A review on Theoretical Analysis of Spray Bowl Interaction

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Abstract— A present paper represents a review of theoretical and numerical analysis of spray bowl interaction done. The main focus of this paper is review the work related to spray bowl interaction and effect of bowl geometry on engine performance and emissions. Several parameters such as injection and ambient pressure, ambient air density, nozzle configuration and the cross flow velocity affect the fuel spray behaviour in the combustion chamber. It is observed that the deflection of the spray due to swirl increases with increase in pressure and swirl ratio. Isothermal spray penetration length is the function of injection pressure as well as nozzle diameter. Spray tip penetration increases with increase in these two parameters.

Index Terms— Spray wall interaction, spray penetration length, swirl.

I. INTRODUCTION

The direct injection diesel engines have been used largely as prime movers for heavy-duty vehicles. With the increasingly stringent regulations on emissions from diesel engines and continual pursuit for more efficient engines, a better understanding of the combustion process in a diesel engine is necessary in order to optimize further the engine performance and emissions. The mixture formation is controlled by the characteristics of the injection system, the nature of air swirl, the turbulence in cylinder, and the spray characterization. To achieve a better combustion with less pollutant emissions, it is necessary to achieve a good spatial distribution of the injected fuel throughout the entire combustion space. This requires matching the fuel sprays with combustion chamber geometry to effectively make use of the gas flows. In other words, matching the combustion chamber geometry, fuel injection, and gas flows is the most crucial factor for attaining a better combustion.

II. LITERATURE REVIEW

Abaniet. al. [1] develops a model to predict spray tip penetration for time varying injection profiles. A new model to predict spray-tip penetration for a time-varying injection profile has been formulated based on gasjettheory. The approach involves using an effective injection velocity for the spray tip based on a representative spray response time. It is assumed that the instantaneous injection velocity affects the spray tip with an exponential response function and that the response time is the particle residence time, consistent with the theory of translation of jet vortex rings from Helmholtz’s vortex motion analysis. The results are also compared with numerical results from a CFD code that has been calibrated for spray simulations.

A.De Risi et. al. [2] perform a theoretical study on the effects of combustion chamber geometry and engine speed on soot and NOx emissions. The objective of their investigation is to assess the influence of the combustion chambers geometry and engine speed on the velocity flow fields, temperature distribution and NOx and soot emissions mechanism of formation. The investigation has been carried out both experimentally and by numerical simulations. A modified version of the computational fluid dynamics (CFD) Code KIVA-3V has been used for modelling combustion process and engine emission.

A. Lotfiani, Sh. Khalilarya [3] develops a mathematical model of an impinging spray due to the swirling air. The paper presents a mathematical model of an isothermal impinging spray deflected in swirling flow field. Pressure forces cause the fuel spray to deflect.

A.S. Kuleshov[4] studied multi-zone DI diesel spray combustion model for thermodynamic simulation of engine with PCCI and high EGR level. A multi-zone, direct-injection (DI) diesel combustion model, the so-called RK-model, has been developed and implemented in a full cycle simulation of a turbocharged engine.

S. Pasupathyet. al.[10] studied Effects of the Re-Entrant Bowl Geometry on a DI Turbocharged Diesel Engine Performance and Emissions using a CFD approach. The purpose of their study is to investigate the influence of re-entrant bowl geometry on both engine performance and combustion efficiency in a direct injection (DI), turbocharged diesel engine for heavy-duty applications. Based on the idea of enhancing diffusion combustion at the later stage of the combustion period, three different bowl geometries, namely, bowl 1 (baseline), bowl 2, and bowl 3 were selected and investigated. The simulation results show that, bowl 3 enhance the turbulence and hence results in better air-fuel mixing among all three bowls in a DI diesel engine.

In this assessment of spray deflection, an approximate method is introduced in which the density of the spray,
the density of the air and the velocity of the cross flow deflecting the fuel spray are assumed to be constant.

Parametric studying of the model shows the effects of the key parameters such as fuel injection pressure, ambient air pressure, ambient air density and the cross flow velocity on the spray development.

III. FACTORS AFFECTING SPRAY WALL INTERACTION

Spray-wall interactions occur if a spray penetrating into a gaseous atmosphere impacts the combustion chamber wall in case of a direct injection engine.

Two main physical processes can be involved: wall-spray development and wall film evolution.

![Fig.1 Spray wall interaction](image)

The above figure shows the spray wall interaction for conventional and re-entrant type of combustion chambers. Hence it is important to study the factors affecting spray wall interaction. Following are some factors which affect the spray wall interaction which are found out from the literature:

**Bowl geometry:**

The shape of the bowl-in-piston is a key parameter controlling the air motion and mixing fuel with air effectively leading to better combustion. Depending on the intake port induced swirl, air swirl can be increased or decreased by changing bowl shape parameter. Piston-bowl configuration provides a compression induced squish motion with consequent formation of a torroidal vortex occupying the whole bowl space.

![Fig. 1 Re-entrant combustion chamber](image)

Now-a-days re-entrant type combustion chamber is widely used in commercial applications. Re-entrant combustion chambers are different from other open combustion chamber. The wall of combustion chamber has a re-entrant angle. Due to this angle re-entrant combustion chamber provides good emission control. The re-entrant combustion chamber has been widely used in high-speed direct injection HSDI diesel engines. Re-entrant combustion chambers are found to be better in swirl and turbulence intensification near top dead center (TDC) of compression, which is better in reducing of soot and particulate matter. Many researchers have investigated the effect of different parameters and regions of the combustion chamber such as bowl lip shape, toroidal radius, and throat diameter.

IV. RESULTS AND DISCUSSION

Results of the authors are discussed on the three main parameters viz. spray penetration length, spray impingement angle and effect of swirl on spray distribution.

**Spray penetration length:**

Spray penetration length is the another important parameter which has great influence on the spray wall interaction. The spray penetration length (S) is defined as the total distance covered by the spray in a control volume, and it’s determined by the equilibrium of two factors, first the momentum quantity with which the fluid is injected and second, the resistance offered by the idle fluid presents in the control volume, normally a gas. Dent J. C. gave the following relation for calculation of spray penetration length [7]

$$S(t) = 3.07 \left( \frac{\Delta P}{\rho_a} \right)^{0.25} \left( \frac{T_a}{294} \right)^{0.25} \sqrt{d_0 t}$$

Where, $S(t)$ is the penetration length

$\Delta P$ is the pressure difference across the nozzle

$\rho_a$ is the gas density

$T_a$ is gas temperature

$d_0$ is the diameter of nozzle

Many researchers have studied the effects of various parameters on spray penetration length.

Injection pressure and nozzle diameter are the most important parameter which affect the spray penetration. Effect of these two parameters on spray penetration is discussed in many literature.

A.S. Kuleshov also discussed the effect of injection pressure and nozzle diameter is the following figures.
Fig. 3 Effect of injection pressure

Fig. 3 shows the variation in spray penetration length due to change in pressure.

It can be seen from the graph that at the same crank angle degree spray penetration for the 1100 bar pressure is highest and the same for the 300 bar pressure is lowest. Thus spray penetration length is function of nozzle diameter. Figure shows that as the injection pressure increases the spray penetration also increases.

Fig. 4 Effect of nozzle diameter

The above fig. shows the effect of nozzle diameter on spray penetration. Spray penetration for three nozzle diameters is calculated viz. 0.11 mm, 0.19 mm and 0.27 mm respectively. It can be seen from the graph that at the same crank angle degree spray penetration for the 0.27mm diameter is highest and the same for the 0.11mm diameter is lowest. Thus spray penetration length is function of nozzle diameter. Figure shows that as the nozzle diameter increases the spray penetration also increases.

Influence of different spray bowl impingement angles on spray wall interaction:

The angle made by spray to the walls of combustion chamber is an important factor which affects the spray wall interaction. Takuya Kitasei et. Al. done the detailed study of influence of the different fuel spray wall impingement angles on smoke emission in a DI-diesel engine. Their study focuses on the two type of impingement angles viz. orthogonal impingement and diagonal impingement.

Fig. 4 Schematic diagram of present two wall impingement angles

If the angle of impingement is less than 90 degree it is called as diagonal impingement and if the angle is 90 degree it is called as orthogonal impingement. Authors discussed the effect of these two angles by CFD simulation.
Effect of swirl on spray deflection and distribution:

Swirl is the motion of air about a vertical axis in the engine cylinder. Swirl is important for better mixture formation and complete combustion of fuel. A. Lotfiani, Sh. Khalilarya develops a mathematical model of an impinging spray due to the swirling air. The paper presents a mathematical model of an isothermal impinging spray deflected in swirling flow field. Pressure forces cause the fuel spray to deflect. In this assessment of spray deflection, an approximate method is introduced in which the density of the spray, the density of the air and the velocity of the cross flow deflecting the fuel spray are assumed to be constant. Parametric studying of the model shows the effects of the key parameters such as fuel injection pressure, ambient air pressure, ambient air density and the cross flow velocity on the spray development. The mathematical model developed by the authors helps to predict the deflection of spray in the swirling air.

V. SUMMARY

The impingement angle of fuel in the combustion chamber has a significant influence on the soot formation in the engine.

Several parameters such as injection and ambient pressure, ambient air density, nozzle configuration and the cross flow velocity affect the fuel spray behaviour in the combustion chamber.

It is observed from the calculations that the deflection of the spray due to swirl increases with increase in pressure and swirl ratio.

Isothermal spray penetration length is the function of injection pressure as well as nozzle diameter. Spray tip penetration increases with increase in these two parameters.

This mathematical model gives the spray deflection and distribution results which are helpful in bowl geometry selection.

This mathematical model gives the result in less time so it reduces development time as well as cost as it can be predicted without actual engine testing.

REFERENCES


[8] Gao, D Jiang, Z Huang, and X Wang, Experimental and numerical study of high pressure swirl injector sprays in DI gasoline engines, 10.1243/095765005X31333


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