CFD ANALYSIS OF PISTON BOWL GEOMETRY FOR C.I. DIRECT INJECTION ENGINE

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Abstract - *This paper represents comparative study of CFD analysis performed on different piston bowl geometries on combustion and emission characteristics of a direct injection diesel engine. After studying various parameters affecting combustion in the combustion chamber, like piston bowl geometry, injection nozzle pressure, hole size, number of holes, size of holes, inclination of injection nozzle, intake manifold geometry out of these all parameters piston bowl geometry was selected for further investigation. The piston provided for a direct injection diesel engine which is having a bowl shape on upper surface of it. This surface is called inner surface of bowl, which includes a bowl shape and a dome like shape. This part defines the volume of air-fuel mixture to receive. The bowl shape or dome shape is targeted for spraying the air-fuel mixture from nozzle.*

For homogeneous mixing of air and fuel geometry of piston bowl plays an important role. Swirl in C.I. engine can be affected widely by varying the geometry of piston bowl. The experimental work performed on three different piston bowl geometries investigates the effect of piston bowl geometry on velocity of air its pressure and streamline path for air molecules inside the combustion chamber.

The piston bowl geometries subjected to the CFD analysis were designed using SOLIDWORKS software. The other parts necessary for performing the CFD analysis were also designed using the same software. The analysis was done by using ANSYS 15.0 software. After the comparative study of results obtained after CFD analysis further give an idea about the combustion in the C.I. direct injection engine.

Key Words: **CFD analysis, combustion chamber, efficiency, compression ratio, atomization, swirl.**

1. INTRODUCTION

Diesel engines are dominant over gasoline type engines in an automobile because of their higher efficiency. They are having a wide range of applications. The Diesel engine which was named after Rudolf Diesel is an internal combustion engine in which combustion takes place due to the mechanical compression of air inside the combustion chamber i.e. the adiabatic compression. By 1892 Diesel got the patent for what we call Diesel engine today. The air inside the combustion chamber is compressed with a compression ratio usually between 15:1 and 23:1. This high compression results in rise in temperature of air inside the combustion chamber. At the end of compression stroke just before reaching the TDC (top dead center) the fuel is injected directly into the compressed air in the combustion chamber. This could be into an empty space in the top of the piston. The fuel injector makes sure that the fuel is disintegrated into small droplets, and that the fuel is distributed evenly. This process is called atomization. The heat of the compressed air vaporizes fuel from the surface of the droplets. The mixture is then ignited by the heat from the compressed air in the combustion chamber, the droplets continue to vaporize from their surfaces and burn, getting smaller, until all the fuel in the droplets has been burnt. Combustion occurs at a substantially constant pressure during the initial part of the power stroke. The start of vaporization causes a delay before ignition and the characteristic diesel knocking sound as the vapor reaches ignition temperature and causes an abrupt increase in pressure above the piston. When combustion is complete the combustion gases expand as the piston descends further; the high pressure in the cylinder drives the piston downward, supplying power to the crankshaft.

In present there is huge number of vehicles running on this type of engine which requires fossil fuels to run it. The limited amount available of these fuels is a bigger challenge for the world. The amount of pollution due to such a large number of vehicles on the road is very high. This opens up a large scope for developments in C.I. engines in order to reduce fuel consumption and the emissions and also for better combustion of fuel.

To meet today's stringent emission norms with internal combustion engines the diesel engines are under continuous improvement and in all this the design of piston bowl performs a major role. The measures being taken to meet the legislative limits are broadly divided into two groups, namely, internal measures and external measures. Internal measures directly affect the engine-out pollutants, while external measures are concerned with the after-treatment of the exhaust gases. The geometry of piston bowl influences significantly the combustion in combustion chamber and thus it affects also the efficiency and emissions at exhaust of an engine. Thus, it represents important parameters for engine performance and the in-cylinder emission control strategy. Different piston bowl concepts have been proposed and implemented over the years for high speed direct injection diesel engines.

2. METHODOLOGY

The figure below represents the methodology used for successful completion of experiment and obtaining result from it.

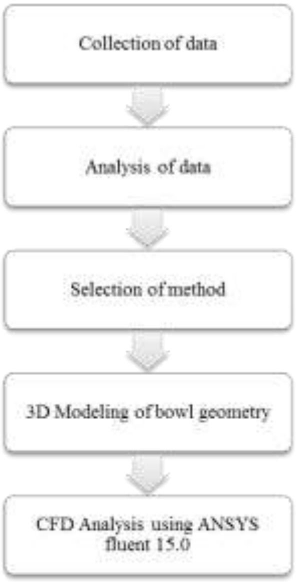

Fig -1: Methodology applied for 3D modeling and CFD analysis of piston bowl geometry

After analyzing and collecting data from various internet sources and websites related to emissions and their norms in different countries, CI direct injection engine was selected for study.

A number of research papers from various sources, international journals and patents were collected and studied which were regarding the emission reduction from vehicles running on Diesel fuel. Then these papers were sorted in two types; one contained all papers regarding the methods which can be implied at outside of engine in order to reduce emissions from vehicles while the second type included papers regarding the in-cylinder techniques used to reduce the emissions from vehicle.

The data collected from various sources involving techniques implied at inside the engine i.e. the in-cylinder methods are described below:

1] Effect of Injection pressure:

- Increase in IP leads to better atomization of fuel, improved spray characteristics and reduced physical delay period; which improved premixed combustion and rapid combustion rate. Owing to this, increase in brake thermal efficiency was observed [8].
- Too high IP may responsible to higher velocity of droplet which will pass away without mixing air properly and lower brake thermal efficiency due to improper combustion.
- With increase in injection pressure, not only the fuel droplet size decreases but also increases the momentum of the droplets.

- The fuel penetration distance become longer and the mixture formation of the fuel and air was improved when the combustion duration became shorter as the injection pressure became higher [13].

- But, if the injection pressure is too high ignition delay become shorter. So, possibilities of homogeneous mixing decrease and combustion efficiency falls down. Therefore, smoke is formed at exhaust of engine [14].

- When the injection pressure is increased fuel particle diameters will turn small. The mixing of fuel and air becomes better during ignition delay period which causes low smoke level and CO emission [8].

2] Effect of Nozzle holes:

- Rise in thermal efficiency with increase in nozzle hole was observed in a research [8] This was due to increase in nozzle hole was responsible to rise in air fuel mixing, fuel vaporization and improved combustion and heat release rate. Thus, in view of this BTE rises with number of holes.
- Higher NOx emissions were observed with increased number of holes.
- In addition, CO emission was found to be decreased with increase in nozzle hole and IPs.
- HC emissions are less which is due to improved atomization and proper combustion. Enhanced atomization will also lead to a lower ignition delay.
- Smoke opacity was found to be decreased with increase in nozzle hole and IPs.

3] Effect of Bowl geometry:

The piston bowl geometry in combustion chamber can be modified in such order to increase the swirl and proper mixing of air and fuel. Changing or modifying the piston bowl geometry can significantly affect the emissions out from a vehicle.

According to the research[1] on different types of bowl geometries following results were obtained:

- SCC has a higher peak pressure at low engine speed while OCC has a higher peak pressure from medium to high engine speeds.

- For SCC design, with the increase of engine speed at medium load condition, the combustion duration increases in terms of crank angle, but the peak HRR decreases.
- OCC presents a faster ascending of heat release under high engine speed condition CO is formed after TDC and gradually increases. After reaching a peak value, CO is oxidized quickly
- Poor mixing happens for SCC due to low magnitude of velocity vector at high engine speed, thereby generating high CO emission. In contrast, the squish of OCC at high engine speed is more significant which dominates the negative effect of increased heat loss, thus the CO emission is relatively lower in comparison with the other two bowl geometries.

Selection of method:

After analyzing all the data collected considering the feasibility and all the merits and demerits of existing methods to reduce pollution from CI direct injection engine, it was found that changing or modifying the piston bowl geometry can significantly affect the emissions out from engine.

The piston bowl geometry referred for analysis for direct injection C.I. engine was designed by Aaron Karch [6] and his colleagues in the year 2013. The piston bowl geometry was shaped to balance combustion efficiency and exhaust properties. This was toroidal shaped piston bowl geometry.

The modified piston was designed by using SOLIDWORKS software.

Modeling and analysis:

The piston and the required components such as cylinder, manifolds and cylinder head for the assembly were designed using SOLIDWORKS software.

Toroidal piston bowl geometry was selected for CFD analysis.

The modified toroidal piston bowl, flat piston bowl and the basic toroidal shaped piston bowl were designed in this software which further subjected to CFD analysis in ANSYS Fluent 15.0.

3. MODELING

3.1 Piston:

The toroidal shaped piston constructed in SOLIDWORKS is shown in Fig -1.

Material - 2618 T61 (SS)

Dimensions- D= 85.996 mm

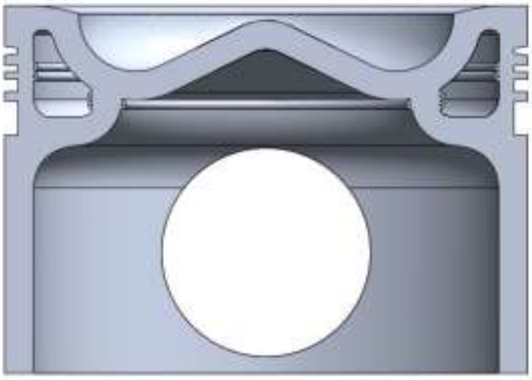

Fig -2: Toroidal shaped piston bowl

3.2 Assembly:

The assembly consisting of cylinder, cylinder head, inlet and outlet manifold, piston was constructed by using SOLIDWORKS.

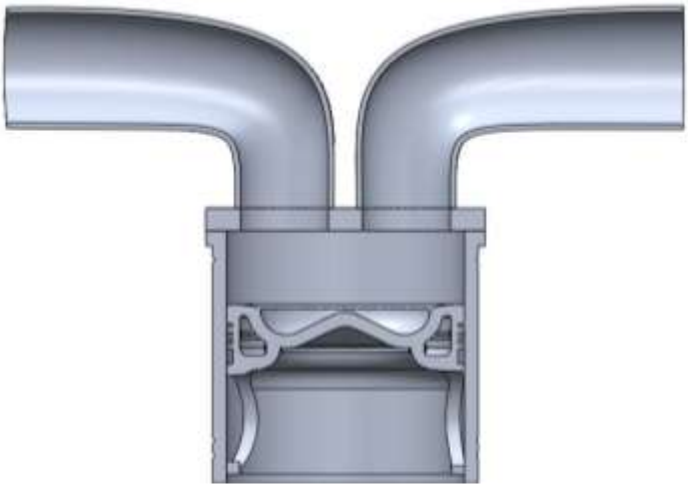

Fig -3: Cross section of piston-cylinder assembly

4. CFD ANALYSIS

- The CFD Analysis part was completed by using ANSYS v15.0

3 different piston bowl geometries were subjected to CFD analysis

1) Flat Piston Bowl geometry.
2) Toroidal shaped geometry.
3) Modified toroidal shaped geometry.

The standard boundary conditions were taken for C.I. engine and were kept constant for all the 3 geometries.

- Boundary conditions:
  1) Inlet velocity = 30m/s
  2) Inlet pressure = 1 bar
  3) Inlet temperature = 30^{o} C

4) Mass flow rate = 12 kg/s

Analysis for pressure and velocity was done keeping temperature as ambient.

Meshing:

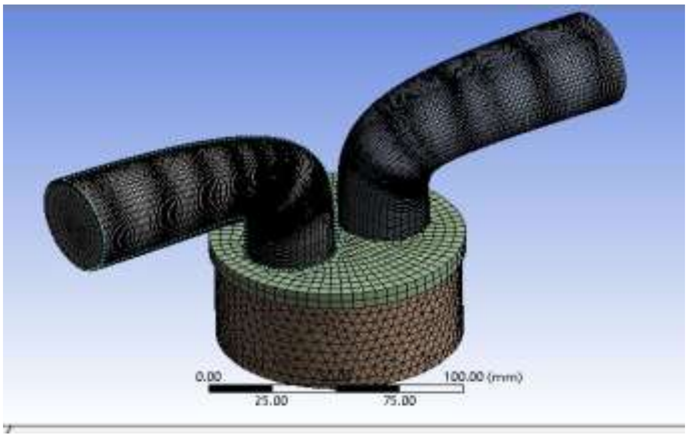

Fig -4: Meshing

- **Analysis for flat piston:**

Streamline path:

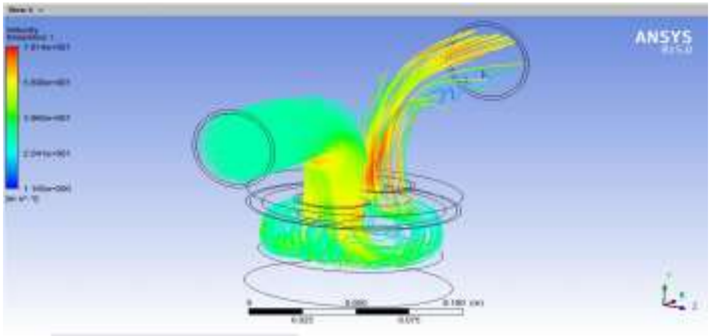

Fig -5: Streamline path of air

Pressure distribution:

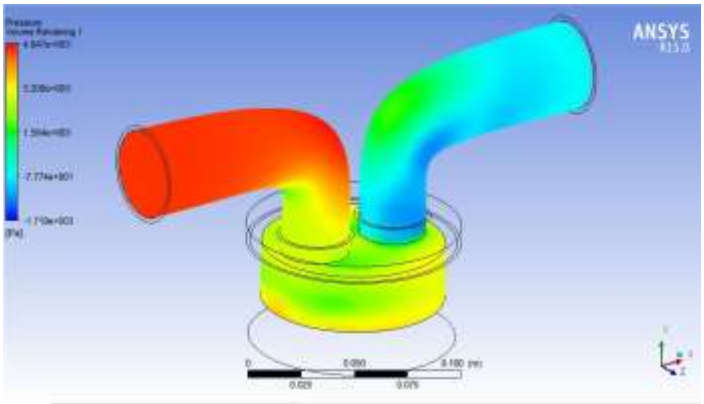

Fig -6: Pressure Volume Rendering

Velocity distribution:

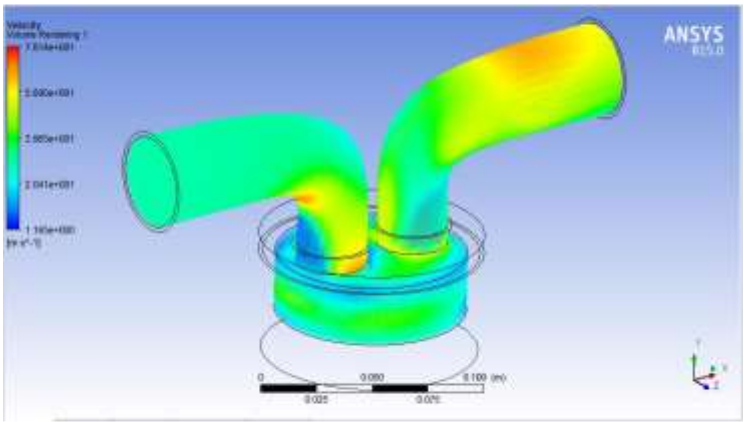

Fig -7: Velocity Volume Rendering

- **Analysis for toroidal shaped piston:**

Streamline path:

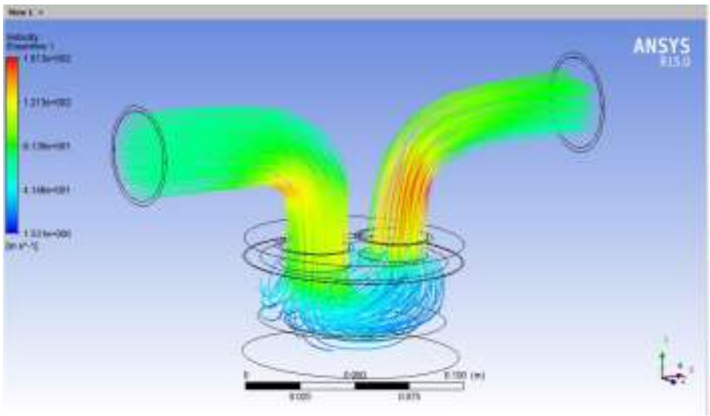

Fig -8: Streamline path

Pressure distribution:

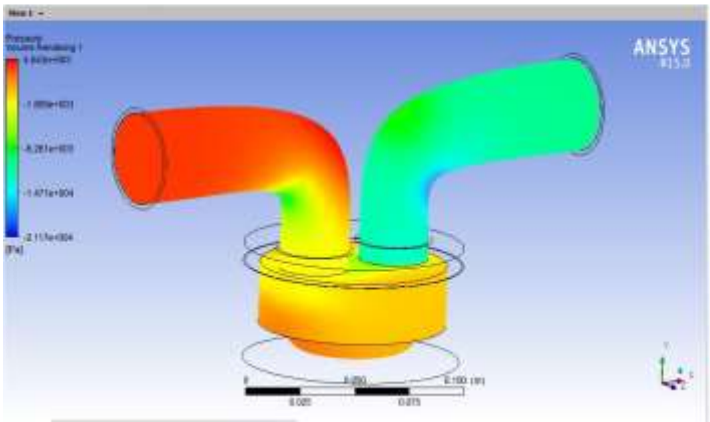

Fig -9: Pressure Volume Rendering

Velocity distribution:

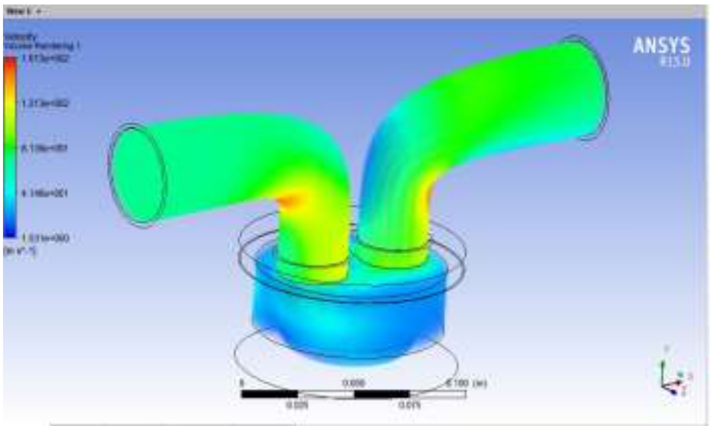

Fig -10: Velocity Volume Rendering

- **Analysis of modified toroidal shaped piston:**

Streamline path:

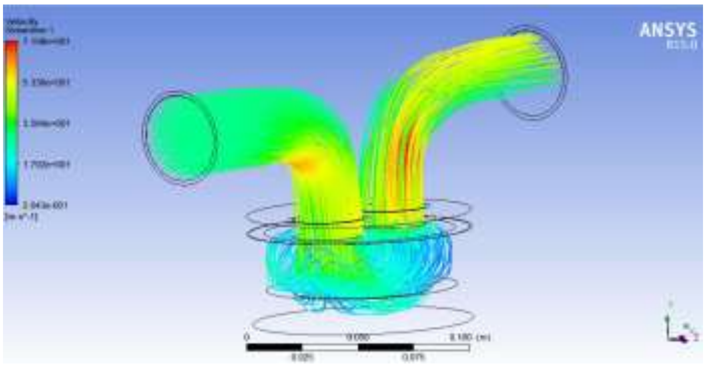

Fig -11: Velocity Streamline

Pressure distribution:

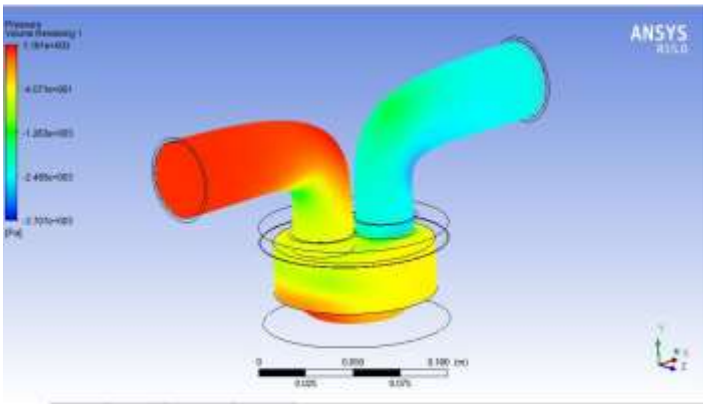

Fig -12: Pressure Volume Rendering

Velocity distribution:

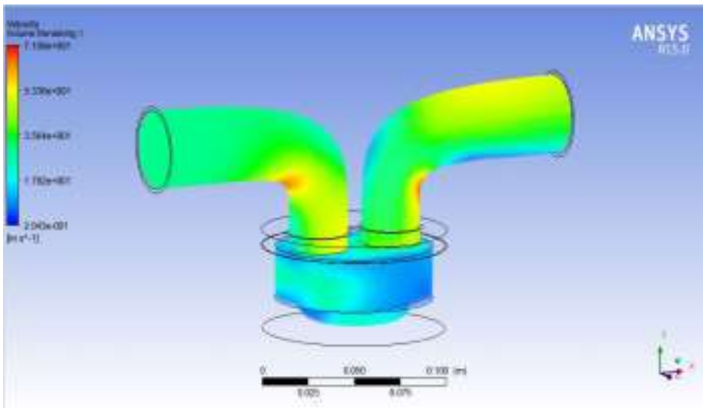

Fig -13: Velocity Volume Rendering

5. OBSERVATIONS

Following observations were made after analyzing the results of CFD analysis of flat, toroidal and modified toroidal piston bowl geometry.

The observations were found by referring **figure 5**, **figure 6**, **and figure 7** for flat piston bowl. For toroidal from **figure 8**, **figure 9**, **figure 10** and for modified toroidal shape from **figure 11**, **figure 12**, **figure 13**.

In analysis of flat piston it was observed that air molecules were not distributed properly, pressure distribution was uneven and velocity distribution was also uneven. For toroidal piston air molecules distribution and swirl was uniform, pressure distribution was more uniform as compared to flat bowl and velocity distribution was uniform but velocity of air molecules was found low. In case of modified piston, air molecules distribution and swirl production was enhanced pressure distribution was enhanced, velocity distribution is more uniform and velocity of air molecules inside the cylinder was also increased.

6. CONCLUSION

Hence from 3D Modeling using SOLIDWORKS and the results of CFD analysis from ANSYS of the piston bowl geometry, it was concluded that in order to achieve proper combustion to increase power output, the swirl formation can be enhanced by modifying piston bowl geometry. After subjecting different piston bowl geometries to CFD analysis is was found that flat piston bowl geometry does not provide proper uniform distribution of air-fuel mixture in chamber because of poor velocity distribution of air inside the combustion chamber and and hence swirl formation which could be eliminated by the use of toroidal shaped piston bowl. The further modifications in piston bowl geometry leads to better distribution of air and thus by enhancing swirl formation so that the velocity of air molecules in the cylinder could help to achieve better combustion and thus the power output might increase for a direct injection C.I. engine.

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