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Design and Fabrication of High Pressure Diesel Spray Chamber

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Abstract: The Objective of this work is to describe the design of a high pressure spray chamber with pre-combustion technique to stimulate the mixture formation and combustion process via optical access. The engineering design criteria of the high pressure spray chamber are considered to ensure the mixture condition of typical CI engines with a compression ratio (CR) of 16-28. The material used to fabricate the high pressure spray chamber is Cast Iron (CI) and two optical glass fitted perpendicular to each other to capture the spray image inside chamber by using high speed camera. The analysis focused on spray characteristic on spray pattern and spray area. The analysis of both spray characteristic and strength of structure is considered for maximum peak pressure inside combustion chamber for real engine. Such that pressure inside the chamber varies up to calculated peak pressure it shows the formation of spray pattern under various pressure stages. The spray characteristics of the fuel greatly influence emissions form diesel engines. Spray development plays a vital role in improving the combustion and emission characteristics of fuel because it directly affects the air fuel mixture. The spray characteristic of fuel mainly depends on fuel injection pressure, fuel density, fuel viscosity, ambient pressure and temperature.

Key words: Injection pump · Optical window · Diesel injector · High pressure chamber · Digital camera

INTRODUCTION

Mechanical engineering design is defined as the use of scientific principles, technical information and imagination in the description of a machine or a mechanical system to perform specific functions with maximum economy and efficiency. The designer is knowledge of the basic and engineering sciences, such as mathematics, physics, statics and dynamics, thermodynamics and heat transfer, vibrations and fluid mechanics reported by Bandari *et al*. [1]. In the compression ignition engines, liquid fuel is injected in the cylinder close to the end of compression stroke in the hot, compressed air. The fuel injection consists of one or several high velocity fuel jets injected at high pressure through small orifices in the injector nozzle, which penetrate far into combustion chamber. The field is injected either directly in the combustion chamber contained in a bowl in the piston crown (direct injection or open chamber engines, DI) or in a small combustion chamber contained in the cylinder head which is attached to the main chamber in the cylinder. The combustion in compression ignition engines is quite different than in the premixed charge SI engines. In the conventional SI engines a homogenous mixture is burnt by flame propagating from a positive source of ignition while in the compression ignition engines, a heterogeneous mixture exist in the cylinder and combustion is initiated by self-ignition of fuel that may occur simultaneously at several locations in the combustion chamber. The various processes involved in mixture formation and combustion in diesel engines. The injected fuel is atomized into small droplets that evaporate and mix with air. As the air temperature is higher than the self-ignition temperature of the fuel, the fuel spontaneously ignites after delay of 5 to 10 degrees of crank angle. A large region of the combustion chamber may be inflamed quite early during combustion. The fuel especially at high engine loads, is atomization, vaporization and mixing with air forming combustible mixture. These process in the fuel injected after combustion had begun occur concurrently with the combustion already under progress. Fuel injection process plays a critical role in fuel-air mixing and combustion in CI engines. The diesel

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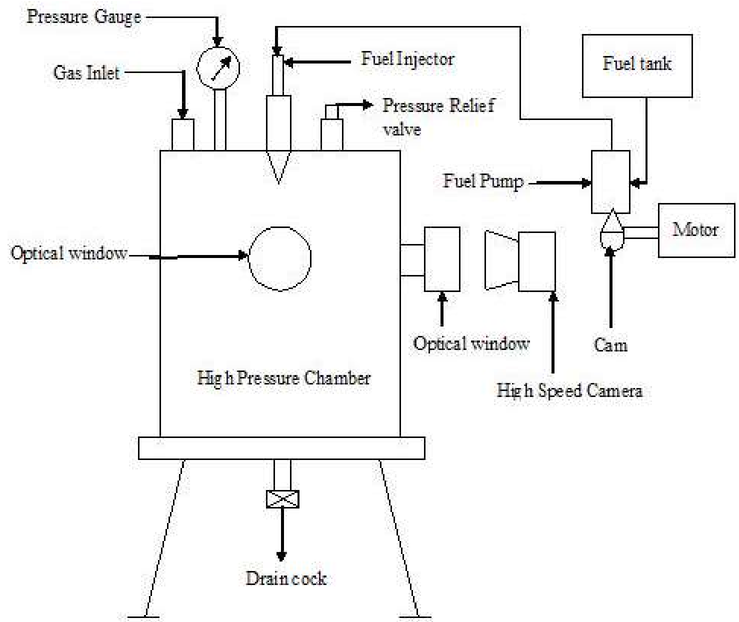

Fig. 1: Schematic Diagram of High Pressure Spray Chamber

engine combustion in fact, is three dimensional in nature and is more complex than the combustion in premixed SI engines. The combustion occurs in heterogeneous air-fuel mixture with local fuel-air ration varying very widely from nearly zero to infinity. Combustion in fuel-rich pockets results in soot formation and appearance of black smoke in the exhaust a characteristic of compression ignition diesel engines. To limit smoke emission, the overall fuel-air ratio at full engine load is kept nearly 30% leaner than stoichiometric which result in lower mean effective pressure Haywood *et al*. [2]. From the environmental concerns due to increased oil consumption, comes a solution for the development of CI engines which are used as alternative, oxygenated fuels. However, there is need of a fundamental study of mixture formation and spray combustion process as fuel change. Macroscopic spray characteristics such as spray penetration, spray cone angle and droplet size distribution are critical parameters that influence the in-cylinder air/fuel mixture and combustion process of the internal combustion engine. The spray performance is influenced by a large number of parameters including the fuel pressure, fuel temperature, ambient pressure, ambient temperature, fuel properties and nozzle geometry. For a direct injection diesel engine, the atomization performance of its fuel is very important because of its close relationship with the engine efficiency and pollutants emissions. In practical application, the combustion efficiency is strongly influenced by the fuel vaporization rate and the vaporization characteristics which are heavily dominated by the fuel spray atomization since the total surface area becomes large and interacts actively with ambient gas Pundir *et al*. [3]. Engines with optical access to the combustion chamber are being used for study of in-cylinder flow, mixture preparation, flame propagation, combustion and pollutant formation studies. The transparent windows at the strategic locations on the cylinder to investigate the most significant events taking place inside the cylinder. Optical access for full length of stroke using annular transparent windows or entire cylinder made of transparent material. This approach has been mostly used in non-firing tests for flow studied Bowditch *et al*. [4]. The material of the cylinder is brittle, such as cast iron or cast steel, Lame's equation is used to determine the wall thickness. It is based on the maximum principle stress theory of failure, where maximum principle stress is equated to permissible stress of the material is discussed by Ugural *et al*. [5].

Experimental Setup: In this study experiment fuel is supplied from the fuel tank to fuel injector using a simple mechanical fuel pump. Fuel injector is actuated by cam driven by a motor. Fig. 1 shows the schematic Diagram of high pressure spray chamber. Single whole nozzle is used to spray the diesel. The macroscopic characteristics such as spray cone angle and spray penetration under various pressure condition can be measured from the images captured by high speed digital camera.

Fig. 2: Photographic view of High Pressure Spray Chamber

Two optical glasses fitted in a chamber which is perpendicular to each other to make the inside observable. Pressure inside the chamber was varied by sending compressed gas to the chamber and to measure the pressure inside the chamber using pressure gauge. To exceed the pressure to set value is maintained by relief valve and injected fuel is drain through drain cock [6-10].

Design Calculation: With reference to Kirloskar single cylinder air cooled diesel engine coupled with alternator. The following calculations are obtained

Peak pressure calculation:

Compression ratio = 17.5 = V_T/V_c

Swept volume = 661.5 cc

Atmospheric pressure (P_1) = 1.03 bar

Reversible adiabatic compression process: 1-2

$(P_1V_1)^{1.4} = (P_2V_2)^{1.4}$

$P_2 = (V_1/V_2)^{1.4} * P_1$

$P_2 = (\text{Compression ratio})^{1.4} * 1.03$

$P_2 = (17.5)^{1.4} * 1.03$

$P_2 = 56.63$ bar

Constant pressure heat supplied: 2-3

$P_2 = P_3 = 56.63$ bar

Chamber calculation:

Assume Pressure $P_2 = P_3 \rightarrow P = 60 \text{ bar} = 6 \text{N/mm}^2$

Tensile stress for Mild steel, $\sigma_t = 350 \text{ N/mm}^2$

Inner diameter, $d_1 = 87.5$mm

Factor of safety = 10 (Assumption)

Using Thick wall Theory of Cylinder:

At $x = r_1 = 43.75$ mm, $P_X = 6 \text{ N/mm}^2$

At $x = r_2 = ?$

$P_X = (b/x^2) - a$

$\sigma = (b/x^2) + a$

Where,

a and b are constants.

$6 = \{b/(43.75)^2\} - a$

$35 = \{b/(43.75)^2\} + a$

$2b/(43.75)^2 = 41$

$b = 39238.28$

$a = 14.5$

At $x = r_2$, $P_X = 0$

$0 = (39238.28/r_2^2) - 14.5$

$r_2 = 52.02$ mm

= 52.5 mm (say)

Thickness of the cylinder, $t = r_2 - r_1$

= 52.5 – 43.75

t = 8.5 mm

Design of Cover Plate:

The thickness of the cover plate is fixed at the ends is given by,

$t_1 = d * \{\sqrt{[(k*p)]/(\sigma_t)]}\}$

k = 0.162 (assume)

$t_1 = 87.5 * \{\sqrt{[(0.162*6)]/(35)]}\}$

$t_1 = 15$ mm

For safety purpose we consider the thickness of the cover plate as 20mm

CONCLUSION

In design, geometric dimensions of the component are calculated by means of analysis of stresses. Elementary equations are used to determine the stress when the component has simple geometric shapes and pressure cylinders. A number of techniques over the years have been used for combustion and flame visualization in IC engines. These studies have resulted in better understanding of flow field, spray structure, penetration, drop size distribution are being studied by LDA, LIF, PIV and LSD. Quantitative data on fuel droplet break-up, droplet velocities, sizes, spray-flow interaction, mixture distribution in the diesel and gasoline direct injection engine cylinders are available. It has resulted into in-depth understanding of fuel-air mixing and combustion process and multi-dimensional mathematical models describing these processes have been validated. These inputs have been used for development of better fuel injection, air motion generation and combustion systems. Measurements of combustion processes and pollutants using high speed combustion photograph. Spray structure and liquid drops can be directly observed with the aid of a back illumination source. The sensitivity of the direct photography to measure fuel vapor concentration, liquid droplet concentration and droplet sizing. It is not affected by presence of oxygen and hence can be applied to conditions that are more realistic. LEA provides line-of-sight measurement along the laser beam. Tomographic techniques are required to obtain spatially resolved measurements of fuel droplets.

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