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EFFECT OF COMBUSTION CHAMBER GEOMETRY ON IN-CYLINDER FLOWS AND EQUIVALENCE RATIO SPREAD IN A DIRECT INJECTION ENGINE – A CFD ANALYSIS

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Abstract:

In this study, a CFD analysis to evaluate effect of combustion chamber geometry on in-cylinder fluid flows and equivalence ratio spread in a Direct Injection Spark Ignition Engine (DISI) during intake and compression stroke has been carried out. The analysis has been carried out using “*STAR-CD es-ice”* software for four piston top profiles viz., flat piston, flat piston with centre bowl, dome piston with a bowl and pentroof type piston with offset bowl at an engine speed of 1000 rpm. For meshing the geometric model, polyhedral trimmed cell are adopted. Solution is obtained by solving conservation of mass, momentum and energy using SIMPLE algorithm. From the results, it is found that for DISI engine, flat piston is the best profile.

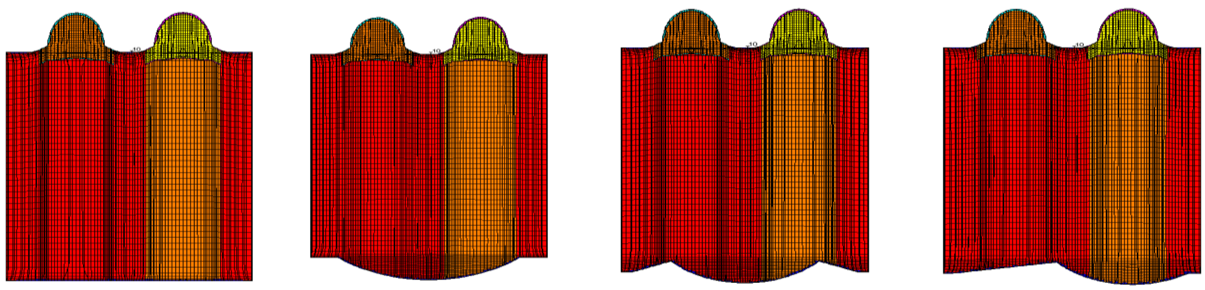
Introduction:

Nowadays, DISI engines are extensively used in automotive industries due to their advantages. In these modern engines, in-cylinder flows and distribution of fuel concentration play major role on their performance and emission characteristics. In-cylinders flows and distribution of fuel concentration mainly dependent on combustion chamber geometry [1]. Therefore, study of the effect of this is very much needed. *Muralikrishna et al.* have conducted flow visualization studies on DISI engine with different piston crown shapes under motoring condition using Particle Image Velocimetry (PIV) technique. They concluded that overall in-cylinder tumble flows are more depend on crank angle position irrespective of engine speed. Flat piston is better choice in terms of tumble ratio and tumble kinetic energy compared to other piston configurations [2]. *Huang et al.* have conducted experiments on four-valve four-stroke engine with different piston shapes under motoring conditions using Particle Image velocimetry technique. They reported that flat crown piston induces higher tumble ratio and turbulence intensity compared to concave piston [3]. *Rudolf et al.* have conducted experiments on four-valve spark ignition engine with different speeds under motoring condition using Laser Doppler Velocimetry (LDV) technique. They observed that the shape of fuel spray dependent on the in-cylinder air motion generated by intake air flows [4]. Above discussion indicates that the fluid motion generated during intake and compression stroke mainly dependent on combustion chamber shape, which in turn affects air-fuel interaction. Also limited studies have been addressed in the literature on finding the effect of combustion chamber shape on air and fuel interaction inside the combustion chamber. Therefore, in this study, an attempt has been made to study through CFD the in-cylinder flows and equivalence ratio spread inside the combustion chamber in a direct injection engine.

Geometrical and Computational Details:

Table 1: Engine Specifications

Type	Two valve, four stroke
Bore	87.5 mm
Stroke	110 mm
Compression ratio	10:1
Speed	1000 rpm
Maximum intake valve lift	7.9 mm
IVO : 4.5^0 bTDC	EVO : 35^0 bBDC
IVC : 35^0 aBDC	EVC : 4.5^0 aTDC



(a) Flat piston (b) Flat piston with center bowl (c) Dome piston with center bowl (d) Pentroof type piston with offset bowl

Figure 1: Sectional view of the meshed grid on a plane passing through axis of the engine

The engine specifications considered for the analysis are shown in Table 1. The engine had straight intake and exhaust ports. The numerical predictions were calculated during intake and compression stroke from 360 to 720^0 crank angles (CA) for four piston geometries viz. flat piston, flat piston with centre bowl, dome piston with central and pentroof type piston with offset bowl. The continuity, momentum and energy equations were solved in order to get in-cylinder flow structure. Fuel concentration was obtained by solving equation of Reitz-Diwakar [6]. Fuel injector was considered to be located at the centre of the combustion chamber. Fuel injection was started at the end of suction stroke i.e. 540^0CA, it timing was considered to be 20^0 CA. Here, starting of suction stroke is considered as 360^0 CA. Injector nozzle-hole diameter was taken as 0.2 mm. The engine geometry was modeled using "*Pro-E"* software. Meshing grid using polyhedral cells was created using "*STAR-CD es-ice"*. Sectional view of the meshed grid on a plane passing through axis of the engine is shown in Fig.1. Grid independence test was conducted with three different grids of 1.8, 3.4 and 6.2 lakh cells. It was found that, grid with 3.4 lakh cells gives reasonably good results with reduced computational time. To maintain uniformity of compression ratio (10:1) with all the piston shapes, compression pressure was computed as shown in Figure 2.

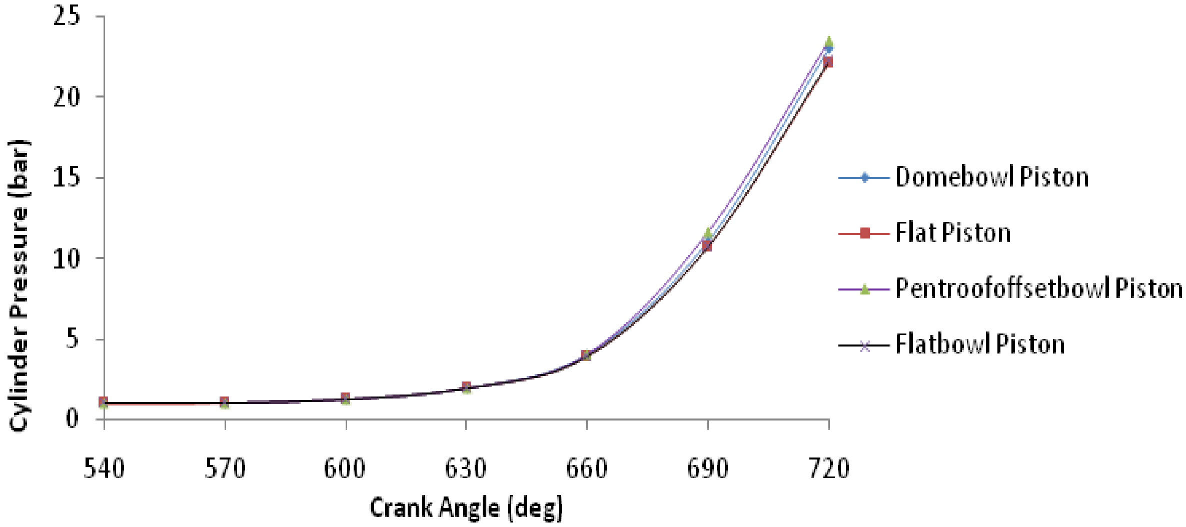
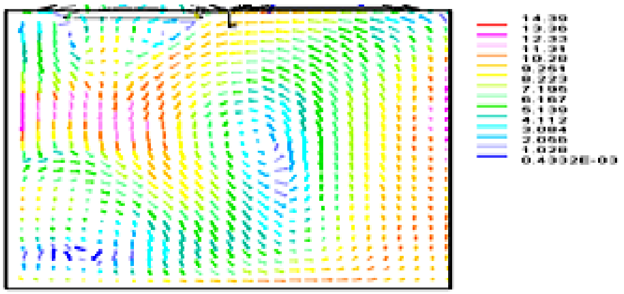


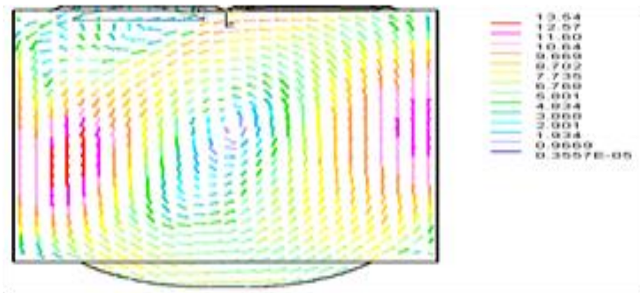
Figure 2: Variation of cylinder pressure with crank angles during compression stroke

Results and Discussion:

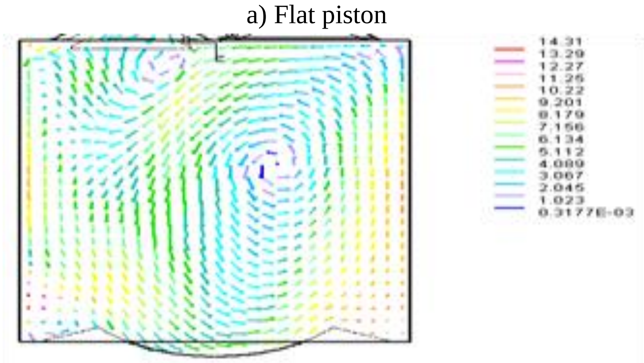
Figures 3 (a-d) show in-cylinder velocity vectors plots at the end of suction stroke with different piston profiles on a vertical plane passing through the axis of the engine. From these figures, it is observed that a counter clockwise (CCW) tumble exits in all the four cases of piston profiles. The tumble vortex is located almost in the centre of combustion chamber in the case of flat piston with centre bowl. It is due to center bowl which confines it to the center. In the other three cases of piston profiles, the tumble vortex occurs slightly towards exhaust side. The tumble velocity is marginally 14.39m/s higher in case of flat piston as compared to other three piston profiles. It may be mainly due to uniform space of combustion chamber above the piston top unlike the other cases of piston shapes. Therefore, it can be concluded that the fuel injector can be located at the centre of combustion chamber in all the cases of piston shapes for better air fuel mixing.



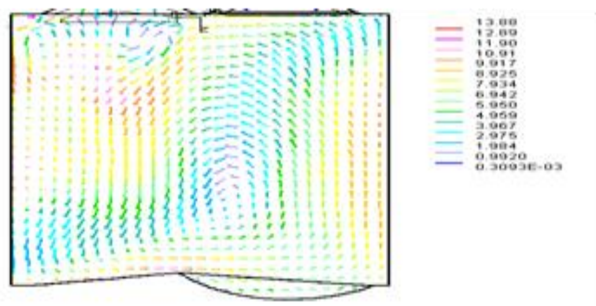
a) Flat piston



b) Flat piston with center bowl



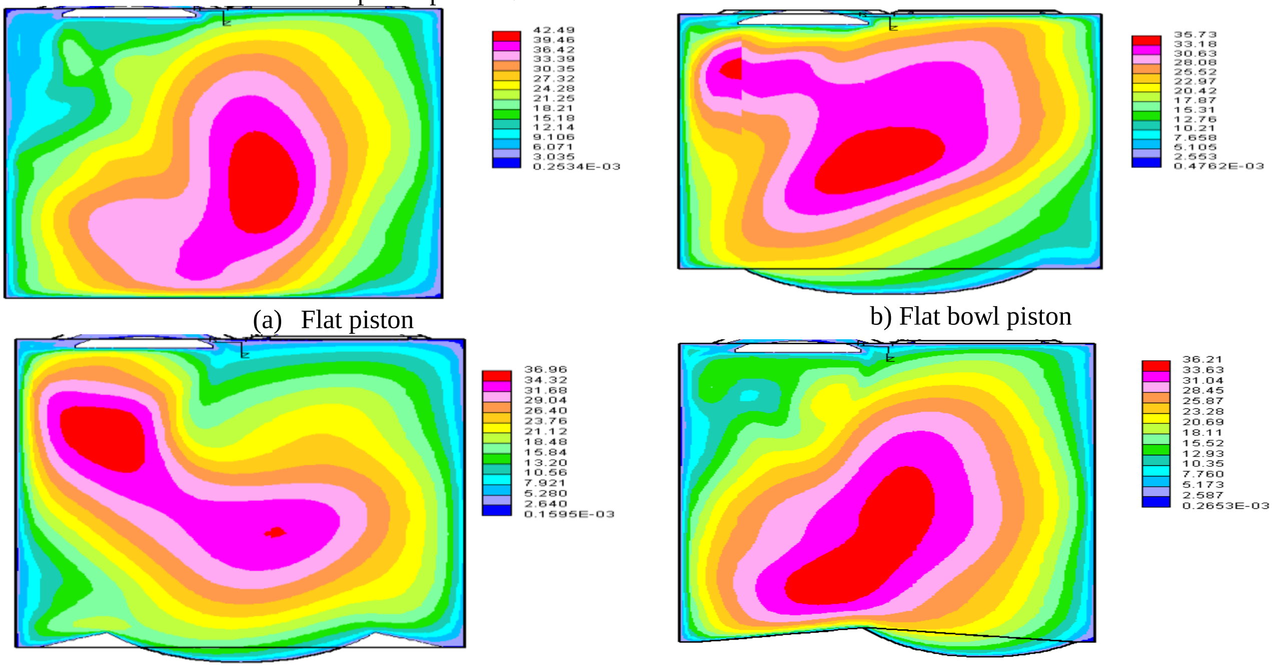
(c) Dome piston with center bowl



d) Pentroof type piston with offset bowl

Figure 3: In-cylinder velocity vector plots at the end of suction stroke (540^0 CA)

Figures 4 (a-d) show the plots of turbulent kinetic energy (TKE) contours at the end of suction stroke for different piston profiles on a vertical plane passing through axis of engine. From these figures, it is found that, the flat piston gives about 18.9% more TKE as compared to other three piston profiles, its magnitude is 42.49 m^2/s^2. The TKE is almost uniformly distributed inside combustion chamber in all the cases of piston profiles.



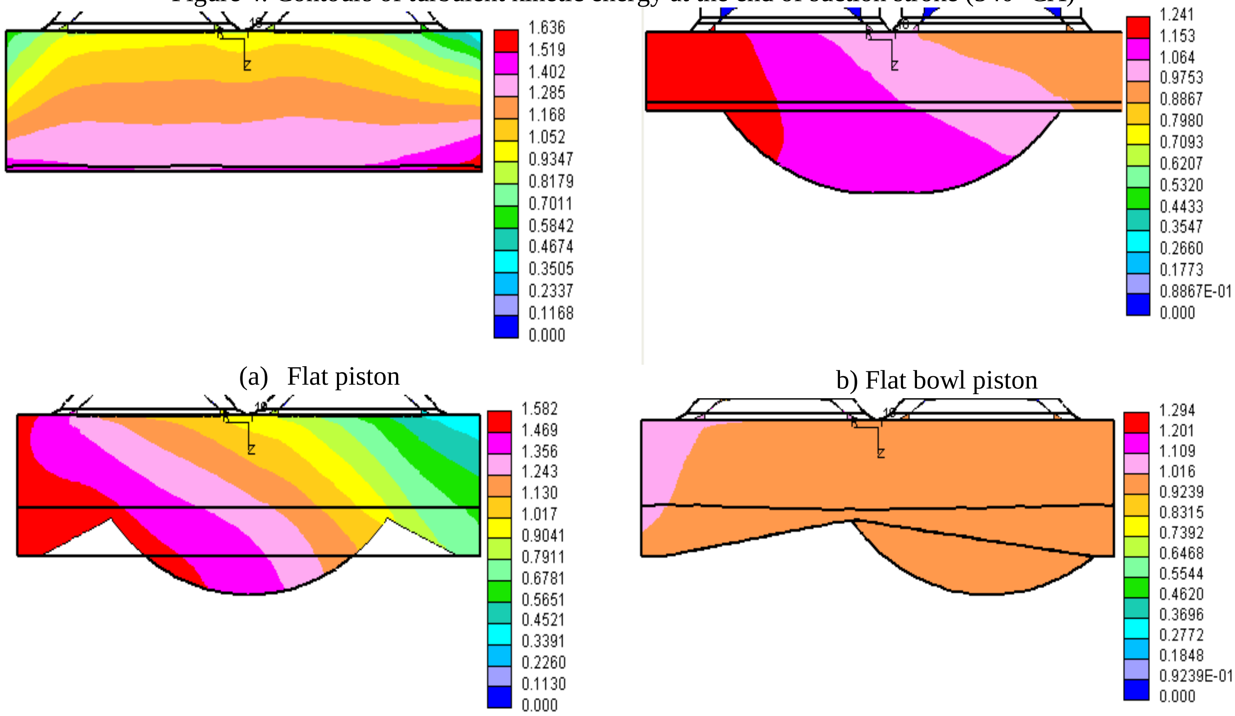
(a) Flat piston

b) Flat bowl piston

(c) Dome bowl piston

d) Pentroof offset bowl piston

Figure 4: Contours of turbulent kinetic energy at the end of suction stroke (540^0 CA)



(a) Flat piston

b) Flat bowl piston

(c) Dome bowl piston

d) Pentroof offset bowl piston

Figure 5: Spread of equivalence ratio at the end of compression stroke (690^0 CA)

Figures 5 (a-d) show the spread of equivalence ratio (ϕ) at the end of compression stroke (690^0 CA) with different piston profiles on a vertical plane passing through the axis of engine. From these figures, ϕ is more uniform in case of pentroof with offset bowl piston. The next uniformity of ϕ is the flat bowl piston compared to other piston configurations. It may be due to centre bowl in the piston profile. In the cases of flat and dome bowl pistons, variation of ϕ across the combustion chamber is high. At spark plug location ϕ value should be more is required in DISI engine.

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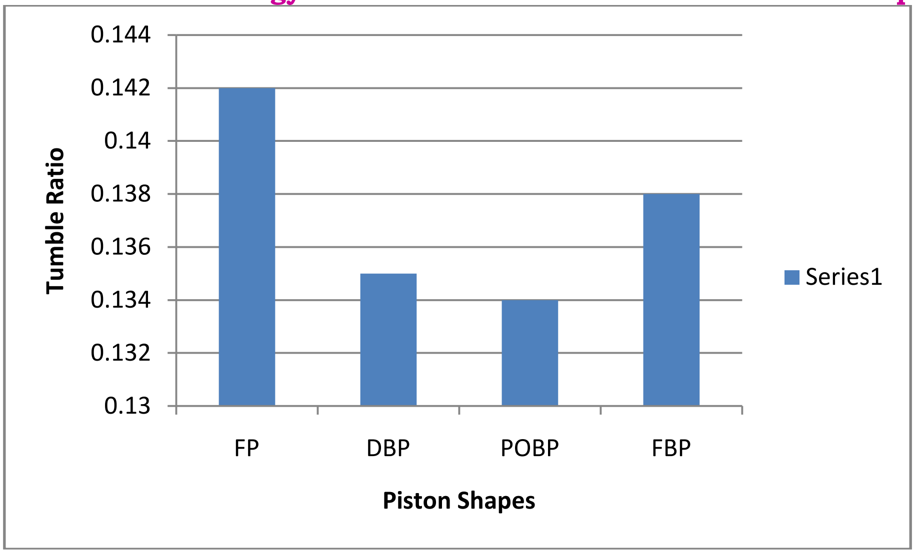

Figure 6: Variation of tumble ratio with different pistons

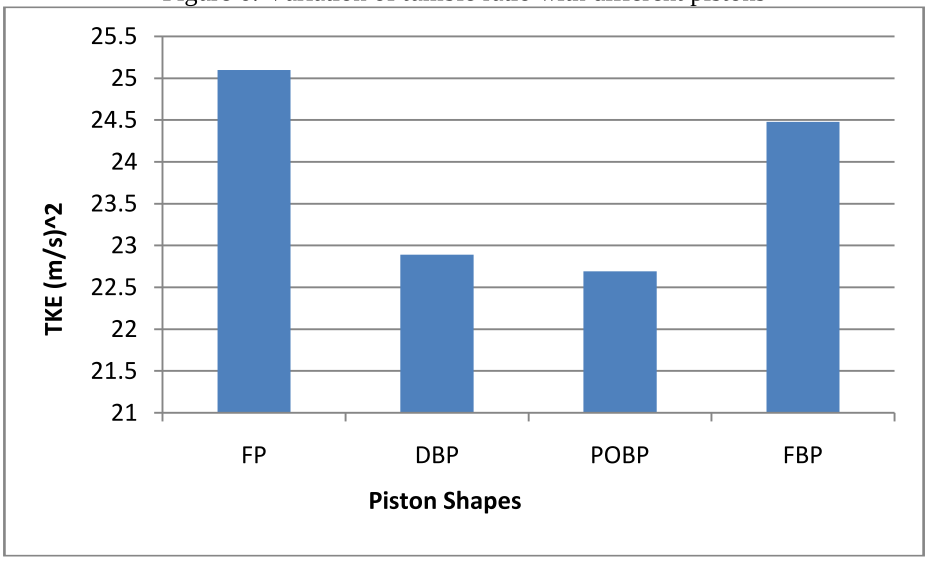

Figure 7: Variation of turbulent kinetic energy with different pistons

Conclusions:

From the CFD analysis on a DISI engine, the following conclusions are drawn.

- ✓ At 540^0 CA, tumble vortex was formed in all the cases of piston profiles, it is almost located at the centre in flat bowl piston and in other cases it is located slightly towards the exhaust valve side.
- ✓ Flat piston shows slightly higher 10.7% of tumble velocity as compared to other piston profiles.
- ✓ Flat piston gives higher 18.9% of TKE as compared to other piston configurations. TKE is distributed all over the combustion space in all piston configurations.
- ✓ The equivalence ratio spread is all over the combustion space in all piston configurations, in case of flat piston more stratified compared to other configurations.
- ✓ Finally, it is concluded that, flat piston is better suitable for direct injection spark ignition engine in terms of good turbulent kinetic energy, tumble flow velocity and spread of equivalence ratio.

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