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Comparison of Velocity Vector Components in a Di Diesel Engine: Analysis through Cfd Simulation

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Abstract: *In direct injection (DI) diesel engines the effect of injection orientation on velocity vector components has high influence on engine performance as well as exhaust gas emissions. The fuel injection 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. Effect of injection orientation angle on in-cylinder fluid flow characteristics were analysed through velocity vector plots in DI diesel engine through CFD simulation. Two bowls are considered for this analysis i.e Mexican Hat Bowl (MHB) and Toroidal Bowl(TB). The Present analysis injection orientation angle is considered for simulation, is 100^0. In case of Toroidal Bowl (TB) at 100^0 injection orientation angle the fluid flows towards squish region. In case of Mexican Hat Bowl injection orientation at 100^0 spray is spreading uniform into the high turbulent zone compared with Toroidal Bowl. Hence at Mexican Hat Bowl injection orientation angle is reasonably good for the fuel spray.*
Key Words: *Diesel Engine, Direct Injection Spray, Velocity Vectors, Mexican Hat Bowl, Toroidal Bowl, CFD*

I. Introduction

To illustrate the potential for multidimensional modeling of internal combustion engine fluid flow and flow field, the results of which are presented in terms of velocity vector components [1].
Plots –Velocity vector components are indicated by the arrows for their direction and its size is indicated by the magnitude of the components [2]

The flow in X-direction is called U-velocity components, in Y-direction is called V-velocity component and Z-direction in called W-velocity component. Large amounts of information on the fluid flow through velocity vectors are generated. It is difficult to present entire information, hence at selected crank angles which are felt necessary are only discussed in their respective section [3, 4].
It is logical to present the details in 2-D planes for better understanding, through the 3-D flow field. Velocity vectors are generated using CFD Code [5, 6].

It is observed that the variation of flow in Y-direction (V-velocity vector components) swirls around the axis of the bowl at minimal. Where X and Z direction flow field variation is observed to be more. Hence, X-Z plane velocity vector components give more information than the other planes. In the X-Z plane at the middle of the fuel spray gives more information than that of the other planes about the fuel spray spreading and other local information. Hence it is selected as X-Z plane at middle of the injector which is selected for the present analysis [7, 8].

In this section the fluid flow field during part of compression and expansion strokes for injection orientation of 100^0 is discussed and analyzed on the basis of the fluid flow calculation plots in X-Z plan [9 10].

II. Methodology

Engine Geometry and Specifications

In the present work, 45^0 sector 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 figurre.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 figure.2. Engine details are given in table.1 and fuel and injection details are given in table.2.

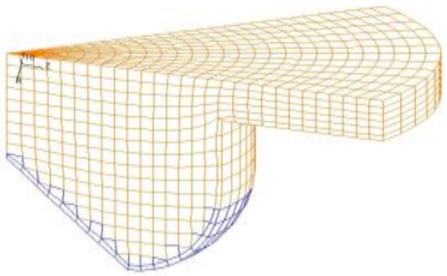


Fig:1 Computational Sector mesh used in the engine simulation at TDC

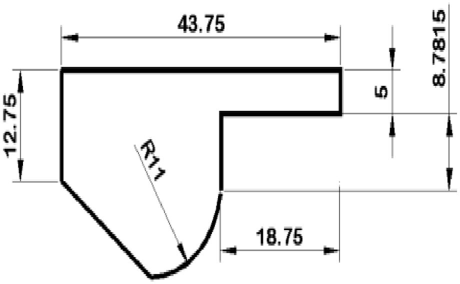


Fig: 2. Geometric dimensions of Piston Bowl

Table 1: Engine Specifications

Bore	87.5 mm
Stroke	110 mm
Connecting rod length	232 mm
Engine speed	1500 rpm

Table.2 Injection Parameter

Fuel	Dodecane
Injection duration	7^0
Start of injection	10^0bTDC
End of injection	3^0bTDC
Spray orientation angle	100^0
Total fuel injection per cycle	13.76 mg
Nozzle hole Diameter	0.4 mm
Number of injector holes	8

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 (bTDC) to 80^0 after TDC (aTDC), 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.

Comparison Of Velocity Vecto Flow Fields At 10^0 Before Tdc

The following velocity vector plots are obtained from CFD package STAR-CD, with the help of these plots a comparison was made on velocity vector flow field for the injection orientation angle. Figure 3 shows the velocity vector flow field observed during compression stroke at 10^0 before TDC. From the Figure it is noticed the velocity vectors are oriented towards the axis of the combustion chamber i.e. (Radial inward) in the squish region. The maximum velocity components are noticed at the top of bowl lip. At this stage the maximum velocities of 11m/s was noticed at the top of the bowl lip towards the cylinder head. A clear vertex formation at the lip of the bowl is also noticed, this is mainly due to the interaction of substantial fluid flows from the squish region with the upward flow along the piston bowl walls. It is also noticed that the traces of fuel spray at the axis of the bowl and along the walls of the bowl. The higher velocity vectors particles are oriented towards the upper side, this is due to the compression of in-cylinder fluids in the compression stroke.

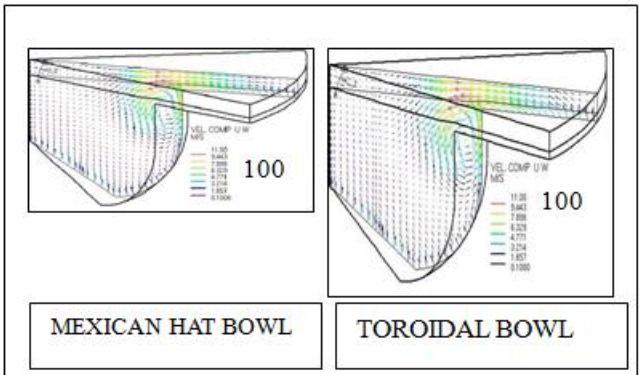


Figure 3 Velocity Vector Plots at 10^0 before TDC in X-Z Plane at 100^0 Injection Orientation

Comparison Of Velocity Vector Flow Fields At 4^0 Before Tdc

The fluid observations after fuel injection starts at 4^0 before TDC, for the 100^0 orientation as shown in Figure 4 orientated in the direction of the fuel jet. This velocity vector plots give the clear visibility and more information on the spray orientation spreading into the cylinder.

It is noticed that the velocity in the range of 54 to 126 m /s are in the core of fuel jet. This is due to high velocity fuel spray through the injector nozzle. The high velocity fluid flows appear to push the in-cylinder fluids in the direction of fuel spray due to the momentum exchange between fuel spray molecule and in cylinder fluid molecules.

At this stage the fuel jet is noticed to impinge on the surface of the cylinder wall. The high velocity fuel jet leaving from the nozzle spreads out and mixes with in-cylinder fluids. The outer surface of the fuel jet gradually break up into droplets of different size and miscible with the in cylinder fluids. As spray moves away from the nozzle, that spray diverges, its width increases and the velocity decreases. At this stage it is also noticed that the spray impinges on the chamber walls. The spray is then flows tangentially along the surface of the walls of the bowl. The cylinder wall causes the spray to split circumferentially into the bowl region or into the cylinder dome region.

In case of Mexican Hat Bowl shows the velocity vector plots for 100^0 injection angle, from the figure it is noticed that a vortex formation is present at lip of the bowl. It is also noticed that after impinging the spray particles on the walls of the bowl surface, some of the particles are moving along with the bowl surface, towards the cylinder head and rest of the particles are moving down side of the bowl region of the walls.In case of Toroidal Bowl 100^0 orientation from the Figure 4, it is noticed that an elongated vortex at the lip of the bowl is diverted towards the downward direction of the bowl region.

Comparison Of Velocity Vector Flow Field

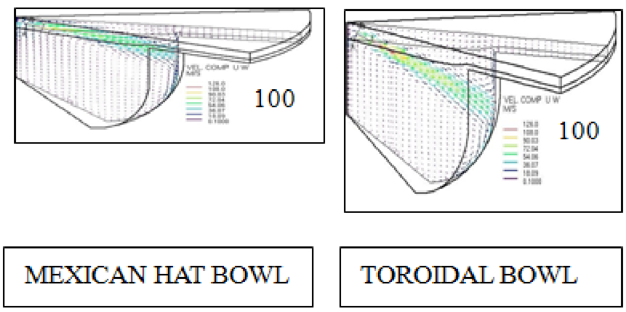


Figure 4 Velocity Vector Plots at 10^0 before TDC in X-Z Plane at 100^0 Injection Orientation

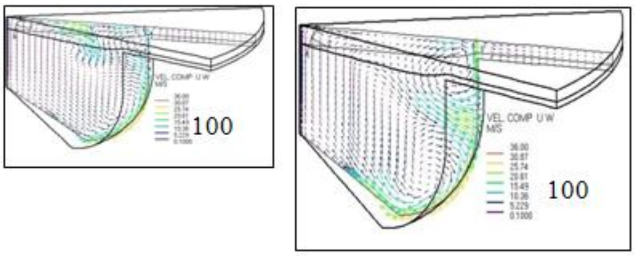
Comparison Of Velocity Vector Flow Fields At Tdc

Figure 5 shows the fluid velocity flow pattern in the bowl region, from the plot it has been noticed that high velocity flow is observed in the bowl region.

This is due to stagnation of flow in the squish region and also due to narrow space between cylinder head and piston. From the figure it is also observed that the traces of spray moving towards the bowl region.

In case of 100^0 orientation, in Mexican Hat Bowl shows two rotating vortices on either side of spray path.

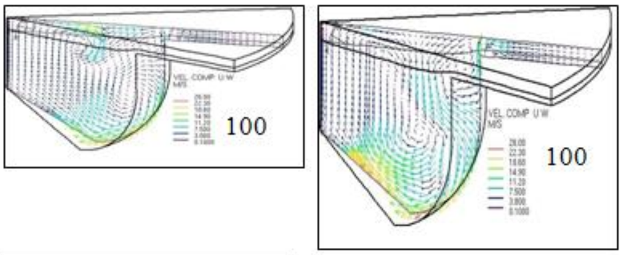
In case of Toroidal bowl at 100^0 orientation, Figures 5 shows two elongated vortices one at the lip of the bowl directed towards the bowl region and the other at the bottom of the bowl.



MEXICAN HAT BOWL | TOROIDAL BOWL

Figure 5 Velocity Vector Plots at TDC in X-Z Plane at Various Injection Orientation

Comparison Of Velocity Vector Flow Fields At 2^0 After Tdc



MEXICAN HAT BOWL | TOROIDAL BOWL

Fig 6 Velocity Vector Plots at TDC in X-Z Plane at 2^0 a TDC Various Injection Orientation

Fig 6.shows the velocity vector plots for the crank angle 2^0 after TDC during the expansion stroke, the piston starts moving towards the bottom dead centre.

In case of Mexican Hat Bowl at 100^0 fuel injection angle, from the Figure 6 it has been observed that fluid is moving towards the squish region. In the bowl region the fluid flow starts moving towards the cylinder head, this can be attributed to that of the combustion.

In the case of Toroidal Bowl the at 100^0 injection orientation angle the flow started to move towards the squish region (reverse squish) due to space due to space created during expansion stroke

Comparison Of Velocity Vector Flow Fields At 8^0 After Tdc

With the help of these plots a comparison was made on velocity vector flow field for the injection orientation angle. at 100^0 From the Figure 7 , it was observed that, during expansion stroke at 8^0 after TDC, the turbulent flow is present in the entire cylinder. A clear strong vertices formation is observed in the bowl region and the peak pressures are noticed at this stage.

In the case of Mexican Hat Bowl at 100^0 injection orientation angle as shown in Figure.7 some velocity vector flow from squish region in to the bowl and get reversed into the squish region back.

In case of Toroidal Bowl at 100^0 injection orientation angle as shown in the Figure 7, it has been observed that a small quantity of combustion flames are moving towards the squish region at the same time another weak elongated vortex formation is noticed at the axis of the bowl region. This is mainly attributed to the upward thrust due to the combustion taking place at the bottom side of the bowl region.

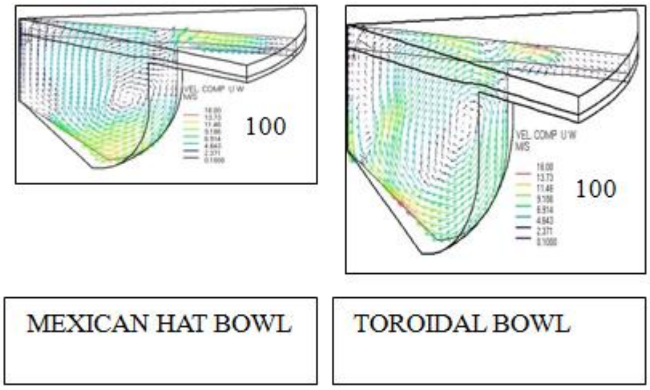


Fig 7 Velocity Vector Plots at 8^0 after TDC in X-Z Plane at 100^0 Injection Orientation

Comparison Of Velocity Vector Flow Fields At 12^0 After Tdc

From the Figure 8 during expansion stroke at 12^0 after TDC is shown, it was observed that a strong fluid flow wave is moving in reverse squish direction, this is due to the space being created during expansion stroke by the piston moving away from the cylinder head. At this stage peak temperature is attained

In case of Mexican Hat Bowl 100^0 injection orientation angle shown in Figure 8 it is noticed that the velocity vectors are more uniformly spread in the entire bowl. At this stage one strong vortex is formed at the side walls of the bowl and a weak elongated vortex at the axis of the bowl is noticed.

In case of Toroidal Bowl at 100^0 injection orientation angle shown in Figure.8 it is noticed that there is one strong vortex at the side walls of the bowl and also another weak vortex formation at the axis of the bowl region.

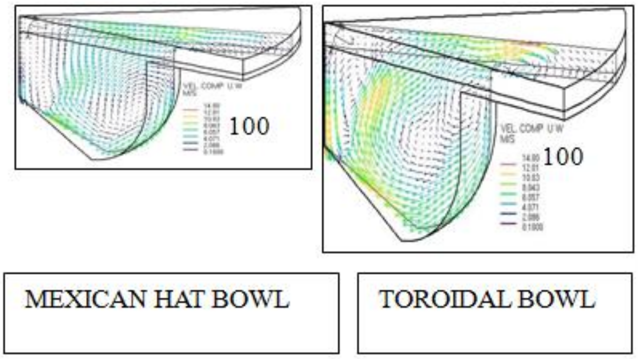


Fig 8 Velocity Vector Plots at TDC in X-Z Plane at 12^0 a TDC Various Injection Orientation

III. Conclusions

Effect of injection orientation angle on in-cylinder fluid flow characteristics were analysed through velocity vector plots in DI diesel engine through CFD simulation. In this work 100^0 injection orientation angle is considered for simulation, viz^0. In case of Toroidal Bowl at 100^0 injection orientation angle the fluid flows towards squish region. In case of Mexican Hat Bowl at 100^0 injection orientation angle spray is spreading uniform into the high turbulent zone. Hence in Mexican Hat bowl at 100^0 injection orientation angle is reasonably good for the fuel spray in comparison with Toroidal Bowl

Nomenclature

a	After
b	Before
TDC	Top dead center
BDC	Bottom dead center
aTDC	After Top dead cent
CFD	Computational fluid dynamics
TDC	Top Dead Center
V	Volume
U	Velocity components in X-direction
V	Velocity components in Y-direction
W	Velocity components in Z-direction
2-D	Two dimensional
3-D	Three dimensional

Greek Characters

θ	Crank angle

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