Combustion Chambers in Ci Engines: A Review

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Abstract : **-** The shape of the combustion chamber is one of the important factors. It decides the quality of combustion, engine performance and exhaust characteristics. Diesel Engine combustion is greatly influenced by air turbulence, created by the shape of combustion chamber. Each Combustion chamber shape creates its own unique turbulence pattern that is required for some specific applications while wrong for others. For complete combustion, the better turbulence helps for preparation of superior quality charge. Turbulence is created by shape of the combustion chamber. This paper re-visits and draws on the prerequisites of combustion chamber, their design, influence in combustion process, timing, etc.

***IndexTerms* - Combustion chamber, compression ignition, swirl, squish and turbulence.**

I. INTRODUCTION

In CI engine, only air as charge is inducted during the suction stroke. It undergoes high compression ratio usually 16: 1 to 20:1. The temperature of pressure of air increase to very high value , then fuel is injected through one or more jets into highly compressed air in the combustion chamber. The most important function of the CI engine combustion chamber is to provide proper mixing of fuel and air in a short time to decrease the ignition lag. An organized air movement called air swirl is provided to produce high relative velocity between fuel droplets and air. When the liquid fuel is injected into the combustion chamber, the spray cone gets disturbed due to the air motion and turbulence inside.

Swirl in CI engines is created by introducing an intake flow of air into the cylinder with an initial angular momentum. Swirl is also used to promote more rapid mixing of hot air and the injected fuel and to speed up the combustion process. Squish is also used in CI engines, that is an effect that creates the radially inward or transverse gas motion of charge occurs towards the end of the compression stroke when piston face and cylinder head approach each other closely.

II. TYPES OF COMBUSTION CHAMBERS

Combustionn chambers are mainly classified as direct and indirect combustion chambers.

2.1 Direct Injection (DI) Combustion Chamber

This type of combustion chamber is also called an *open combustion chamber*. In DI combustion chambers, the entire volume of the combustion chamber is located in the main cylinder and the fuel is injected into this volume. The Direct Injection combustion chamber is shown in Fig.1. Its use is increasing due to their more economical fuel consumption (up to 20% savings).

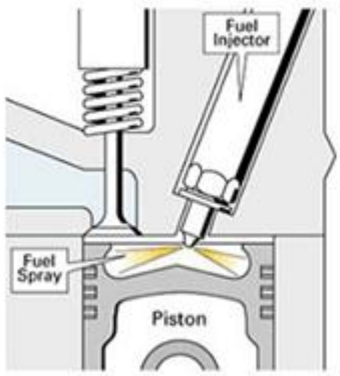

Fig.1 Direct Injection Combustion Chamber

Features of Direct Injection combustion chambers

- For DI engine, ω piston crown recess is most widely used. In this design, the fuel is injected directly into the cylinder chamber.
- Lower combustion surface wall area compared to combustion volume in comparison with IDI.
- More combustion taking place in and on the piston and less contact with coolant.
- DI chamber has highest fuel efficiency rating compared to other chamber design.
- Smaller engines tend to be of the high-swirl type, while bigger engines tend to be of the quiescent type.

Classification of direct injection combustion chamber

DI combustion chambers can be classified as

(a) Shallow depth chamber,
(b) Hemispherical chamber,
(c) Cylindrical chamber, and
(d) Toroidal chamber

Shallow depth chamber

The shallow depth combustion chamber has large diameter cavity in the piston. The depth of the cavity is moderately small. This chamber is normally used for large engines running at low speeds, since the squish is negligible. It shown in Fig.2(a).

a) Hemispherical chamber

The hemispherical combustion chamber provides small squish and swirl. However, in this chamber, the depth to diameter ratio can be varied to give any desired squish for engine better performance. It shown in Fig.2(b).

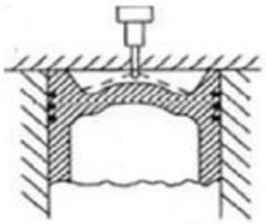

Fig.2(a) Shallow depth chamber

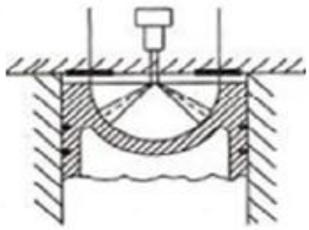

Fig.2.(b) Hemispherical chamber

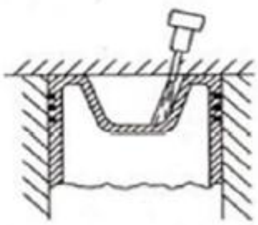

Fig.2(c) Cylindrical chamber

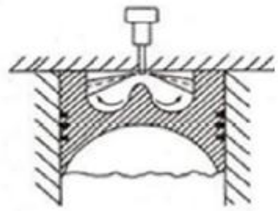

Fig.2(d) Toroidal Chamber

b) Cylindrical chamber

Cylindrical combustion chamber is a modified version of the hemispherical chamber. It has cavity in the form of a truncated cone with a base angle of 30 degree. The swirl was produced by masking the valve for nearly 180 degree to the circumference. Squish can also be varied by varying the depth. It shown in Fig.2 (c).

c) Toroidal chamber

The toroidal combustion chamber provides a powerful squish along with the swirl in form of smoke ring within the chamber. Due to powerful squish the mask needed on inlet valve is small and there is better utilization of oxygen. The cone angle of spray for this type of chamber is 150 to 160 degree. It shown in Fig.2(d).

2.2 IDI combustion chamber types

Indirection injection (IDI) combustion chambers have the combustion space divided into two or more compartments connected by restricted passage(s). During combustion, there is a substantial pressure difference between them during combustion, that creates a high degree turbulence and swirl.

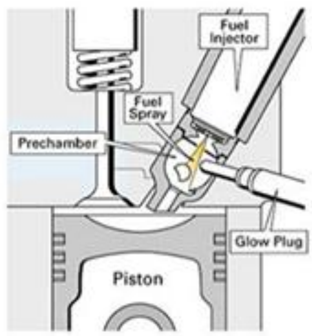

Fig.3 IDI Pre Combustion Chamber

Features of IDI Combustion chambers

The good and bad features of IDI combustion chambers are

Good Features

- Excellent mixing of burnt and unburned charge is possible due to very high degree turbulence characteristics of the chamber.
- In IDI combustion chamber, the lower quality fuel Can easily be burnt.
- They require lower injection pressure
- The chances of knock are minimum in these combustion chambers.
- They create low noise and complete combustion is possible with low exhaust emissions

Bad Features

- IDI combustion chamber has very high temperature and pressure in injection chamber
- Due to high temperature during combustion, there is possibility of formation NOx in emission.
- Engine with IDI Combustion chamber is require more power to start and glow plugs
- They are less efficient

These are also classified as

a) Turbulent pre-combustion chamber type
b) Swirl pre-combustion chamber type, and
c) Air-cell pre-combustion chamber type

a) Pre-combustion Chamber

Fig.3 shows an indirect fuel injection pre-combustion chamber. The combustion space is divided into pre-chamber and a spherical combustion space. The pre-combustion chamber is mounted in a heat resisting alloy in the cylinder head slightly to one side of the single inlet and exhaust valve seats.

During the compression stroke, as piston approaches TDC, 40% to 50% of compressed air is forced through the nozzle holes and parallel throat passage where it is exited into a vigorous and highly turbulent mass. The fuel is injected through a pintle nozzle. It has a specially shaped baffle in the centre of the chamber diffuses the jet of fuel that strikes it and mixes it thoroughly with the air.

The resulting pressure from burning charge forces burnt and unburnt charge through the throat into the piston crown. The thrust of combustion a gases project the directional jet of flame-fronts towards the cylinder walls and, in doing so, sweeps the burnt gases and soot to one side while exposing the remaining fuel vapour to fresh oxygen.

b) Swirl Chamber System

The swirl indirect injection combustion chamber is divided in two chambers. The upper half is a sphere swirl chamber, cast directly in the cylinder head, and the lower half is a separate a twin disc shaped recesses in the piston crown as shown in Fig.4. The combustion is initiated in the swirl chamber that has approximately 60% of the compression volume. As soon as combustion starts in swirl chamber, the air-fuel mixture is forced under pressure through the throat into the cylinder chamber, where it is turbulently mixed with the remaining compressed air as shown in Fig.4(b).

(a) (b)

Fig.4 Swirl Indirect injection combustion chamber

c) Air-cell chamber

This chamber is divided into the main combustion chamber and energy cell. The energy cell is divided into two parts, major and minor, which are separated from each other and from the main chamber by narrow orifices as shown in Fig.5. The high degree turbulence is created by an energy cell.

During the compression stroke, the piston forces a small amount of compressed air into the energy cell. Near the end of compression stroke, a pintle nozzle injects the fuel, a small quantity of fuel is directed into the cell and remaining amount is injected into main combustion chamber.

While the fuel charge is travelling across the centre of the main chamber, the fuel mixes with hot air and instantaneously burns. The remainder of the fuel enters the energy cell and start to burn. At this moment cell pressure rises sharply, causing the products of combustion to flow at high velocity back into main combustion chamber as shown in Fig.5(b). This setup a rapid swirling movement of burning charge in each lobe of main chamber promoting fuel air mixing within remaining charge to ensure complete combustion as shown in Fig.5(d).

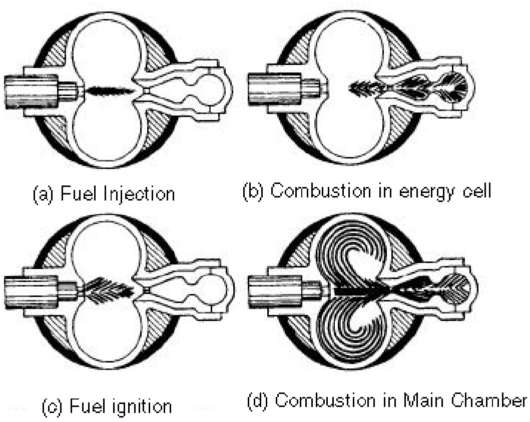

Fig.5 Different operations in Air cell combustion chamber

The two restricted opening of energy regulate the time and rate of eviction of the turbulence discharge from the energy cell into main chamber. Therefore, the rate of pressure rise on the piston is gradual, resulting into smooth engine operation.

The air cell combustion chamber ensures a clean and complete burning of charge in the cylinder. This system is very effective and provides better torque.

CI ENGINE COMBUSTION CHAMBERS ARE ALSO CLASSIFIED ACCORDING TO SWIRL IN COMBUSTION CHAMBERS. THESE ARE CLASSIFIED AS

(a) Low-swirl or quiescent engines, (b) Semi Swirl combustion Chamber, and (c) High-swirl combustion chamber

(a) Low-Swirl Or Quiescent Air

These are characterized by having a **shallow bowl** in the piston, a **large number of holes** in the injector and higher injection pressures. The air movement is almost quiescent and the mixing of the fuel and air is purely achieved by the intensity and distribution of the spray and atomizing fuel particles, therefore known as *quiescent open chambers*.

The main features of low-swirl or quiescent combustion chambers are

- They are suitable for large, slow and medium speed engines running up to 1500 rev/min.

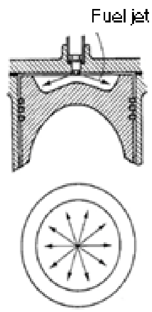

Fig.6 Shallow depth chamber with quiescent air

- There is sufficient time for the fuel to be injected into the cylinder and for it to be distributed and thoroughly mixed with the air charge so that combustion takes place over the most effective crank angle movement just before and after TDC, without induction swirl and compression squish.
- Further, they have very low ratio of surface area to volume, and no significant velocity of hot gases, therefore, heat loss from the engine is the least compared with all other semi-open or divide combustion chambers, thus its thermal efficiency is the highest.
- The injector is located in the center of a four valve cylinder head. The injector nozzle has 8 to 12 holes all equally spaced and pointing radially outwards so that they are directed towards the shallow wall of the combustion chamber as shown in Fig.6.
- Usually, open quiescent combustion chambers provide good cold starting and the lowest specific fuel consumption values relative to semi open and divided combustion chambers.

(b) Semi Swirl Combustion Chamber

It has a slightly offset bowl in the piston combustion chamber surrounded by a large annular squish zone formed between the piston crown and flat cylinder head. The combustion phenomenon in Semi Swirl combustion Chamber is discussed below with help of Fig.7.

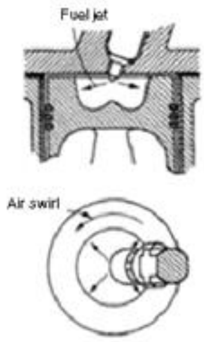

Fig.7 Semi swirl combustion chamber with multi hole nozzle

The induction of swirl in charge during induction, compression, injection, ignition and expansion in Semi swirl combustion chamber is illustrated with the help of Fig.8.

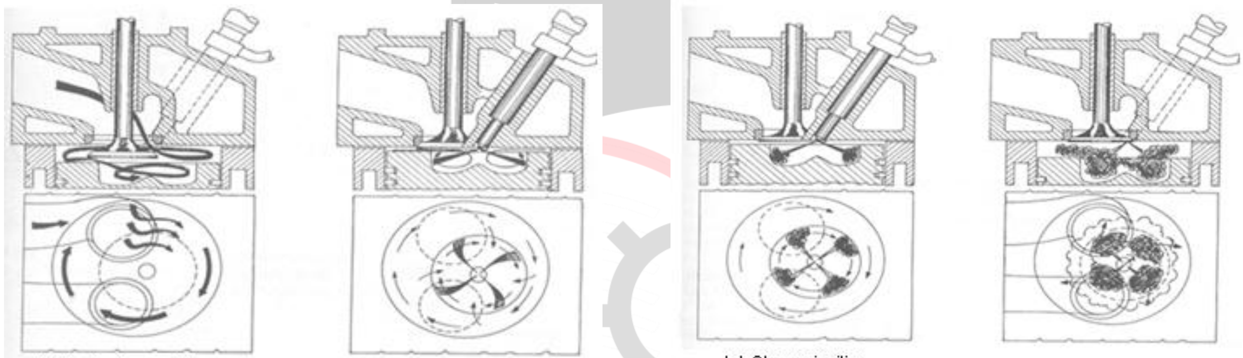
(a) Induction swirl (b) Compression and injection (c) Charge ignition (d) Burning and expansion

Fig.8. Semi swirl combustion chamber

- The incoming air enters in a tangentially in downward direction due to the valve port and seat being positioned to one side of the cylinder axis. Air is thus forced in spiral way down in the cylinder as shown in Fig.8(a).
- Towards the end of the compression stroke the bump-clearance between the flat annular piston crown and the cylinder head quickly decreases causing to squeeze the swirling air inwards towards the inner chamber bowl. The air stream from all sides of the annual squish zone flows radially inwards meeting at the center bottom of bowl from where it is then deflected radially outward. The upward moving air experiences inwardly moving compression squish which again pushes the air towards the center and down as shown in Fig.8(b).
- The fuel is injected radially outwards until it strikes the chamber wall. Some of this fuel bounces back off the wall while the remainder stays and spreads over the wall. The fuel jets first become finely atomized and then vaporized and heated to get its self ignition, causing ignition to occur as shown in Fig.8 (c).
- The nuclei of flames, established randomly around the fuel vapors, propagate rapidly towards the bulk of the mixture concentration near the chamber walls; the flames are then distributed and spread throughout the bowl due to the general air movement within the chamber as shown in Fig.8(d).
- During expansion stroke, the outward movement of the piston enables mixing of air and fuel efficiently by the combined effect of air swirl and reversed squish.

(c) High-swirl design chambers

The High-swirl design combustion chamber is a spherical cavity in the piston crown with a small secondary recess on one side, which aligns with the injector in the cylinder head to provide access for the fuel spray discharge as shown in Fig.9. The injector has a **low number of holes** and moderate injection pressures. It uses two valves in cylinder head with a high swirl or vortex type induction port with an inclined injector, which is located to one side of the cylinder axis.

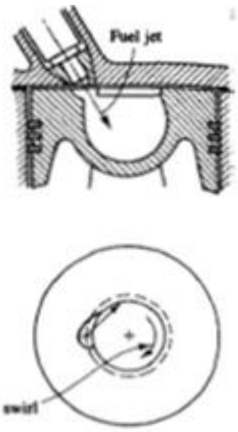

Fig.9 High Swirl combustion chamber

Salient features and formation of swirl of the combustion chambers are discussed below with the help of Fig.10.

- A high degree of swirl is generated in air within the curved induction port passage before it enters into the cylinder and then air is forced to rotate about the cylinder axis in a progressive spiral fashion as the piston moves away from the cylinder head on its induction stroke as shown in Fig. 10 (a).

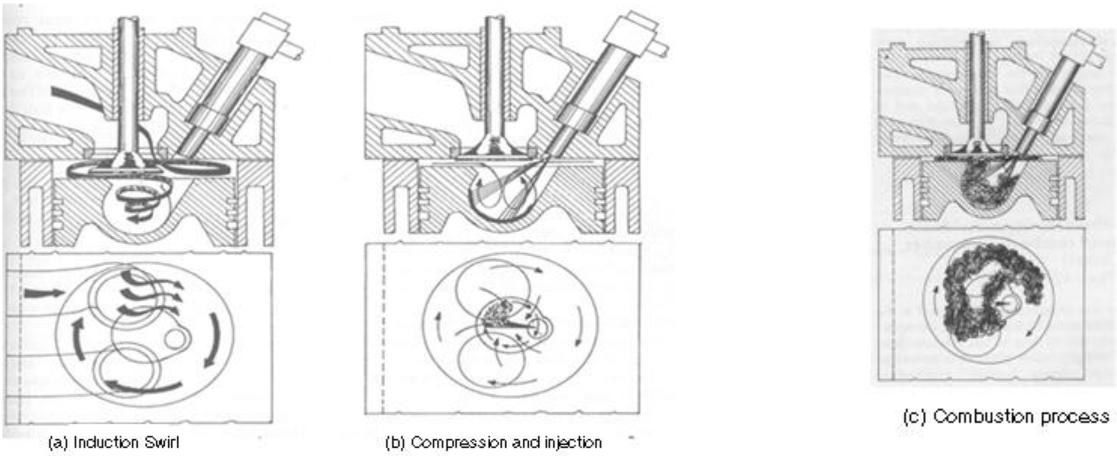

Fig.10 Semi open M Type DI Combustion chamber

- After the cylinder has been filled with air having a high intensity of swirl, the inlet valve closes and the air is compressed
- between the cylinder head and the inwardly moving piston crown.
- As the piston rapidly approaches TDC, air from the annular squish area surrounding the chamber recess is squeezed towards the center of the chamber; it is then forced downwards to follow the contour of the spherical chamber wall. The direction of air is changed from the annular squish area to the inner chamber causes the rotational movement of the air around the cylinder to be considerably increased as it moves into the much smaller spherical chamber.
- Near to end of the compression stroke, fuel is injected into the cylinder from two nozzle hole set at acute angles to the chamber walls so that after the spray penetrates the swirling air and reaches the cylinder wall, it is not reflected but spreads over the surface in the form of a thin film as shown in Fig.10.(b).
- 5 to 10% of the total quantity of fuel discharged per cycle burns in the spray stream near the injection nozzle with the minimum of delay. The vaporized fuel is carried away by the air stream and burns in the flame front spreading from the initial ignition zone to the center of the chamber. The energy released due to combustion, causes a rapid pressure rise and simultaneously an expansion of the burning charge as shown in Fig.10(c).

III. RELEVANCE WITH CURRENT PRACTICES

Presently most of the diesel engines used on automobiles are have better control due to electronically controlled operations. Engine manufacturing company like Hyundai, Honda, Volkswagen Group, Ford, Renault etc. are using CRDi, i-DTEC, TDi, duratorq which are way more efficient and clean due to improved combustion chamber design as one of the factors.

Even CI engines using bio-diesel focus on clean combustion and its chamber design for increase in efficiency for the eco-friendliness. The new i-DTEC clean diesel engine was introduced to the North American market in 2009 subsequently launched in Indian market as well.

The i-DTEC engines are known for reduced noxious exhaust emissions while boosting power and fuel efficiency. A combination of optimized combustion chamber design and reduced injection time results into a clean and quiet engine operation with excellent performance.

CONCLUSIONS

This paper gives an insight into the importance and effects of good combustion chamber design. There is a strong need of research and innovation in combustion chamber design with advent of new technologies in engine and fuel type innovations, this is crucial. Moreover, whatever is the type of fuel, the combustion will be always there with enormous heat libration through combustion of fuel only. Better combustion and reduced heat leakages give better thermal efficiency and excellent power generation. Hence study of combustion chamber is of prime importance and that too in CI engines because their applications are varied and widespread.

REFERENCES

[1] Rathore Mahesh M., Thermal Engineering, McGraw Hill Education, New Delhi, 2010.
[2] Heywood John B., Internal Combustion Engine Fundamentals, McGraw Hill, 1988.
[3] Ganesan V., Internal Combustion Engines, 4th ed., McGraw Hill Education, 2012.
[4] Campbell A. S., Thermodynamic Analysis of combustion enegines, John Wiley, New York 1979.

[5] Ferguson C. R. and Kirkpatrick A.T., Internal Combustion Engines Applied Thermosciences, 2nd ed. John Wiley & Sons Inc., 2004.

[6] Mehta P.S., Prediction of combustion chamber geometry effect in Direct injection diesel engines, Proceeding of XVIII National Conference on IC engines and Combustion, Combustion Institute (Indian Section), 2003.

[7] Moore C. H. and Hoehne T. L. , Combustion Chamber insulation effect on performance on low heat rejection Commins V-903, Engine, SAE Paper 860316, 1986.

[8] Flemming R.D. and Eccleston, Effect of fuel composition and equivalence ratio and mixture temperature on Exhaust emissions, SAE Paper, 710012, 1971.

[9] Ladommatos N. and Stone R., Conversion of diesel engine for gaseous fuel operation at high compression ratio, SAE Paper 760160, 1976.

