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Analysis of effect of injection pressure on emissions of DI diesel Engine by using STAR-CD

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Abstract - *Internal combustion engines, now a day are the best available reliable source of power for all domestic, large scale industrial and transportation applications. The major issues with these engines arise at the efficiency. The major pollutants are Oxides of Nitrogen (NOx), Carbon Monoxide (CO), Soot particles. These are formed due to incomplete combustion of the fuel in combustion chamber of diesel engine. One of the important factors which influence the performance and emission of diesel engine is fuel injection pressure. Emissions can be controlled by different techniques like EGR, changing the injection pressure of fuel into the combustion chamber etc., It is a well-known fact that as the injection pressure of fuel increases, the mass flow rate of fuel will vary for proper mixing of fuel and air in the combustion chamber. In the present work, it is proposed to investigate the effect of variations in injection pressure on emissions and for this, STAR-CD will be used as a tool.*

***Key Words*: Diesel Engine, STAR CD, Analysis, Injection Pressure, Caterpillar3401**

1.INTRODUCTION

Research are being carried out in the field of IC engines for increasing the efficiency. Major issues arise while increasing efficiency of an internal combustion engine are emissions. The major pollutants are oxides of nitrogen(NOx), CO and soot. Injection pressure is one of the important factor which influence the performance and emission of diesel engine. A study on Caterpillar 3401 engine parameters were performed by varying its injection pressure. STAR-CD is used as the software tool for this analysis.

It is always economical to find an optimum injection pressure which will increase the combustion efficiency and reduce NOx , CO and soot emission accordingly rather than creating a new engine model. Analyzing the variation of combustion efficiency, NOx, CO and soot emissions for various injection pressures will help to find the optimum injection pressure.

2. COMPUTATIONAL PROCEDURE

Modeling of piston bowl geometry was done using Solid-Works. Surface mesh generation done by Prosurf. Then a 60-degree sector mesh was generated in es-ICE (Expert Systems in IC Engine). After this, the sector grid is used as a part of STAR-CONTROL for applying initial conditions, boundary conditions like beginning temperature, initial pressure and cylinder crown temperature and so on.

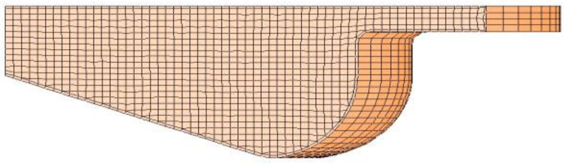

Fig -1: Computational grids at TDC

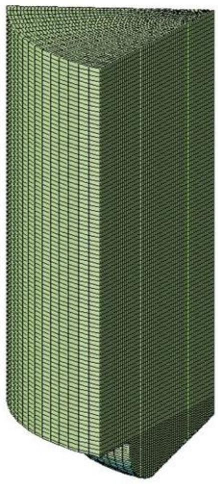

Fig -2: Computational grids at 100degree before TDC

This sector grid is further utilized as a part of PRO-STAR for applying the fuel properties and injection parameters like injection temperature, nozzle hole diameter etc.

Simulation was started in solver after completion of PRO-STAR. After the results were obtained in es-ICE, injection droplets in cylinder bowl of direct injection diesel engine at different injection pressures (600, 800, 1000, 1200 bar) and 9 degrees before TDC were done.

3. ENGINE PARAMETERS & DETAILS

Table -1: Engine Specifications

CATERPILLAR 3401	
Bore	13.719 cm
Stroke	16.51 cm
Compression Ratio	16.1 : 1
Displacement	2.44 L
Connecting rod length	26.162 cm
Squish Clearance	4.14 mm
Inlet Valve Opening	-32° A TDC
Inlet Valve Closing	-147° A TDC
Exhaust Valve Opening	134° ATDC
Exhaust Valve Closing	29 °A TDC
IMAP	184°K Pa
IMAT	310 k
Piston Shape	Mexican Hat Style

4.EQUATIONS

Mass Flow Rate of Fuel

$$\dot{m} = Cd*A_n*\sqrt{(2*\rho_f \Delta p)}*((\Delta\theta)/360N)$$

Cd = Coefficient of discharge of injector = 0.7
A_n = Area of one injector hole= $(\pi*.00026^2/4)$ $=0.5309*10^{-7}$ Kg/s
ρ_f =Density of fuel = 749.5 kg/m^3
Δp =Pressure difference =Injection pressure - In cylinder pressure =1000 – 15 = 985 bar
Δθ = Injection duration = 20^0
N = Engine RPM = 1600

$$\dot{m} = 0.7*0.5309*10^{-7}*\sqrt{(2*749.5*985*10^5)}*[20/(360*1600)]$$
$$= \mathbf{4.95*10^{-7}\ kg/s}$$

5. RESULTS AND DISCUSSIONS

5.1 VALIDATION

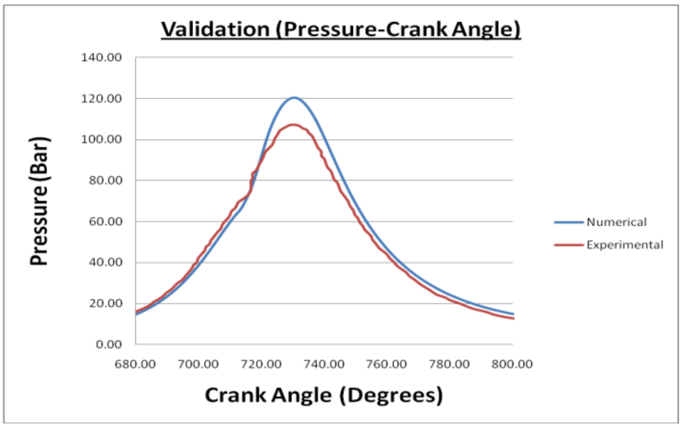

Fig.3. Validation between numerical and experimental graphs

A comparison between experiments and simulation is presented, in order to assess the accuracy of the subsequent predictions. As visible, Fig. 3.10 computational in-cylinder pressure agrees fairly well with the experimental trace. The computed and experimental in-cylinder pressures 90 bar and 100 bar respectively. The peak pressure discrepancies between experimental and computation are 8.5%. The trend predicted by the model is reasonably close to experimental results, although there are still some differences.

5.2 PRESSURE

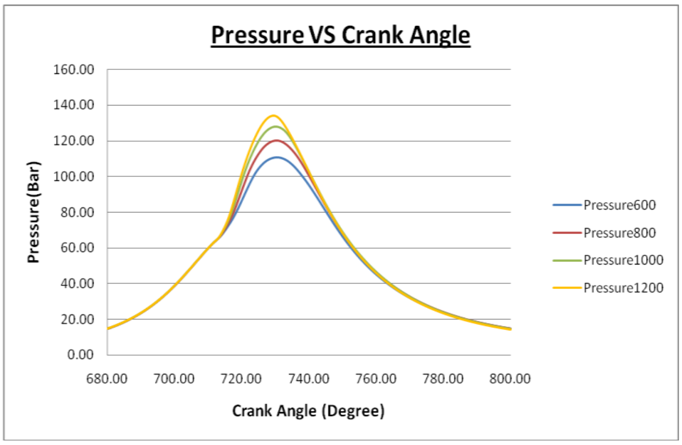

Fig.4.cylinder pressure with respect to crank angle at different injection pressure

As the injection pressure is increased from 600 bar to 1200 bar, peak in-cylinder pressure increases from 110 bar to 135 bar. This is due to the fact that higher injection pressure reduces the size of the fuel droplets interacting with hot in-cylinder air. So, it results in better mixture formation and efficient combustion of the charge.

5.2 TEMPERATURE

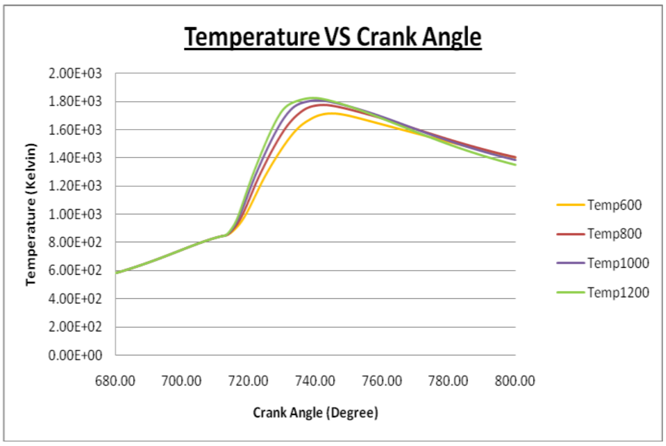

Fig.5.cylinder temperatures with respect to crank angle at different injection pressure

Fig.5. shows In-cylinder temperature variations versus crank angle at different injection pressures. As the fuel injection

pressure increases from 600 bar to 1200 bar temperature is also increasing from 1700K to 1810K. This is because of the better combustion at higher fuel injection pressure.

5.3 NOx EMISSION

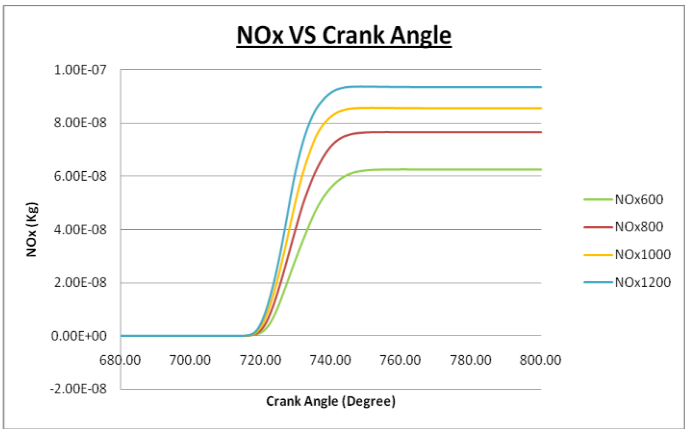

Fig.6.NOx emissions with respect to crank angle at different injection pressure

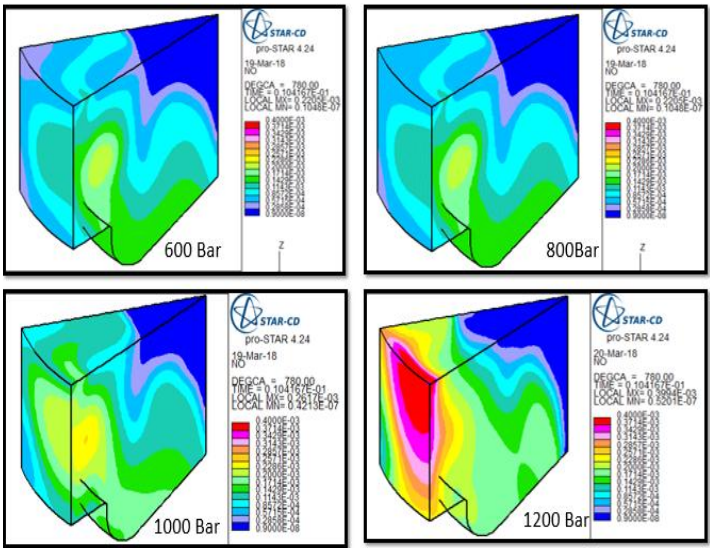

Fig.7. NOx contour at 780 degree crank angle at different injection pressures

The figure shows NOx emissions variations versus crank angle at different injection pressures. Figure shows NOx contour at injection pressures 600, 800, 1000, 1200 Bar respectively. NOx is created mostly from nitrogen in air. At low temperatures atmospheric nitrogen exists stable diatomic molecule. Therefore, only very small trace amounts of oxides of nitrogen are found. However, at very high temperatures those occur in the combustion chamber of an engine, some diatomic nitrogen N2 breaks down to monoatomic nitrogen (N) which is reactive. As injection pressure increases in-cylinder temperature and pressure increases. So the NOx emission also increases.
The decreasing temperature due to expansion and due to mixing of high temperature gas with air or cooler burned gas freezes the NO chemistry. So as the temperature decreases much less decomposition of NOx occurs.

5.4 SOOT EMISSION

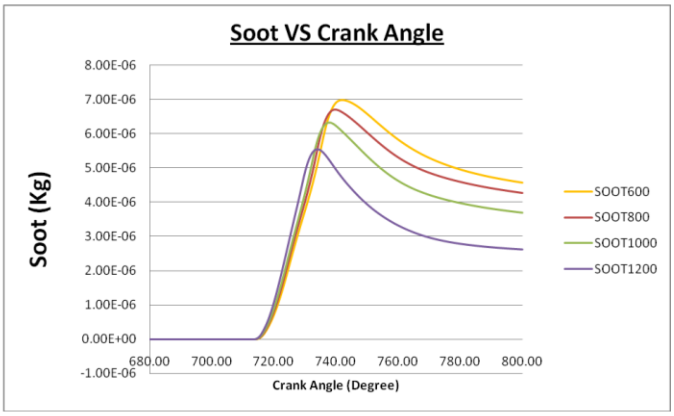

Fig.8. soot emissions at different injection pressures

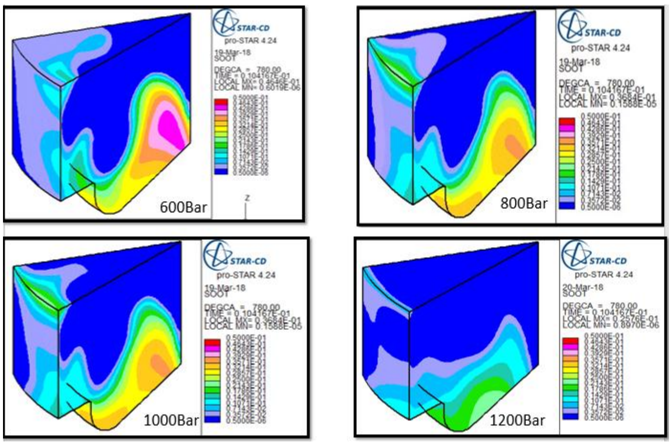

Fig.9. soot emission contour at 780 degrees for different injection pressures

Soot is originated from the agglomeration of very small particles of partly burned fuel, partly burned lube oil, ash content of fuel oil and cylinder lube oil and water. As injection pressure increases size of fuel particle decreases due to better atomization and better combustion occurs hence the soot emission decreases.

From the graph it is clear that almost 60% of the soot formed is oxidized through the combustion process prior to exhaust. The contour shows soot is concentrated at the top of the piston bowl geometry, because fuel concentration is high at this region.

5.5 CARBON MONOXIDE EMISSION

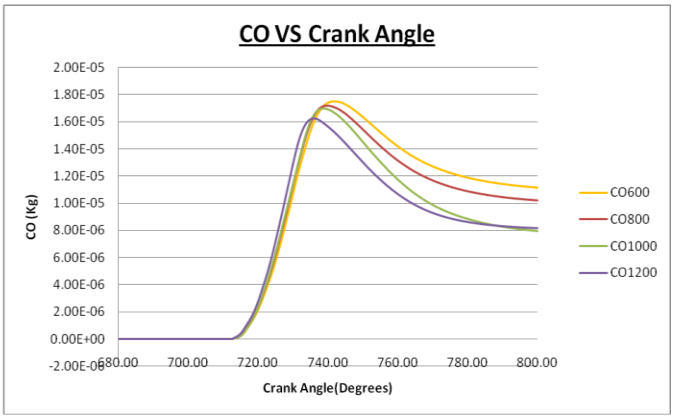

Fig.10. CO emissions at different injection pressures

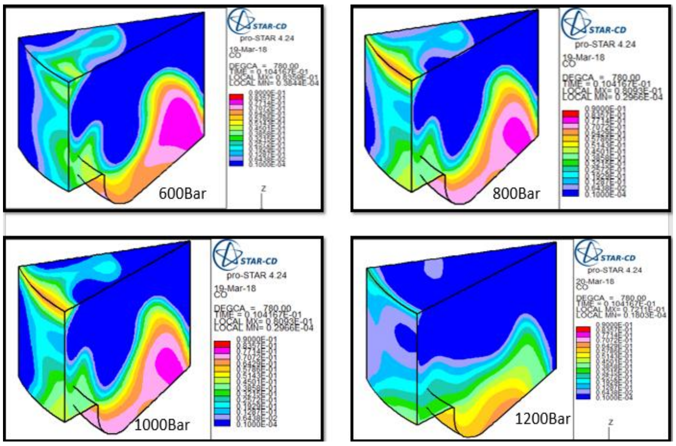

Fig.11. CO contour at 780 degrees for different injection pressures

Carbon monoxide results from the incomplete combustion where the oxidation process does not occur completely. As High injection pressure generates better atomization the surface area of fuel particles increases, and hence better oxidation of carbon occurs. This results in reduction of CO emissions. As the burned gases cool during the expansion and exhaust strokes depending on the temperature and cooling rate, the CO oxidation process may not remain locally equilibrated. This is illustrated in the above graph.

6. CONCLUSIONS

- Analysis at compression ratio 16:1 for different injection pressure was completed using STAR-CD and results were obtained.
- Higher fuel injection pressure is better for smaller droplet size and leads to better combustion.
- As the injection pressure increases, NOx emission is increasing whereas soot & CO emissions are decreasing.
- Best injection pressure was found to be 1000 bar

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