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Research Article

EFFECT OF INJECTION ORIENTATION ON EXHAUST EMISSIONS IN A DI DIESEL ENGINE: THROUGH CFD SIMULATION

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ABSTRACT
In direct injection (DI) diesel engines theAnalysis of fuel spray with various injection orientations has high influence on engine performance as well as exhaust gas emissions. The fuel injector orientation plays very important role in fuel air mixing. A single cylinder four stroke DI diesel engine with fuel injector having multi-hole nozzle injector is considered for the analysis and a computational fluid dynamics (CFD) code, STAR-CD is used for the simulation. In the present study, various injector orientations are considered for the analysis. In-cylinder fuel spray is discussed through the 3D fuel spray distribution plots 95^0, 100^0 and 110^0 orientation are considered for the analysis. It is concluded that there is an optimal CO, Soot are formed in case of 100^0 orientation. The highest NO is formed in the case of 100^0 orientation. Because of improved combustion process temperatures are attained higher in turn NO formation is higher.

***Key Words**: Diesel engine, spray, CO, Soot, NO, STAR-CD*

INTRODUCTION
Exhaust emission like HC, CO, NOx, soot are the most important, concern with the diesel engines. In DI diesel engines the fuel is injected just before the end of compression stroke, as a result fuel distribution is non-uniform, this causes the combustion mixture is non-stoichiometric. Hence, the combustion process in the DI diesel engine is heterogeneous in nature. It causes the increase the emissions dissociate the nitrogen; impurities in the fuel and air are the other region.
Liquid fuel is injected through the nozzle by the fuel injection system into the cylinder through the end of compression stroke. The liquid jet leaving the nozzle becomes turbulent and spreads out as it entrains and mixes with the in-cylinder air. The outer surface of the fuel jet breaks up into droplets [R.D 1979]**.** The initial mass of fuel evaporates first thereby generating a fuel vapour-air mixture sheet around the liquid containing core. Larger droplets provide a higher penetration but smaller droplets are requisite for quicker mixing and evaporation of the fuel. The sprayed fuel stream encounters the resistance from the dense in-cylinder fluids and breaks into a spray. This distance is called the Breakup Distance. Further they vaporize and mix with compressed high temperature and high pressure in-cylinder fluids. At this stage the in-cylinder fluids have above the self-ignition temperature of the fuel. It causes the fuel to ignite spontaneously and initiate the combustion at various locations, where desired condition is prevailed (J.D 1988).
The spray impinging on the wall of the cylinder becomes an unavoidable. Because of compact high speed DI diesel engines. In fact due to the short distance between injector nozzle and the cylinder walls and also high injector pressures, fuel spray may impinge on the cylinder walls before vaporization takes place. Accordingly spray wall interaction becomes an important phenomenon in high speed DI diesel engines [T. Bo 1997]. The spray impingement has a great influence on the distribution of fuel jet, evaporation and

subsequent combustion processes. Accordingly injector orientation angle is highly influencing on the spray impingement and subsequent phenomena [G.M.1999].
In this section the three dimensional plots of spray distribution in a DI diesel engine cylinder for three injector orientation angles at selected Crank angles are presented[A.D 1999]. The fuel injection parameters are listed in table -2 are considered for the analysis. It is assumed to begin the fuel injection at 10˚ before TDC and end at 3˚ after TDC in the duration of fuel injection is 7˚ CA and the mass flow rate of fuel is considered as 0.0177 kg/sec [Paul 2000]. A fuel injector with eight nozzles spaced uniformly is considered for the analysis. Due to symmetry in construction of fuel injector nozzle a 45˚ sector is considered for the analysis [A.S 2005].

MATERIALS AND METHODS

Engine Geometry and Specifications: In the present work, 45^0sector is taken for the analysis due to the symmetry of eight-hole injector in the model. The computational mesh when the piston is at Top Dead Center (TDC) is shown in fig: 1. the computational domain comprises of the combustion chamber with piston crown. The number of cells in the computational domain at TDC is 10608. Piston bowl dimensions are given in fig: 2. Engine details are given in table 1 and fuel and injection details are given in table 2.

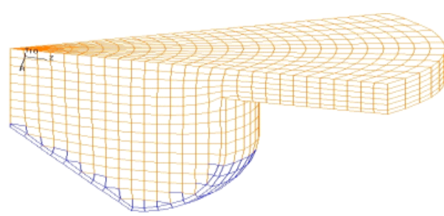

Figure 1: Computational Sector mesh used in the engine simulation at TDC

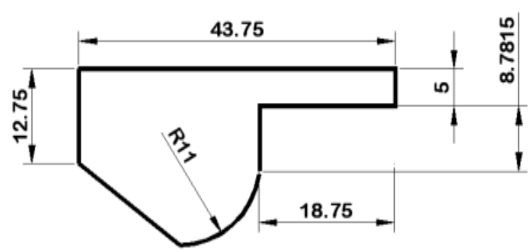

Figure 2: Geometric dimensions of Piston Bowl

Initial and Boundary Conditions: It is important to study the in-cylinder fluid dynamics during the later part of combustion and initial part of expansion strokes in DI diesel engines. Analysis is carried out from 40^0 before TDC to 80^0 after TDC, as fuel injection combustion and pollutant formations are taken place during this period.
The initial swirl is taken as 2m/s and the constant absolute pressure and temperatures as 9.87 bar, 583 K respectively. The turbulent model has the Intensity length scale as 0.1 and 0.001 respectively and it shows no traces of fuel and exhaust gases. The initial surface temperatures of combustion dome region and piston crown regions are taken as 450 K and the cylinder wall region has temperature of 400 K.

Table 1: Engine Specifications

Bore	87.5 mm
Stroke	110 mm
Connecting rod length	232 mm
Engine speed	1500 rpm
Fuel	Dodecane
Injection duration	7^0
Start of injection	10^0bTDC
End of injection	3^0bTDC
Spray orientation angle	95^0, 100^0, 110^0
Total fuel injection per cycle	13.76 mg
Nozzle hole Diameter	0.4 mm
Number of injector holes	8
Fuel	Dodecane
Injection duration	7^0
Start of injection	10^0bTDC
End of injection	3^0bTDC
Spray orientation angle	95^0, 100^0, 110^0
Total fuel injection per cycle	13.76 mg
Nozzle hole Diameter	0.4 mm
Number of injector holes	8

RESULTS AND DISCUSSION

Effect of Injection Orientation on Exhaust Emissions

The effect of injection orientation on exhaust gas emissions has been analysed with the help of graphs plotted from the data predicted from the CFD simulation of combustion process. Exhaust emissions like HC, CO, NO_x, soot are the most important concern with the diesel engines. In DI diesel engines the fuel is injected just before the end of compression stroke, as a result fuel distribution is non-uniform, this causes the combustion mixture a non-stoichiometric. Hence, the combustion process in the DI diesel engine is heterogeneous in nature. It causes the increase of emissions.

Analysis on CO Formation

Figure 3: gives the comparison of CO vs. crank angle with four injection orientations. A bump at the beginning of CO formation at around 4^0 after TDC is noticed due to the start of ignition, later on sharp increase in CO formation is noticed. This is due to heterogeneous combustion, where there is insufficient oxygen present to burn fully for all the carbon atoms present in the fuel at fuel rich zones, resulting in the CO formation.

In case of 95^0 injection orientation angle it is observed that a peak CO formation at 18^0 after TDC is 0.018 mg, in case of 100^0 injection orientation angle 0.025 mg, at 5^0 after TDC and 0.015 mg, at 6^0 after TDC in case of 105^0 and 110^0 orientations are noticed. In case of 95^0 injection orientation angle there is very high CO at 18^0 after TDC. After 18^0 after TDC there is a rapid drop in the CO formation.

In case of 100^0 injection orientation angle it is observed that low CO formation was noticed at the tail i.e. 0.009 mg.

In case of 105^0 and 110^0 injection orientation angle 0.113 mg at 6^0 after TDC is noticed. There is a sharp decrease in CO formation is observed and at the end of 80^0 after TDC it about is 0.0135 mg. This decrease of formed CO is due to the oxidation of the existing CO by gradually mixing with the oxygen available at the other regions to form CO_2 at the later stages of expansion stroke.

Analysis on Soot formation

When a rich and lean gas pockets of CO exists in numerous. Soot particles may be formed on the rich side of the hot interface, there by forming un-oxidized soot in the exhaust.

Figure 4: gives the comparison of soot formation at different crank angles for three different injection orientations. It is noticed that the formation of soot begins from the start of combustion. In case of 95^0 injection orientation angle, it is increasing drastically towards the end of expansion stroke, at 80^0 after TDC it amounts to 0.316 mg. In case of 100^0 injection orientation angle the soot is about 0.103 mg and in case of 110^0 injection orientation angle the soot is about 0.176 mg. In case of 105^0 and 110^0 orientation there is decrease of soot formation 13^0 after TDC, this is due to gradually mixing of oxygen available at the other regions till the favorable temperatures are available. However once soot formation is over, its decomposing is not as easy as that of CO decomposition, because the soot particles are cluster of numerous minute carbon particles.

Analysis of NOx Formation

In IC engines combustion of mixture of air and fuel produces combustion reaction temperatures, high enough to drive endothermic reaction between atmospheric nitrogen and oxygen in the flames, yielding various oxides of nitrogen. Most of this will be NO, with a small amount of NO_2 and other emissions, whereas the higher the burned gas temperature the higher in the rate of NO formations. The burnt gases get cooled during expansion stroke thereby freezing the NO formation.

Figure 5: represent the Mass of NO vs. crank angle for the four injection orientations. NO formations are taking place between 3^0 after TDC to 23^0 after TDC.

In case of 95^0 injection orientation angle at 16^0, after TDC there is a peak NO amounts to 0.18 mg, in case of 100^0 orientation at 18^0, after TDC the amount of NO is 0.2 mg and in case of 105^0 and 110^0 injection orientation angles at 14^0, after TDC .0.15 and 0.14 mg is noticed.

After reaching the peak level of NO formation a little drop in NO formation is noticed for all the four different injection orientation angles. This is due to decomposition of formed NO into another formation, where favorable temperature conditions are prevailed.

At 80^0 after TDC, 0.16 mg of NO is noticed in case of 95^0 injection orientation angle, 0.18 mg of NO formation is noticed in case of 100^0 injection orientation angle and 0.14 mg of NO in case of 105^0 and 110^0 injection orientation angles.

The highest NO formation in case of 100^0 orientations can be attributed to the effective fuel-air mixing and more uniform distribution of fuel.

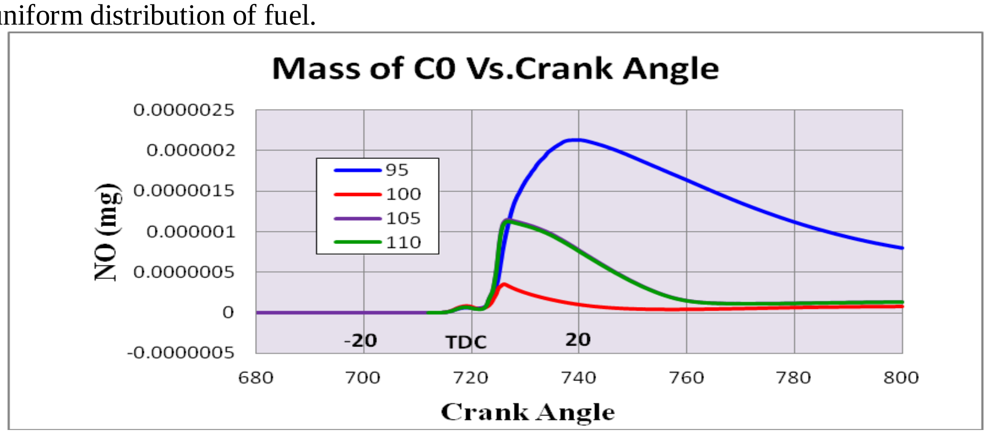

Figure 3: Comparison of Mass of CO vs. Crank Angle Profiles for the four Spray Orientations

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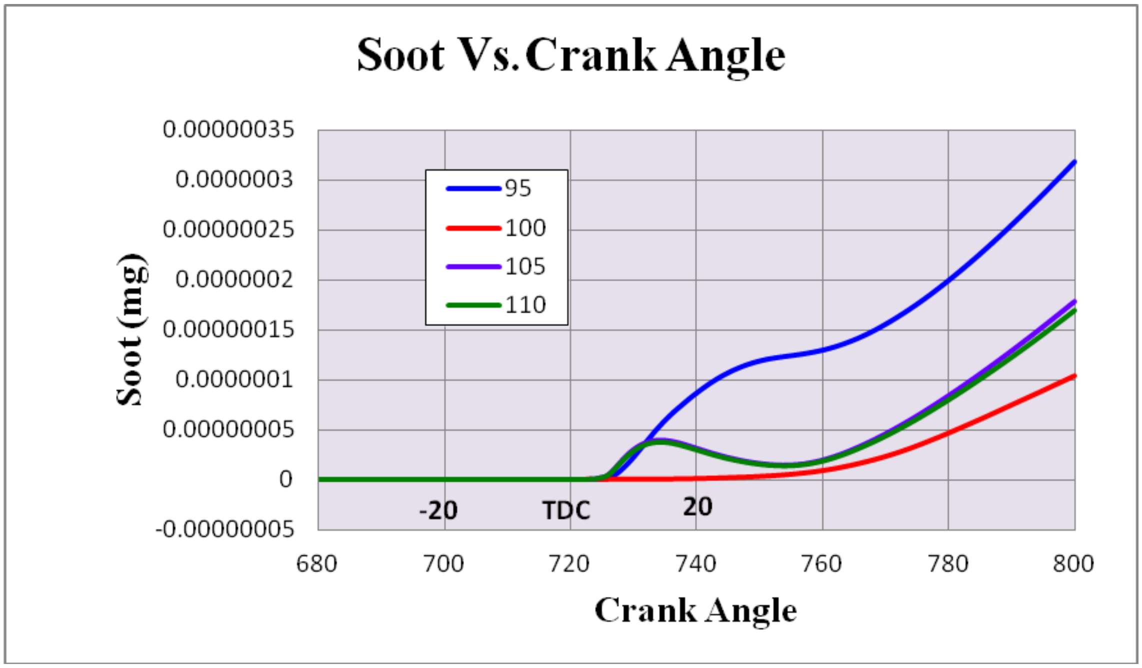

Figure 4: Comparison of Soot vs. Crank Angle Profiles for the four Spray Orientations

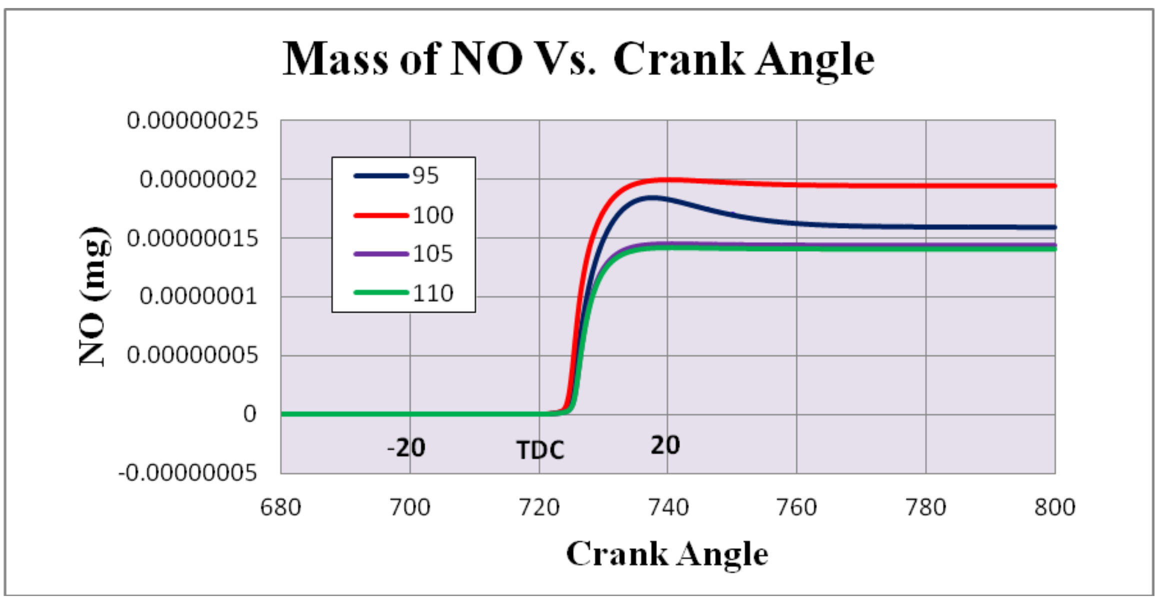

Figure 5: Comparison of Mass of NO vs. Crank Angle Crank Angle Profiles for the four Spray Orientations

Conclusions

It is observed that in case 100^0 orientation CO formation is found lesser than that of 95^0 and 105^0 110^0orientation. It is also observed that in case of 100^0 orientation the Soot formation is lesser than that of 95^0 105^0 and 110^0orientation.Finally it is observed that in case of 100^0 orientation the highest NO formation is noticed than that of 95^0 105^0 and 110^0. Because of improved combustion process, temperatures are attained higher in turn NO formation is higher.

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