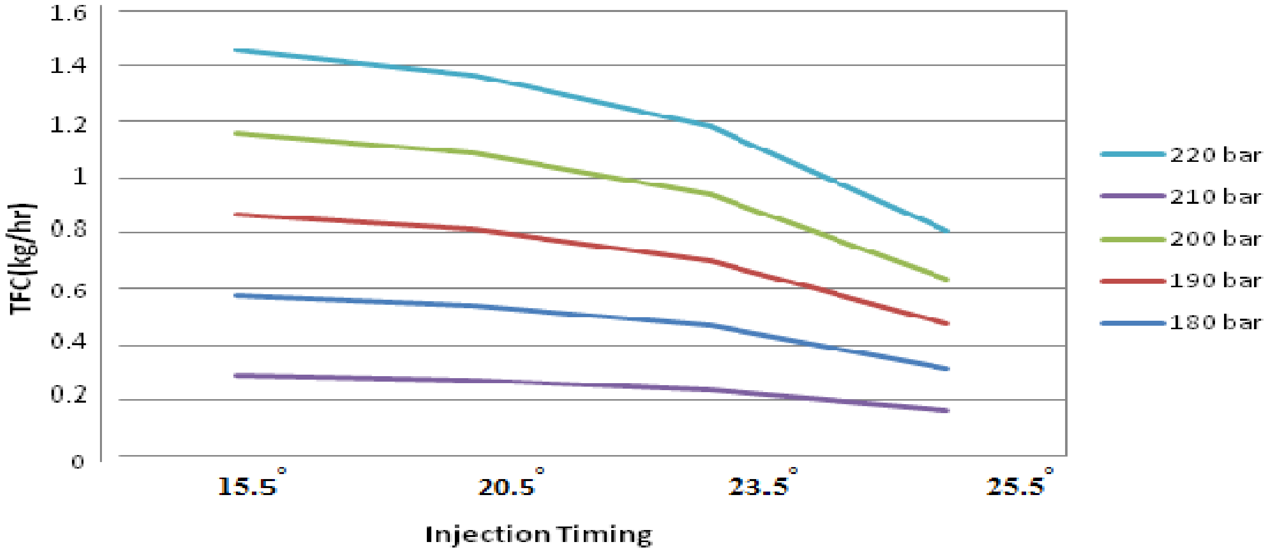

Figure 5. Total fuel consumption Vs Injection timing for various injection pressures.

It is noticed that the brake thermal efficiency was improved with injection pressure along with injection timing. It was found to be the best at injection pressure 220 bar and 25.5° BTDC due to better combustion. The fuel injection pressure and Injection timing affects the Total Fuel Consumption performance of an engine as shown in Figure 5. The variation of Total fuel consumption for diesel at different injection pressures and timings is observed in Figure 5. The Total Fuel Consumption decreases with increasing load, irrespective of injection pressure and increasing timing. The lowest Total Fuel Consumption of 0.18 kg/hr was noted for an injection pressure of 180 bar and injection timing of 25.5° BTDC at 100% load condition. The reduction in Total Fuel Consumption was due to the increase in injection pressure which leads to proper mixing of fuel and air. Impact of fuel injection pressure shows that the highest Total Fuel Consumption took place at 220 bar at injection timing 15.5° BTDC, and injection pressure and the least Total Fuel Consumption at 180 bar at injection timing 25.5° BTDC.

C. *Emission parameters*

Figure 6, shows the variation of NOx emissions with different injection pressures and injection timings for full load conditions. NOx emissions were lower for 180 bar injection pressure at injection timing 15.5º BTDC in comparison with all injection pressures and injection timings. It is also noted that, as the injection pressure increases with proper timing, NOx increases for all loads till 200 bar, since the formation of NOx is very sensitive to temperature, which is responsible for thermal NOx formation.

NOx concentration increases monotonically with increase in engine load except for the lowest load. In case of engines, with less injection pressure, more fuel is injected at high engine loads, leading to improper atomization and penetration, which results in higher temperature of the burning gas. NOx concentration is drastically increased after 200 bar and recorded to be highest at 220 bar at injection timing 23.5º BTDC due higher injection pressure leading to higher combustion temperature. When pressure is more and injection time is retarded NOx is found to be low. This may be due to retarded injection timing might reduced and compensated the high combustion temperature, which would be obtained due to high pressurized fuel injection into the engine cylinder. Result obtained may be smaller fuel particles, better penetration and atomization hence best combustion would have been obtained and reduced the NOx formation.

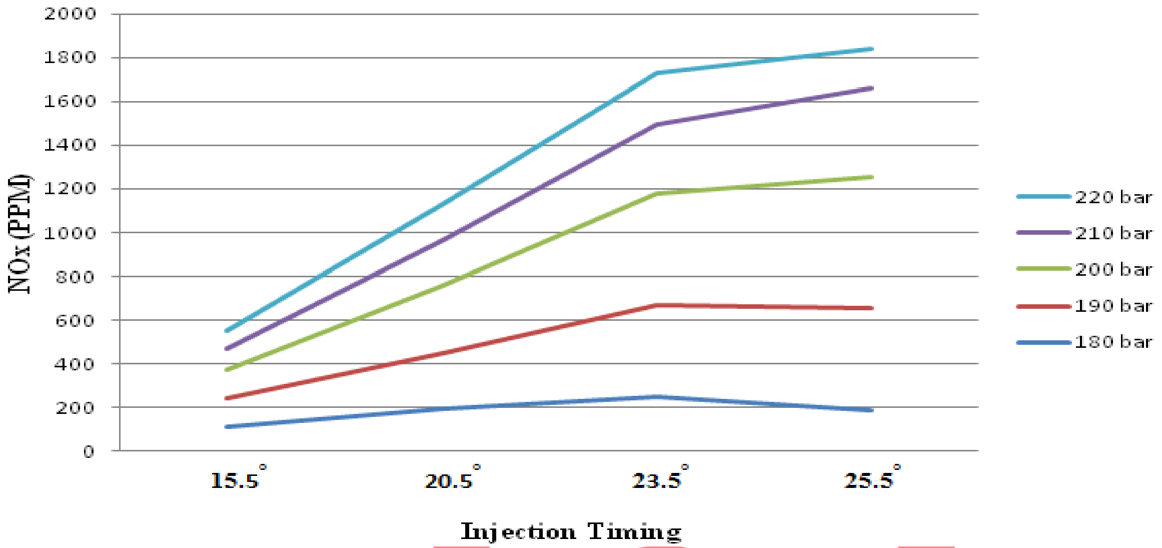

Figure 6. NOx Vs Injection timing for various injection pressures.

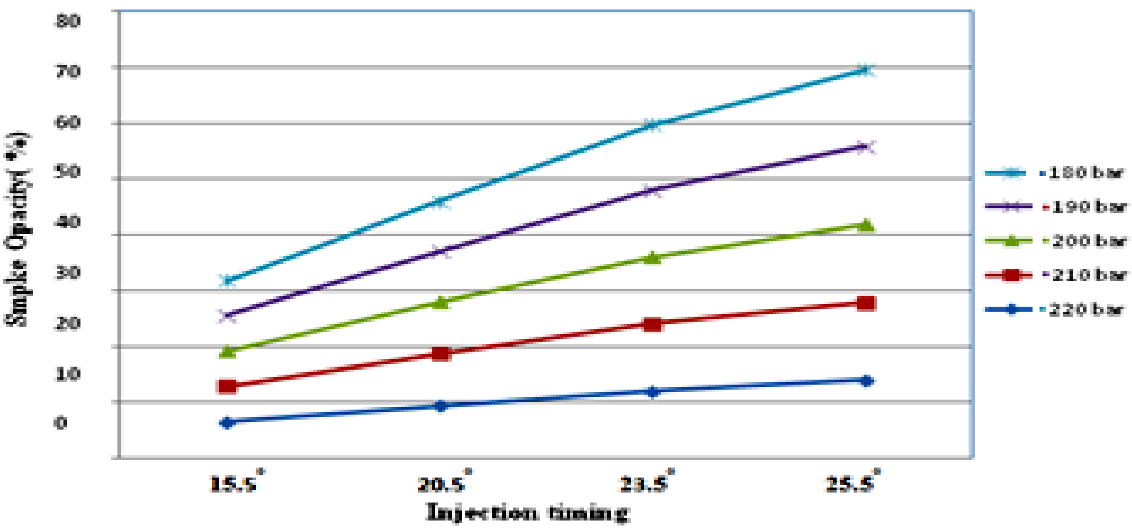

Figure 7. Smoke Opacity Vs Injection timing for various injection pressures.

From Figure 7 it is observed that, smoke opacity gets reduced with increase in injection pressure and retarded injection timing for all loads. In general, retarding injection timing reduces NOx emissions from the diesel engine because it decreases the combustion temperature as well as the residence time of the high-temperature-burned gas inside the cylinder. On the other hand, advanced injection timing, an earlier crank angle achieves high pressure and, hence, higher combustion temperature results in high NOx emissions. It is also clear that, at the lower injection pressure results in higher smoke emissions than high injection pressure. At lower injection pressure, the atomization process will be poor. This resulted in bigger droplets and hence bigger kernel. Therefore, at lower injection pressure, higher smoke emissions were formed due to bigger droplet. However, at a higher injection pressure of 220 bar, it was observed that lower smoke emissions were formed due to small size fuel droplets, better air-fuel mixing and complete combustion. Injection pressure 220 bar provided 57% reduction of smoke opacity when compared with the standard engine fueled with 180 bars. This is probably because of the smaller drop size of the injected fuel and proper timing results in better atomization of fuel and sprays propagation leading to improved and complete combustion.

CONCLUSIONS

It is clear from the experimental investigations results that, for a diesel fueled engine, an increase in the injection pressure with proper injection timing will significantly increases the engine performance with drastic reduction in emission. Higher injection pressures and appropriate injection timing also shows a cut down in specific fuel consumption with the smooth engine operation. It is strongly recommended to study the impact of ultra high injection pressure with proper injection timing for improvening the performance and emissions of a diesel engine fueled with biodiesel blends, with a hope to obtain better results for higher percentage blends, so as to help the socity by reducing the harmful emissions and depleting diesel problem.

Finally, it is concluded that the information obtained from this investigation is useful in the analysis of injection pressure impact in increasing the performance of diesel engines along with their emission control to meet current and future government regulations.

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