A SIMULATION STUDY OF AIR FLOW IN DIFFERENT TYPES OF COMBUSTION CHAMBERS FOR A SINGLE CYLINDER DIESEL ENGINE

by

Premnath SUNDARAMOORTHY [a*], Devaradjane GOBALAKICHENIN [b], Kathirvelu BASKAR [c], and Shanmugasundaram PALANINATHAN [a]

[a] Department of Automobile Engineering, Sri Venkateswara College of Engineering, Kancheepuram,Tamil Nadu, India
[b] Department of Automobile Engineering, Madras Institute of Technology, Anna University, Chennai, India
[c] Department of Automobile Engineering, Rajalakshmi Engineering College, Thandalam, Kancheepuram, Tamil Nadu, India

Original scientific paper
DOI: 10.2298/TSCI16S4145S

The objective of this research work is to improve the in-cylinder air flow for facilitate better mixing and ultimately achieve complete combustion. From the literature it is revealed that the bowl shape of the piston has influence on creating effective swirl, tumble, and cross tumble motions during intake and initial stages of compression stroke. Different types of combustion chambers have been designed by keeping the same bowl volume to maintain the constant compression ratio and to ensure that the improvement is only due to geometric parameters such as bulge diameter, lip distance, and bowl to bore diameter ratio. Simulation work is carried out using ANSYS Fluent 14.5 computational fluid dynamics tool. The influence of these parameters on in-cylinder flow was also studied in this paper. The values of swirl, tumble, and cross tumble were calculated. Further to ensure the results of theoretical simulation a modified re-entrant combustion chamber was fabricated and the experimental work has been carried out in Kirloskar TAF 1 single cylinder, 4-stroke, compression ignition engine for diesel and jatropha methyl ester blend 20%. The experimental results were compared with the conventional chamber. It is found that the modified re-entrant chamber improves the brake thermal efficiency and reduced HC, CO, and smoke emissions of diesel and jatropha methyl ester blend 20% for all the tested conditions when compared to the conventional chamber.

Key words: *modified re-entrant chamber, ANSYS, squish and tumble*

Introduction

The effect of combustion chamber geometry on engine performance and exhaust emissions has been investigated by many researchers in the past, since with the proper combustion chamber design significant benefits can be achieved regarding the reduction of pollutant emissions, without affecting seriously the engine performance. The results showed that by changing

* Corresponding author; e-mail: prem@svce.ac.in

the geometric parameters on piston bowl, the amount of emission pollutants can be decreased while the other performance parameters of engine remain constant [1]. Squish flow plays an important role in the turbulence generation process near the top dead center (TDC) during compression, the coupling among the swirl, squish, bowl shape, and turbulence is much more pronounced for the flow fields in the combustion chambers and the piston bowl configurations should be designed to coincide with the contour lines of the turbulence [2]. It is given that the piston geometry had little influence on the in cylinder flow during the intake stroke and the first part of the compression stroke. However, the bowl shape plays a significant role near TDC and in the early stage of expansion stroke [3].The shape of the combustion chamber helps improve the mixing of air and fuel [4]. Smaller engines are more sensitive to intake air conditions, fluctuations of air movement in the intake system occurrence and a high swirl number reduces the smoke and soot emissions, as turbulence is high [5]. In Diesel engines only about 80% of the air inducted can effectively be utilized during the combustion process, the remainder has insufficient time to mix with the fuel [6]. The present research work focuses on the air flow analysis to achieve the effective mixing of fuel and air by having a modified re-entrant chamber for diesel and biodiesel blends

Materials and methods

Squish velocity

An important geometric design consideration is the *squish* region, which is the region around the perimeter of the combustion chamber with the smallest clearance volume between the piston and the cylinder head at top center.

Effect of bowl to bore diameter ratio on squish

The objective of designing a bowl shape is to improve the air motion in the combustion chamber. The eqs. (1) and (2) give the calculation of the squish velocity and the effect of varying the bowl to bore diameter (D/B) ratio.

$$\frac{v}{s} = \frac{B}{4(c + l + a - s)}\left[\left(\frac{D}{B}\right)^2 - 1\right]\frac{V}{A(c + l + a - s) + V} \tag{1}$$

$$s = a\cos\theta + \sqrt{2l - 2a\sin 2\theta} \tag{2}$$

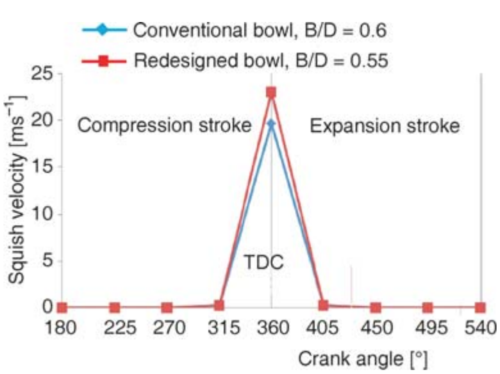

Figure 1. Crank angle *vs.* squish velocity

where v [ms^{-1}] is the squish velocity, B [mm] – the bowl diameter, θ [deg.] – the crank angle, V [mm^3] – the bowl volume, D [mm] – the piston diameter, a [55 mm] – the crank radius, l – the length of connecting rod [234 mm], S – the mean piston speed [5.5 m/sfor 1500 rpm], A – the cross-section area of cylinder [6013.2 mm^2], s [mm] – the distance between crank axis and piston pin axis, and c [mm] – the distance between piston crown and cylinder head at TDC.

Figure 1 shows the relation between the bowl to bore diameter ratio and the squish velocity, it indicates that squish velocity is higher for low D/B ratio, higher squish velocity enhance better mixing of air and fuel by converting swirl and tumble to turbulence at the end of compression stroke.

Design of combustion chamber bowls

Figures 2-5 shows conventional, re-entrant, toroidal, and the modified re-entrant bowls, respectively. The B/D ratio of the conventional bowl is maintained as 0.6 the remaining three bowls (figs. 2-4) are designed by keeping bowl to bore diameter ratio 0.55 to increase the squish velocity at the end of compression stroke. To combine the positive effects of both the re-entrant and toroidal bowls, a new type of combustion chamber called as the modified re-entrant chamber was designed with bulge diameter 12 mm and bowl centre depth of 6 mm to enhance swirl and tumble motion, respectively.

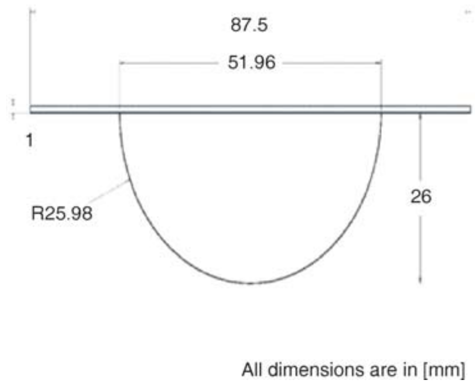

Figure 2. Conventional bowl

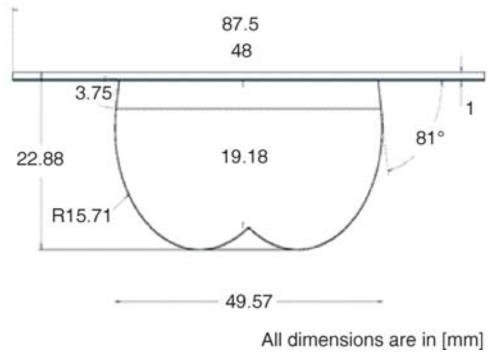

Figure 3. Re-entrant bowl

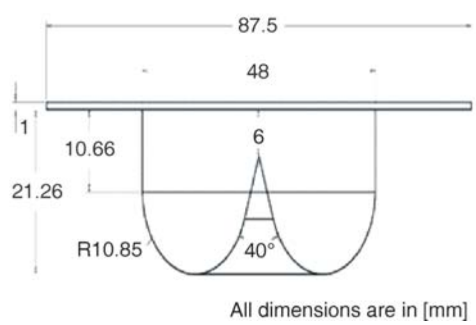

Figure 4. Toroidal bowl

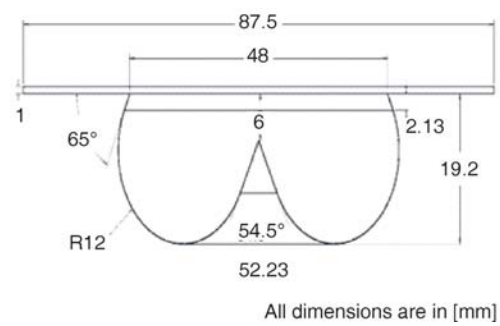

Figure 5. Modified re-entrant bowl

Flow analysis

Simulation work has been carried out for the designed bowls after converting the modeled domain into IGES format it has been imported into AnsysICE (internal combustion engines) as Geometry, followed by decomposition of the geometry parts where each part or region has been assigned appropriately. After decomposition, the domain has been meshed. AnsysICE uses ICEM-CFD for meshing. Figure 6 shows the meshed domain of modified re-entrant bowl and tab. 1 shows mesh parameters defined in the solver FLUENT. These pa-

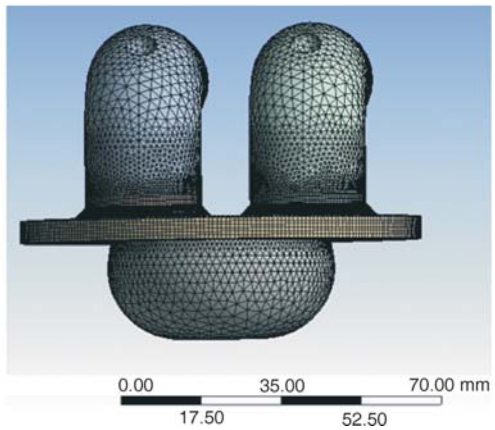

Figure 6. Meshed domain of modified re-entrant bowl

Table 1. Mesh parameters

Mesh type	Coarse
Reference Size [mm]	0.93
Min mesh size [mm]	0.31
Max mesh size [mm]	2.79
Normal angle [°]	30
Growth rate	1.2
Pinch tolerance	0.1
No. of inflation layers	3

rameters are useful for adding additional elements when the piston and valves move during an engine cycle.

Figures 7-10 for the velocity streamline shows that the velocity of air flow inside the combustion for conventional bowl is $7.105e^{+000}$, for reentrant bowl is $1.416e^{+001}$, for toroidal bowl it is $1.865e^{+001}$, and for modified reentrant bowl is greater than all the bowls approximately $5.00e^{+001}$. The increase in airflow in that chamber confirms that the air utilization and the effective mixing of fuel and air will be attained.

Swirl, tumble, and cross tumble ratio

The ANSYS workbench automatically calculates swirl, tumble, and cross-tumble ratio. The software uses the eqs. (3-5) for calculating the ratios.

$$\text{Swirl ratio} = \frac{\dfrac{L_{\text{sa}}}{I_{\text{sa}}}}{\dfrac{\text{engine RPM} \cdot 2\pi}{60}} \tag{3}$$

$$\text{Tumble ratio} = \frac{\dfrac{L_{\text{ta}}}{I_{\text{ta}}}}{\dfrac{\text{engine RPM} \cdot 2\pi}{60}} \tag{4}$$

$$\text{Cross tumble ratio} = \frac{\dfrac{L_{\text{cta}}}{I_{\text{cta}}}}{\dfrac{\text{engine RPM} \cdot 2\pi}{60}} \tag{5}$$

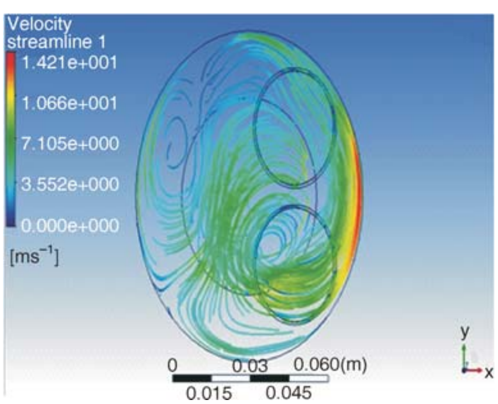

Figure 7. Velocity streamlines of conventional bowl

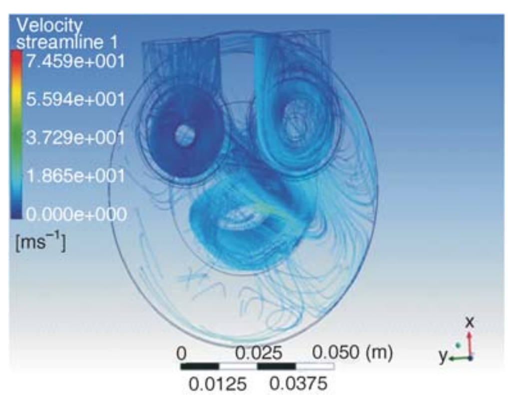

Figure 8. Velocity streamlines of toroidal bowl

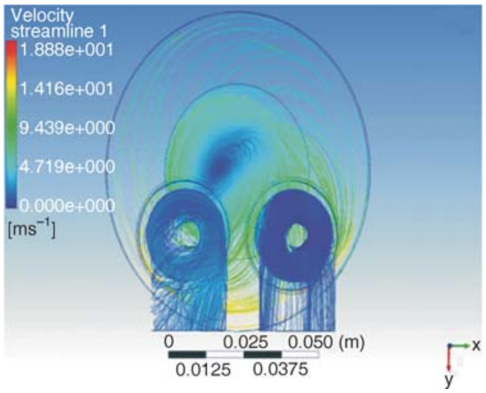

Figure 9. Velocity streamlines of reentrant bowl

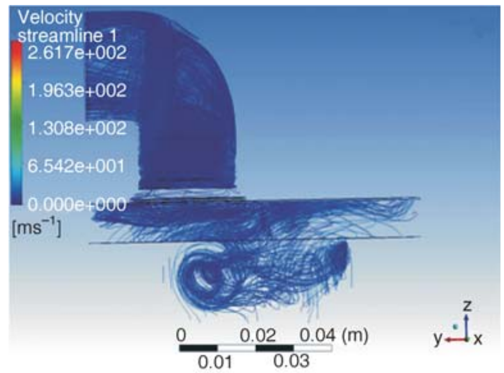

Figure 10. Velocity streamlines of modified reentrant bowl

where L_{sa}, L_{ta}, L_{cta} is angular momentum of fluid mass about swirl, tumble, cross tumble axis, respectively, and I_{sa}, I_{ta}, I_{cta} is moment of Inertia of fluid mass about swirl, tumble, cross tumble axis, respectively.

Having annular lip results in a longer residence time of the swirling air in the lower portion of the combustion chamber below the lip. It is clear that the swirl ratio for the proposed new (modified re-entrant) bowl is greater than the other bowl at the end of compression stroke. It is obvious that the swirl ratio in all the chambers goes high during compression stroke. Air is deflected downwardly by the conical projection upstanding in the base which is to say away from the piston crown and not towards it. So the secondary swirling motion of the air (tumble and cross tumble) is higher for modified re-entrant chamber than the other chambers at the end of compression stroke.

Result table

Table 2. Swirl, tumble, and cross tumble values for the designed chamber

Parameters at the end of compression stroke	Conventional chamber	Re-entrant chamber	Toroidal chamber	Modified Re-entrant chamber
Swirl ratio	0.826896	1.226896	0.26903	1.262796
Tumble ratio	0.04474	0.11289	0.007973	0.035452
Cross tumble ratio	0.12392	0.12827	0.03628	0.29812

Experimental work

The experimental work was done for three different types of combustion chambers like conventional, toroidal, and modified re-entrant chamber the experiment were conducted from no load to full load on a single cylinder direct injection 4-stroke Diesel engine coupled with an electrical dynamometer with all the necessary accessories. For a compression ignition engine, combustion chamber shape is one of the most important parameter which influences the performance, emission, and combustion characteristics of the engine. In view of that this work concentrates on the effect of combustion chamber shape (conventional chamber and the modified re-entrant chamber), and the fuel type (diesel and J20.) were studied after the theoretical simulation work.

Brake thermal efficiency

The variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) for conventional, toroidal, and re-entrant combustion chamber for diesel and J20 (20% jatropha oil methyl esters and 80% diesel) as fuels are shown in figs. 11 and 12.

It is observed that the BTE increases with increase in BMEP under all the test conditions due to the increased in-cylinder pressure, temperature and heat release rate.

It can be observed from figs. 11 and 12 that the BTE of reentrant combustion chamber with standard injection timing is comparatively high compared to conventional combustion chamber and the toroidal chamber for both diesel and J20 fuels. This is due to the improved air motion (squish and tumble) inside the combustion chamber which results in better mixing of the air and fuel. This reduces the ignition delay and promotes combustion of air fuel mixture. It can be further noticed that the BTE of diesel fuel is slightly higher than J20 fuel for both conventional and re-entrant combustion chambers. This may be due to the higher viscosity (poor atomization and mixing of fuel with air) and lower calorific value of J20 compared to diesel resulting in higher fuel consumption of blends at all BMEP [7]. By conducting the similar type of experimental work already it is proved that the modified re-entrant chamber reduced the regulated emissions by running the J20 fuel is HC by 24%, CO by 26%, and the smoke by 24% and the unregulated emissions at the maximum injection pressure [8].

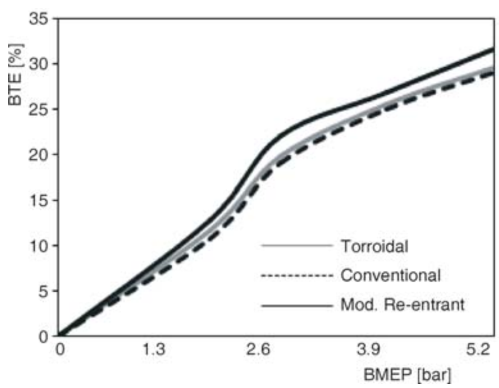

Figure 11. Diesel

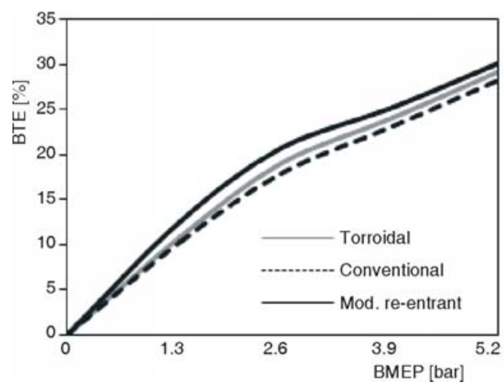

Figure 12. The J20

Conclusions

It is evident from the analysis that the conventional bowl and re-entrant chamber has the maximum swirl and cross tumble at the end of compression stroke. In contrary toroidal chamber has the high swirl at the end of compression stroke. The modified re-entrant chamber has the positive effects of the both re-entrant and toroidal chambers *i. e.*, high swirl and cross tumble ratio at the end of compression stroke. The implication from this is that the bowl shape of the piston has very little influence on creating an effective swirl, tumble, and cross tumble motions during intake and initial stages of compression stroke. It can be predicted from the simulation that the proposed new design has the annular lip which provides longer residence time for swirling air in the bowl, which ensures better mixing and reduces the proportion of the burning mixture subjected to wall quenching, which reduces the hydrocarbon generation. The experimental work have also been carried out for the combustion chambers and it is confirmed that the performance parameters are increased and the emission parameters reduced at the modified reentrant chamber when compared with the other two chambers for both diesel and biodiesel.

Nomenclature

BMEP – brake mean effective pressure, [bar]
BTE – brake thermal efficiency, [%]
J20 – jatropha methyl ester blende 20%

Note

This research work is not funded by any of the organizations.

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Paper submitted: September 6, 2015
Paper revised: January 3, 2016
Paper accepted: February 9, 2016