Cfd Analysis of Cavitation in Diesel Engine Fuel Injector Nozzle

[1]Sachin Vasoya, [2]Vidt Patel, [3]Anup Chaudhari
[1]Student, [2]Student, [3]Assistant Professor
[1]Mechanical Engineering
[1]PIET, Parul University, Vadodara, India

Abstract: From past several time, there has been gradually increase the demand of automobile vehicle for transportation purpose, it is due to increases the population of world day by day. The basic requirement of people is to get more power and less pollution. It will be achieve by proper combustion of fuel inside the combustion chamber and further combustion of fuel will be achieve by proper fuel spray behavior. Fuel spray directly related to cavitation. Cavitation is depends on the geometry of nozzle, fuel properties, inlet and outlet condition of injection nozzle. Effort will be made to understand this phenomena and its effect on fuel injector nozzle. Present study focus on qualitative and quantitative comparison of Cfd model.

***Index Terms* – Cavitation, Vapour Pressure, Nozzle, Fuel Injector, Fuel spray, Saturation Pressure**

I. INTRODUCTION

Over the past decades, there has been a massive increase in the requirement of automobile vehicles for the purpose of public transport. The reason behind such increasing demand is attributed to the increase in world population. At the same time, there is a flowing need for better environment protection and air quality which poses a stiff challenge for engineers to design vehicles with higher power output yet better fuel economy and less pollutant formation. Direct injection (DI) diesel engine has become an important area of research as it achieves higher compression ratio compared to conventional spark ignition engine and thus it serves the purpose of better fuel economy and better thermal efficiency.

The diesel fuel injector is integral part of the diesel engine as it injects the fuel into the compressed air in the combustion chamber. It is also responsible for the fuel atomization, which for engines running by the diesel principle has a major influence on the combustion process and directly effects the power outlet, fuel consumption and emissions.

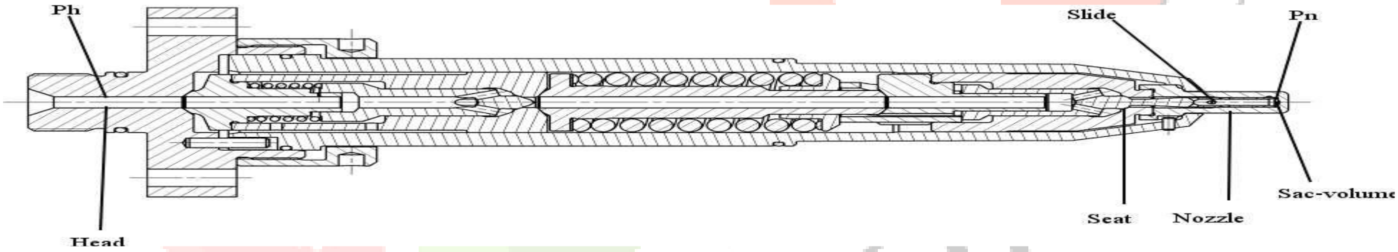


Figure 1.1 SAC-type Diesel fuel injector

Figure 1.1 show a SAC type fuel injector atomizer as the one mounted on MAN Diesel & Turbo engines. Fuel is delivered to the nozzle from a supply pump with supply pressure at approximately 800 bars in the point marked "Head" on the left hand side of figure 1.1. Further downstream there is a valve that opens at 350 bars giving the fuel a reasonable way through the sac volume and comes out from the nozzle holes.

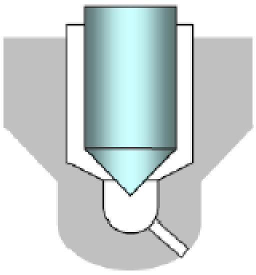


Figure 1.2 Principle sketch of sac volume and needle

Figure 1.2 shows the nozzle and demonstrates the needle, sac volume and nozzle hole. The objective of this project is to scrutinize the flow field in this region of the atomizer, where cavitation is mostly occur.

Cavitation is commonly known as the process of formation of vapor droplets in a liquid created by a sudden drop in the local pressure below the saturation pressure for the liquid. When the local tension ($p_v – p$) exceeds the tensile strength of the liquid ($p_v - p_{cr}$) the fluid surface rupture and yields a small void which serves as a nuclei for the phase transition process.

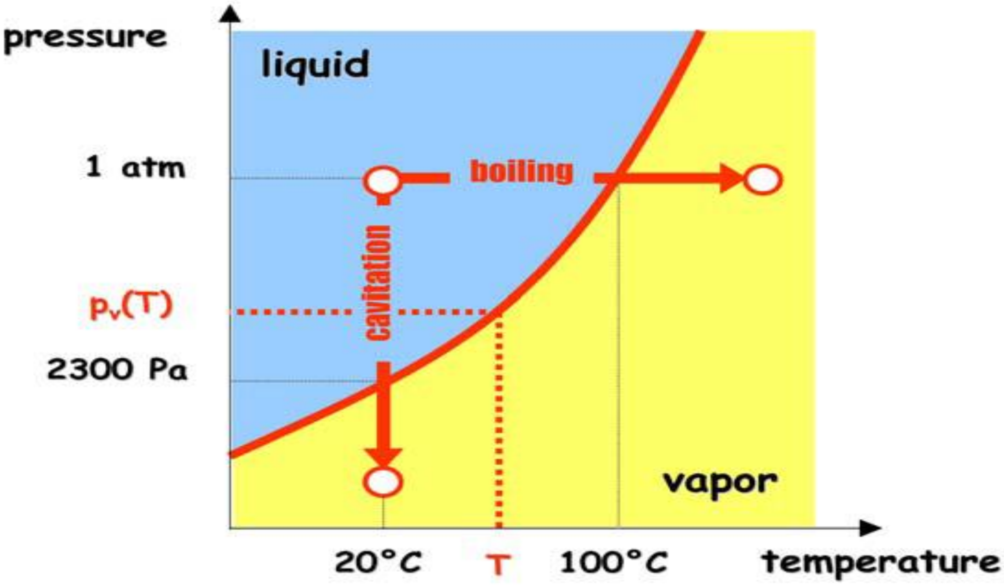


Figure 1.3 Schematic diagram of phase change for water

Since the density of vapor phase is assumed much smaller than the liquid phase the amount of heat consumed locally for the evaporation is negligible the process can be assumed isothermal. This is illustrated in figure 1.3 which shows a schematic diagram of the phase change of water. It shows the cavitation and boiling share the same phase changes and the physical pheno-menon is completely different. For boiling the driving phenomenon is a baro-tropic change in temperature, while cavitation is promoted by a isothermal change in pressure.

Cavitation is occurred in many mechanical applications, like hydro dynamical systems, turbo pumps, on the trailing edge of a propeller-shaft and inside the diesel injector nozzles. Cavitation in the all these examples are the result of a sudden change in the velocity due to changes in the injector nozzle geometry. This is understood by use of the Bernoulli equation:

$$P + \frac{1}{2}\rho V^2 = constant \qquad \text{(i)}$$

The Bernoulli equation gives the relation between the static and dynamic pressure.

II. LITERATURE REVIEW

Since aim of present study is to capture cavitation phenomena in diesel engine fuel injector nozzle, which is in the range of 150µm. Fuel injection process is very high speed phenomena which deals with very high injection pressure (1000-1800 bar). Due to extreme parametric condition it is very difficult to capture cavitation inside diesel engine fuel injector. Only few research is available with real size nozzle geometry & high injection pressure.

Winklhofer et al initiate experiment study with realistic condition of fuel injector and developed optical method to capture cavitation. Study reported extensive analysis of the structure of cavitation flow in Diesel injector-like geometries (transparent nozzle of rectangular cross-section).

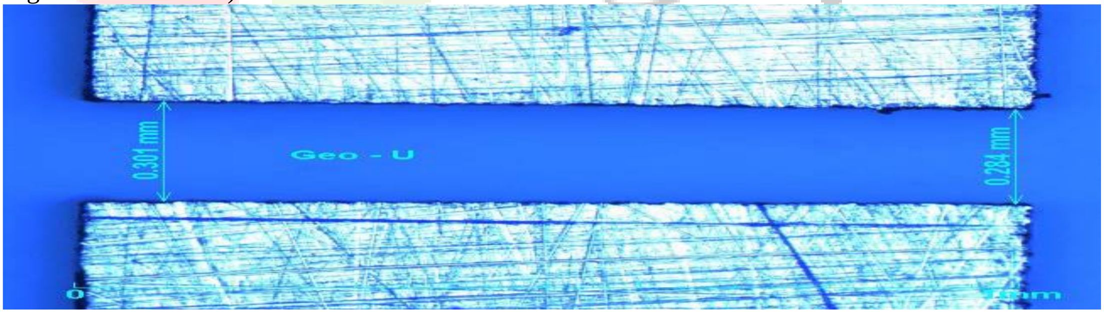


Figure 2.1 Throttle geometry “U” in 300 µm thick sheet steel

Visualization of the vapour field distribution, the pressure in the liquid, measurements of velocity, as well as, mass flow were reported for standardized throttle sets in stationary flow conditions at different inlet pressure levels.

David Grief et al reported optical methods for engine fuel injection diagnostics. In this study they investigate the effects of high pressure cavitating diesel flows similar to those in real diesel engines with common rail injectors. A two-dimensional high-pressure throttle with optical access for flow visualization was investigated experimentally and numerically.

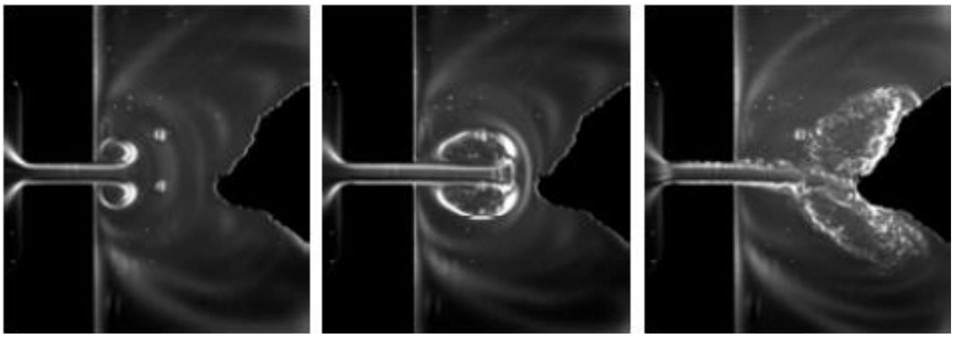


Figure 2.2 Turbulence “schlieren” measurements, Flow development during injection

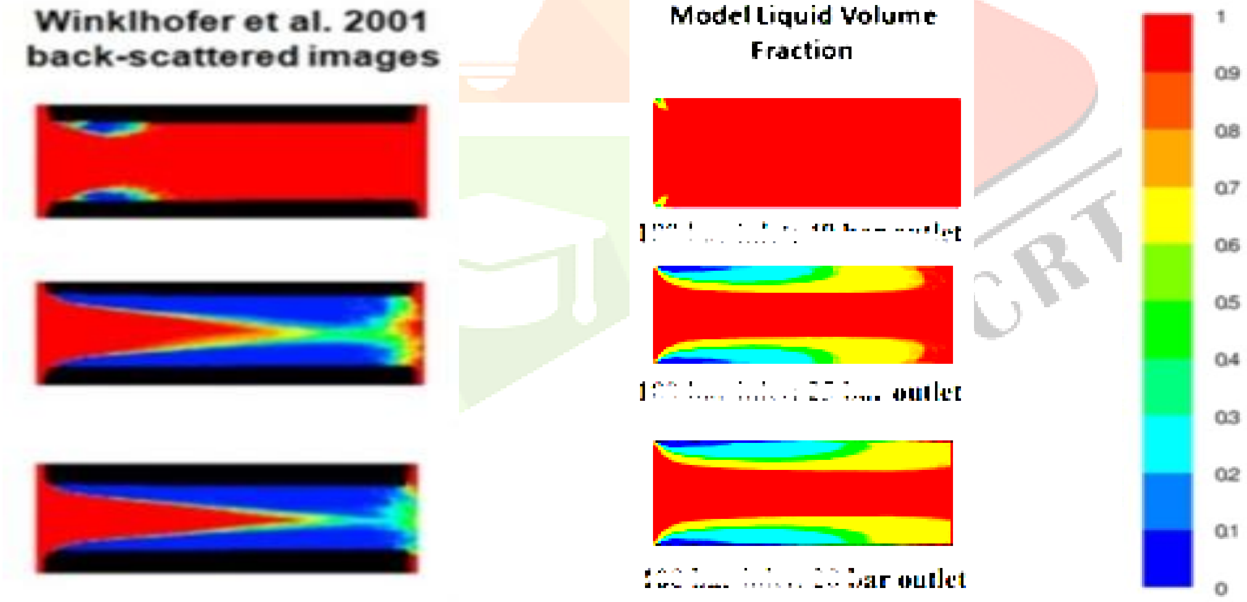
Hiroyasu et al. conducted one of the useful experiment using large-scale transparent nozzle to predict the presence of cavitation. They took pictures in the low speed of nozzle flow to observe the correlation between the nozzle cavitation and spray atomization. They found out that spray atomization is improved by the extension of cavitation to the exit of injector nozzle, and first break-up length is decreased due to the present of cavitation inside nozzle.

Badock et al. performed experiments with both laser sheet illumination and shadowgraph technique. They realized that compared to the images taken by the shadowgraph, laser illuminated images reveal the same length of cavitation inside the injector hole. Additionally, laser based technique enables a view of the liquid core which is shrouded by cavitation films which is otherwise not visible with shadowgraph.

III. EXPERIMENT WORK

1. Qualitative Comparison:

In the Winklhofer et.al. Experiment the nozzle was back illuminated and back scattered images were recorded. The vapor content was not quantitatively measured. However the predominantly vapor and liquid regions were identified. In the experimental images there is a greenish-yellow fuzzy region at the core of the flow which indicates that there is some chance of presence of vapor. The blue region, indicates presence of considerable vapor and red region denotes dominance of liquid.

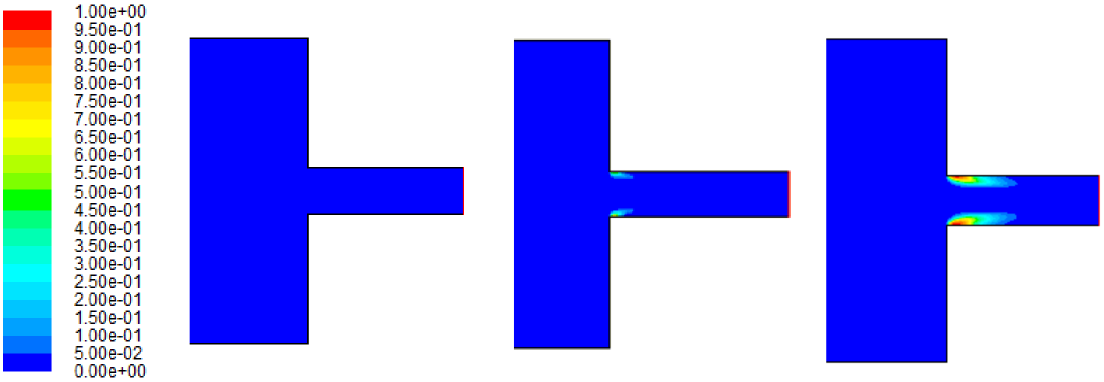


(a) Liquid fraction experimentally captured by Winklhofer et. al

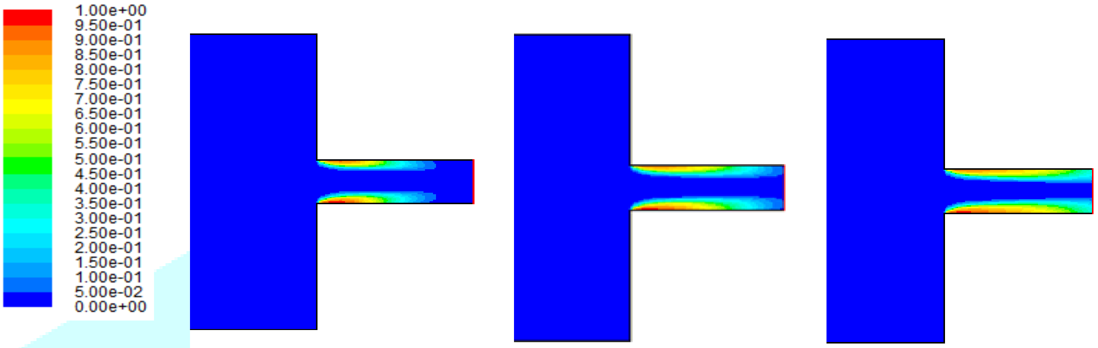
(b) Liquid fraction captured by present study

Figure 3.1 Qualitative validation of present work with experimental work

As a result the fuzzy region is not always guaranteed to have cavitation. No scale or color map was available for the experimental images. In the experimental images, as mentioned before, a red region represents the non-cavitating region and the blue regions the cavitating regions and the light greenish region the fluctuations between liquid and vapour phases. The color map provided is only meant for numerical predictions.



(a) ΔP=20 bar (b) ΔP=60 bar (c) ΔP=65 bar



(d) ΔP=70 bar (e) ΔP=75 bar (f) ΔP=85 bar

Figure 4.2 Contour of vapor fraction at different pressure

It is seen that the model initially under predicts the extent of cavitating zones, but performs better when the pressure difference between the inlet and the outlet is increased.

2. Quantitative Comparison

Cavitation is mainly govern by pressure difference across the nozzle inlet and outlet. This phenomena is captured by performing numerical simulation with constant inlet/injection pressure and wide range of outlet/back pressure. The value of injection pressure is kept fix i.e. 100 bar & back pressure is varying from 15 bar to 80 bar. Results shows that cavitation will initiate at pressure difference of 60 bar. Due to sudden decrease in area, local pressure reach below vapor pressure value which leads formation of vapor bubble near to vena contracta. This is the beginning of two phase flow inside fuel nozzle known as cavitation inception. With increase in pressure difference cavitation will propagate along the axial direction shown in Figure 4.2. Once cavitation reach at the outlet of nozzle, phenomena is known as super cavitation. This is the case in which complete two-phase flow occurred at the outlet of the fuel injector nozzle, which significantly affect atomization process of fuel.

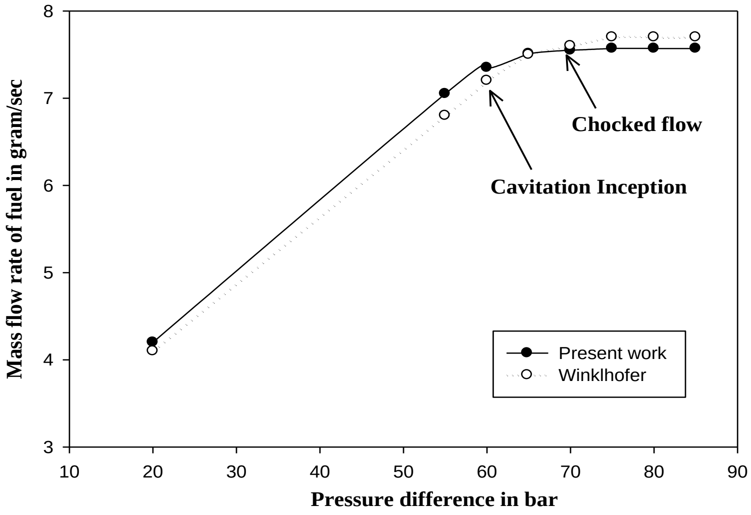


Figure 4.3 Effect of pressure difference on mass flow rate of fuel

Moreover with the reduction in back pressure, mass flow rate of fuel is increases linearly up to cavitation inception phenomena. Once cavitation start inside the nozzle, rate of increase in mass of fuel is slow down. Now condition arise, where mass flow rate of fuel does not change with pressure drop. This is known as “chocking” in nozzle, shown in Figure 4.3. Results obtained for choking phenomena are in good agreement with experimental results produced by Winklhofer et.al. [9]. shown in table 4.1 and Figure 4.3.

Table 4.1 Comparison between Experiment & Numerical results for mass flow rate of fuel in gram/sec

ΔP in bar	**20**	**55**	**60**	**65**	**70**	**75**	**80**	**85**
$\dot{m}$ (Winklhofer)	4.1	6.8	7.2	7.5	7.6	7.7	7.7	7.7
$\dot{m}$ (Present work)	4.2	7.05	7.35	7.51	7.55	7.57	7.57	7.57

IV. RESULTS AND CONCLUSION

The mass flow rate predicted results are found to be deviated from the experimental results by about 2.6%. However, this deviation is not critical for the further analysis of this case study. The study is aimed at showing the ability of the model to describe variations in the length of the vapour region with the pressure difference, rather than at providing exact validation of the model, since this would require more specific experimental information about the cavitating flow. In fact, the slight deviation may be linked to the uncertainties in the values of liquid viscosity. Indeed, it was found that the effect of liquid viscosity can have a significant influence on the amount of cavitation.

V. FUTURE WORK

In this paper, we carried out the quantitative and qualitative comparison, further, work can be done on the reducing cavitation by changing the different parameter and also work be done on the types of nozzle.

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