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Effect of Cavitation Formation on Velocity and Vorticity

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Abstract: In this study, flow in a rectangular shape nozzle has been simulated. Fully hexahedral mesh elements are utilized with having boundary layer mesh in order to avoid excessive mesh destiny in the orifice area. It was found that velocity magnitude, axial velocity and vorticity magnitude increases intensely at the beginning of the orifice area which makes it possible for the cavitation phenomena to occur rapidly. The cavitation that occurs inside diesel fuel injector nozzles has a significant impact on atomization, and modelling this phenomenon will be useful in future injector development.
The Schnerr cavitation model was chosen among three distinct cavitation models available in Ansys Fluent v21 because it is capable of properly forecasting choke conditions in cavitating flow. The two-phase flow inside a nozzle is assumed to be a homogenous combination of vapor, liquid, and noncondensable gas in this model. The pressure and velocity profiles derived from the simulations were compared to planar throttle flow experimental findings.

Keywords: Cavitation, Vorticity, Velocity, Two-Phase Flow, Hexahedral Mesh

1. INTRODUCTION

Nozzle body is impacted significantly by the injection of diesel fuel inside nozzle which can be by the contribution of geometry, physical properties and environmental features which leads to significant changes in fuel spray, engine performance, air pollution and economy of fuel consumption. There are numerous factors which can trigger occurrence of cavitation inside diesel injector nozzle which are fuel spray discharge, atomization and spreading angle. It has been a big question since decades ago to realize the effect of cavitation formation on performance of engine and environmental pollution [1-3]. Several experimental and numerical investigation has been performed to assess significance of cavitation phenomena to understand cavitation inception, super-cavitation and erosion. Some condition such as angled nozzle can create uneven cavitation phenomena [4]. Moreover, numerous nozzle configuration such as sac-type, valve covered orifice and multi-hole nozzles were investigated in order to determine what changes occurs to atomization and spray process. Visualization of cavitation structure and formation has been a continuous challenge to determine flow behavior in near nozzle regions and internal combustion engines. In order to study thoroughly the formation of cavitation phenomena mostly transparent nozzles were utilized to obtain optical structure with materials such as quartz and acrylic in the design process where index of refraction found an important parameter to control the stated process[5-7]. Controlling index of refraction can result in having a better result by eliminating artifact that are unwanted [8, 9]. There are many limits toward the material that are used in transparent nozzles in which the most important one is pressure limit [10]. Mostly, the pressure that is used for experimental studies are lower than the actual pressure among nozzles in real life due to the mentioned limitations of the material properties. Therefore, lowering the scale of the study found to be necessary in order to evaluate and compromise with the experimental results [11]. Also, in order to match with experimental analysis there has been some efforts to perform the numerical study based on dimensionless parameters in which cavitation numbers and Reynolds were hold even though nozzle geometry scaled up [12]. Afterward, some scaling issues appeared in which selecting the proper material for the nozzle found to be necessary [13]. It was found that for finding the most accurate quantitative and qualitative calculation, utilization of x-ray method is crucial inside the orifice of the nozzle. Even though there are pros and cons in all scientific techniques, x-ray method has a robust perforate capability while refraction issue remained unsolvable [14].

Cavitation phenomenon causes formation of numerous bubbles and liquid phase change and can severely affect the afterward processes which are liquid-jet break up and atomization. Generally, the nozzles simulated in phase change field are very small and it requires a lot of resources and time. Short microchannel has been fully explored for the hydrodynamic cavitation phenomenon and it was found cavitation occurs in a different pace than what it used to occur. Bubble collapse due to cavitation phenomenon creates two different phenomena which are erosion and atomization. If the bubble collapses inside the orifice are of the nozzle, the erosion phenomena occur which is extremely detrimental and can reduce the nozzle efficiency [15, 16]. On the other hand, bubble collapse at the outlet region of the nozzle, can cause atomization which is significantly beneficial for the air-fuel mixing process and can noticeably improve the combustion quality of the combustion engines [17, 18]. There have been many studies performed both numerically and experimentally to understand the behavior of bubble formation. In which those that investigated bubble formation inside the orifice, found that bubble collapse and impinging microjets are in charge of detrimental erosion behavior. While on the other side, bubble collapse solely is in charge of atomization at the nozzle outlet and formation of super-cavitation, hinders the process of bubble formation toward the outlet of the nozzle which will make the outlet jet coming of the nozzle outlet very fast and indeed efficiency of the combustion process improves drastically [19]. Hence, altering the location of cavitation bubble toward the end of the nozzle has been a goal for many researchers since it has improved the air-fuel mixing process significantly. Also, it was found that cone angle of spray is noticeably affected by cavitating flow inside the nozzle. There was a study in which a two-dimensional approach was used on a nozzle that had material of acrylic resin [20].

Cavitation occurs when the local pressure falls below the fluid's vapor pressure, resulting in the development of bubbles in a liquid flow, resulting in a two-phase combination of liquid and vapor/gas. Fundamentally, the transition from liquid to vapor can be affected by heating the substance. Boiling is the process of heating a fluid at a constant pressure, or by lowering the pressure. Cavitation is the process of maintaining a constant pressure at a constant temperature. Because the density of vapor is at least two orders of magnitude lower, the phase transition is believed to be isothermal when compared to that of a liquid. Cavitation is thought to occur when the local pressure falls below the vapor pressure of the fluid at the appropriate temperature in most applications. Modern diesel engines are engineered to run at high injection pressures and high injection velocities. As a result, high-pressure gradients and shear stresses in a diesel injector nozzle can cause cavitation or the creation of bubbles [21]. Cavitation is ubiquitous in hydrodynamic equipment such as pumps, valves, and other similar devices, where it is undesirable because it can reduce system efficiency, create mechanical wear, and potentially damage the equipment. Cavitation can help the development of the fuel spray in diesel fuel injectors because it improves the initial break-up and subsequent atomization of the liquid fuel jet. Turbulence, aerodynamics, and intrinsic instability generated by the cavitation patterns inside the injector nozzle orifices are thought to cause primary breakdown in the region extremely near to the nozzle tip. Cavitation is ubiquitous in hydrodynamic equipment like pumps and valves, where it is undesirable because it can reduce system efficiency, create mechanical wear, and potentially damage the equipment. 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Imploding cavitation bubbles inside the orifice can also cause material degradation, reducing the injector's life and performance. It is obvious that an optimal amount of cavitation is desired, therefore it is critical to understand the sources and quantity of cavitation in order to build more effective nozzles [22]. Cavitation can be triggered by both "geometrical" and "dynamic" forces. Several experimental and computational/modeling studies concentrating on the beginning of cavitation and the resulting two-phase flow inside the diesel engine injector have been described. The numerous cavitation models may be divided into two categories: single fluid/continuum models and two-fluid models. The average mixture parameters, such as density and viscosity, are derived in single fluid/continuum models based on the vapor volume fraction [23-25]. Two sets of conservation equations are used in two-fluid models to address the liquid and vapor phases independently [26]. The models in this section can be divided into two groups: (i) Eulerian–Eulerian models and (ii) Eulerian–Lagrangian models. The Eulerian–Eulerian models are based on volume fraction transport and a source term that represents phase transition and is driven by the difference between local and vapor pressure. The existence of bubble nuclei or microbubbles inside the liquid, which can develop or collapse as they are convected in the flow, is thought to cause cavitation, as described by the vapor fraction transfer equation [27]. The Rayleigh's simplified bubble dynamics equation accounts for both growth and collapse. In an Eulerian frame of reference, liquid is considered the carrier phase, whereas vapor bubbles are considered the dispersion phase in a Lagrangian frame of reference [28]. To replicate the whole population of genuine bubbles, bubble packages are employed. These bundles are thought to contain a number of noninteracting bubbles that are all similar [29]. Nuclei are intentionally produced to start cavitation, and the size of each nucleus is sampled from a probability density function [30]. The whole nonlinear Rayleigh–Plesset equation is used to determine bubble dynamics. On the bubble parcels, the effects of turbulence dispersion, drag force, pressure gradient, and lift forces are also examined. This is clearly a more sophisticated model since it accounts for the majority of scattered phase processes.

2. MESH TOPOLOGY

In this study fully structured mesh has been used to simulated the flow field as was introduced by Nezamirad et al. [31, 32] in which boundary layer mesh was introduced in order to reduce the need for a dense mesh and made it possible to evaluate the effects of needle height and numerous diesel fuels.

Two equal volumes assumed at the inlet and outlet of the nozzle which made it feasible to decrease dissipation as much as possible. Furthermore, in the inlet a controlled radius is utilized to avoid excessive formation of the cavitation phenomena. At the outlet of the nozzle, no radius is designed since there is no chance for the occurrence of the cavitation phenomena.

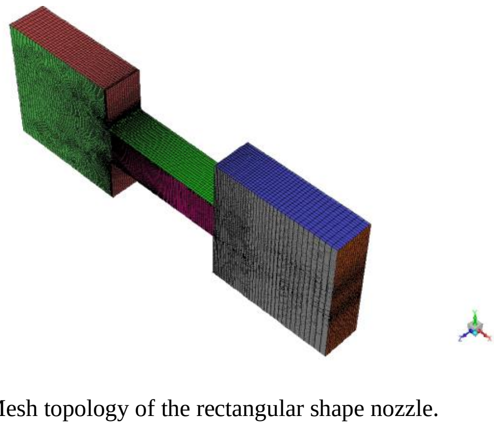

Figure 1. Mesh topology of the rectangular shape nozzle.

3. RESULT & DISCUSSION

Figure 2 Velocity magnitude versus position in the rectangular shape nozzle. It can be seen that the velocity increases intensely at the inlet of the orifice which makes it feasibly for the cavitation phenomenon to occur. Afterwards, the flow tends to come back to its normal characteristic.

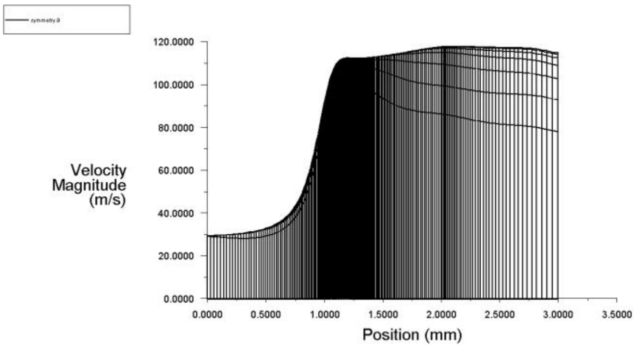

Figure 2. Velocity magnitude versus position in the rectangular shape nozzle.

Figure 3 shows formation of the actual velocity versus the position of the flow in a rectangular shape nozzle. It can be seen that the actual velocity is symmetric which is due to utilization of a symmetric nozzle.

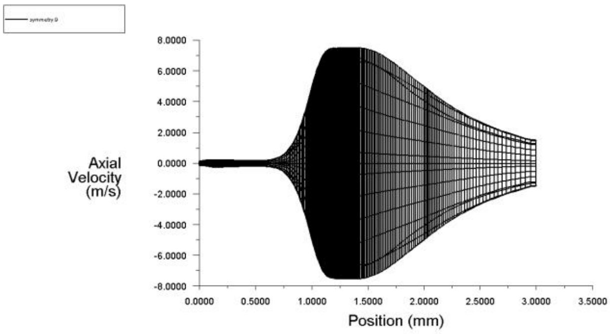

Figure 3. Axial Velocity versus position in the rectangular shape nozzle.

Figure 4 shows formation of the vorticity magnitude versus flow fit position. It can be visualized that the amount of vorticity reaches to its peak value at the inlet of the orifice which makes it possible to have immediate reduction in the amount of pressure while temperature is unchanged and again sudden decrease in the vorticity creates two phase flows of vapor and diesel.

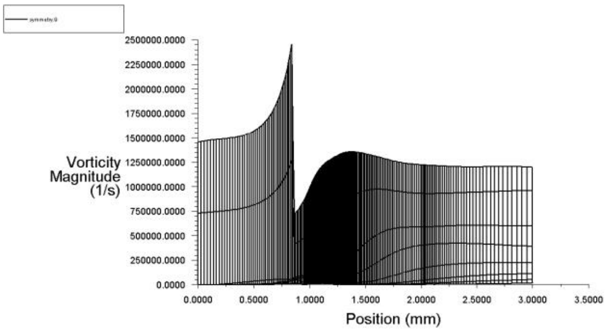

Figure 4. Vorticity magnitude versus position in the rectangular shape nozzle.

Figure 5 shows formation of wall y plus versus position in the rectangular shape nozzle. It can be found that wall y plus value experiences it's highest value as soon as the flow enters to the orifice area and it increases significantly.

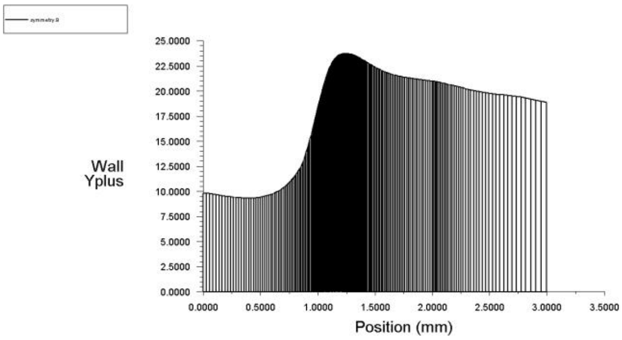

Figure 5. Wall y plus versus position in the rectangular shape nozzle.

Figure 6 shows formation of the cell Reynolds number versus position in the rectangular shaped nozzle. It can be observed that the cell Reynolds number decreases drastically when enters the orifice region.

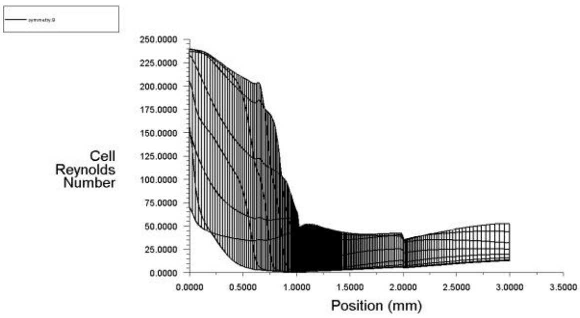

Figure 6. Cell Reynolds number versus position in the rectangular shape nozzle.

4. CONCLUSION

The flow inside a rectangular shaped nozzle has been investigated thoroughly and the following conclusions have been made:

1. Velocity magnitude increases intensely at the beginning of the orifice.
2. Actual velocity exorbitantly elevates symmetrically by the entrance of the orifice.
3. Vorticity experiences a sudden increase and decreases at the beginning of the orifice, which makes it possible for the cavitation phenomena to occur.

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