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TRANSIENT FLOW SIMULATION INSIDE PRESSURE SWIRL ATOMIZER

Alireza Razeghi[1] and Özgür Ertunç[2]
Özyeğin University
Istanbul, Turkey

ABSTRACT

In this paper, flow structure inside pressure swirl atomizer is studied numerically. Based on results, cavitation phenomenon occurs inside atomizer before full flow establishment. Flow structures illustrates that three main vortical structures are active inside pressure atomizer in the flow establishing period. Furthermore, discharge coefficient variation is shown in transient regime, which shows large oscillations. After flow spray establishment, large fluctuations diminish and discharge coefficient tends toward a constant value.

INTRODUCTION

Atomizers as one of the important devices in generating droplets have received engineers and scientists attention in the recent decades. They have vast variety of applications, ranging from medical inhalers to internal combustion chambers. In diesel engines, the efficiency of combustion is highly affected by the spray characteristics such as droplet spatial distribution, Sauter Mean Diameter (SMD) and flow specifications [Lefebvre, 1980; Lefebvre & Ortman, 1985]. These characteristics are highly dependent on the internal flow structure inside atomizer. Based on the atomization process ongoing inside atomizers, they are classified into different categories. Airless, air-assisted, air-blast and simplex atomizers (pressure swirl atomizers) are some the frequently used atomizer types. In pressure swirl atomizers, fluid enters the atomizer from tangential inlet ports and causes a rotating motion inside. For a specific amount of swirl intensity m pressure inside atomizer drops to such a level which causes ambient air suction. In this case, the outgoing liquid shapes a hollow cone. Due to high velocity and density difference between liquid sheet and ambient gas, drag forces cause waves on liquid sheet which eventually results in primary and then secondary atomization. Several studies regarding the flow field inside and outside of pressure swirl atomizers are done up to now. [Kenny et al., 2009] have made some modifications on the atomizer designed by [Bazarov & Yang, 1998] and studied the effects of ambient pressure on swirl atomizer spray. It is noted that, for constant mass flow rate, the increase of chamber back-pressure increases the discharge coefficient. Weber number effect (ratio of inertia to surface tension force) and ambient gas density on spray characteristics such as breakup length, spray cone angle and spray distribution are studied experimentally and compared with linear instability theory by [Kim et al., 2007]. Based on their results, increasing the ambient pressure up to 4 MPa shows no significant change in cone angle unless after breakup of liquid sheet, which

[1]GRA in Mechanical Engineering Department, Email: alireza.razeghi@ozu.edu.tr
[2]Ass. Prof. in Mechanical Engineering Department, Email: ozgur.ertunc@ozyegin.edu.tr

decreases the cone angle considerably, especially for small We numbers. Also breakup length decrease is reported with We number and ambient gas density. [Kim et al., 2010] investigated the effect of four geometry dimensions, extra swirl chamber length (The vertical distance between nozzle top and inlet slot), swirl chamber length, orifice length and swirl chamber diameter on the film thickness at the nozzle exit. They have stated that liquid film thickness increases with swirl chamber and extra swirl chamber length with fluctuating behavior, especially for longer swirl chamber length. [Nouri-Borujerdi & Kebriaee, 2012] studied internal flow field of injector design by [Horvay, M., and Leuckel, 1986] numerically using level set method to capture liquid-air interface. They have shown that, laminar flow assumption gives better results in comparison to case of turbulent flow assumptions. In their results, laminar flow assumptions shows bigger air-core radius in comparison to that with turbulent flow assumptions in which, they attributed this deviation to the growth rate of turbulent eddy viscosity which reduces velocity magnitude and hence air-core diameter. Most of the atomizer systems in automotive applications operate in pulse mode and considerable portion of the operation falls in the developing flow regime, which is a transient process. To the authors best knowledge, almost all of the studies up to now are done in steady operating conditions. In this study, three dimensional transient flow structures and flow characteristics inside atomizer has been analyzed. Furthermore the pressure distribution and the process of generation of air-core have also been reported.

METHOD

In this study, continuity and Navier-Stokes equations are solved numerically using finite volume method. Volume of Fluid (VOF) model is used to consider multiphase flow with High Resolution Interface Capturing (HRIC) method to precisely capture the liquid/gas interface. To assess the occurrence of cavitation phenomenon, Schnerr-Sauer cavitation model [Sauer, 2000; Sauer & Schnerr, 2000] is used to model cavitation inside atomizer, which is reduced model of Rayleigh-Plesset model [Brennen, 2013]. STAR-CCM+ CFD package is used to solve the discretized equations. Special care is taken in selecting the time step to assure that Courant number will be less than unity.

RESULTS

Transient 3-D flow simulations are done to study the multiphase fluid flow inside pressure swirl atomizer. Grid independency along with validation of numerical procedure is given in the next sections. Next, pressure distribution and spatial distribution of phases are given at different states. Shown states are normalized with the state in which, the air-core is established and no further change in cone angle is observed. Normalized time (T^*) is defined as,

$$T^* = \frac{t}{t'} \tag{1}$$

In which, t' is the time that air-core is generated and there is no variation in cone angle.

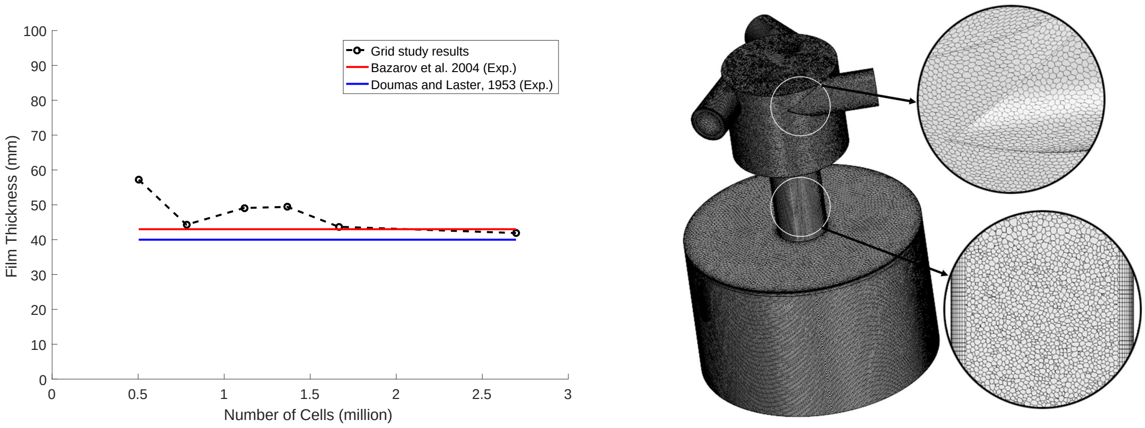
Validation

Unstructured grids are used to discretize the solution domain as shown in figure 1b. Grid independency study has been conducted to reach unique results independent of the grid quality. Several grids has been tested and illustrated in figure 1a. Finally, grid with 1666231 cells shown in figure 1b is selected. Finer grid resolution is used in the regions where higher gradients are expected such as near walls and in the orifice section.

Validation of numerical approach is done by comparing numerical results with experimental data and results are shown in table 1. As shown in table 1, there is a good agreement between numerical results and experimental data.

Pressure distribution inside atomizer

Figure 2 depicts the spatial distribution of pressure inside atomizer at different times. Figure 2 illustrates that, as time goes on and the pressure in the centerline decreases, the fluid is pushed



(a) Grid independency study (b) Mesh used for simulation

Figure 1: Grid Independency and mesh used

Table 1: Validation of numerical approach with experimental data

Parameter	Film Thickness (mm)	Cone Angle (degree)
Numerical Results	0.43	53.31
Bazarov et al. 2004	0.43	49.01
Doumas and Laster 1953	0.40	51.08

toward walls and pressure value near the walls get much greater values than other locations especially in the centerline of atomizer.

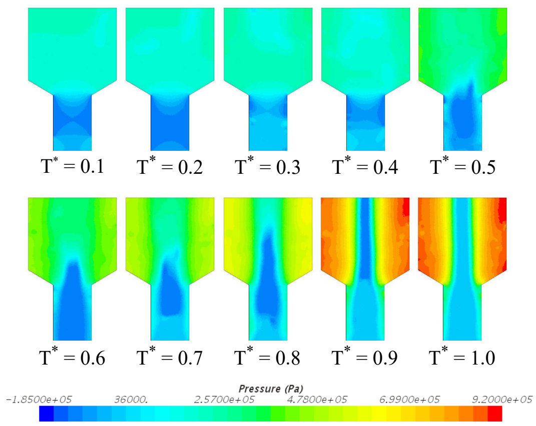


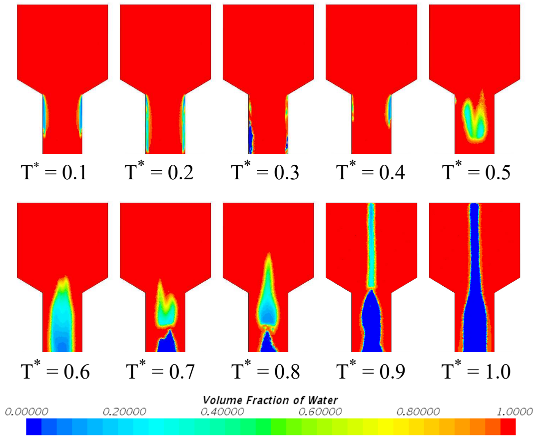
Figure 2: Spatial distribution of pressure inside atomizer at different times

Volume Fraction of phases

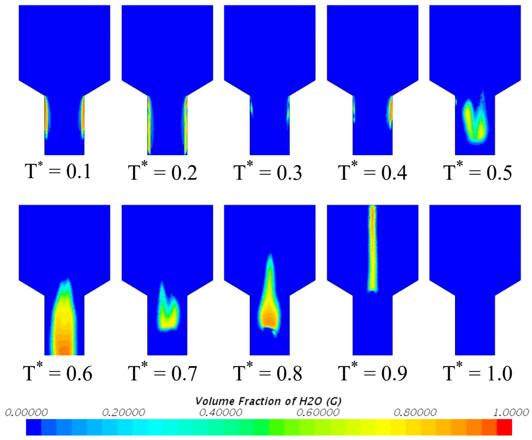
Figure 3a illustrates the volume fraction of the liquid phase at different solution times. To distinguish cavitating flow and sucked ambient gas, in figure 3b only the vapor volume fractions corresponding to same states are illustrated. As shown in figure 3b, initial cavitation happens at the orifice inlet corners du to acceleration of fluid and pressure drop.

Vortical Structures inside atomizer

Figure 4 shows the streamlines inside swirl atomizer at different times. In figure 4a three main vortical structure generated at swirl chamber entrance are illustrated. These shear vortexes are generated due to area expansion and relative velocity difference between tangential nozzle section and swirl chamber.



(a) Volume fraction of liquid phase



(b) Volume fraction of vapor phase

Figure 3: Spatial distribution of volume fractions

Furthermore, at the beginning of orifice section, separation and recirculation zones are depicted in figure 4d.

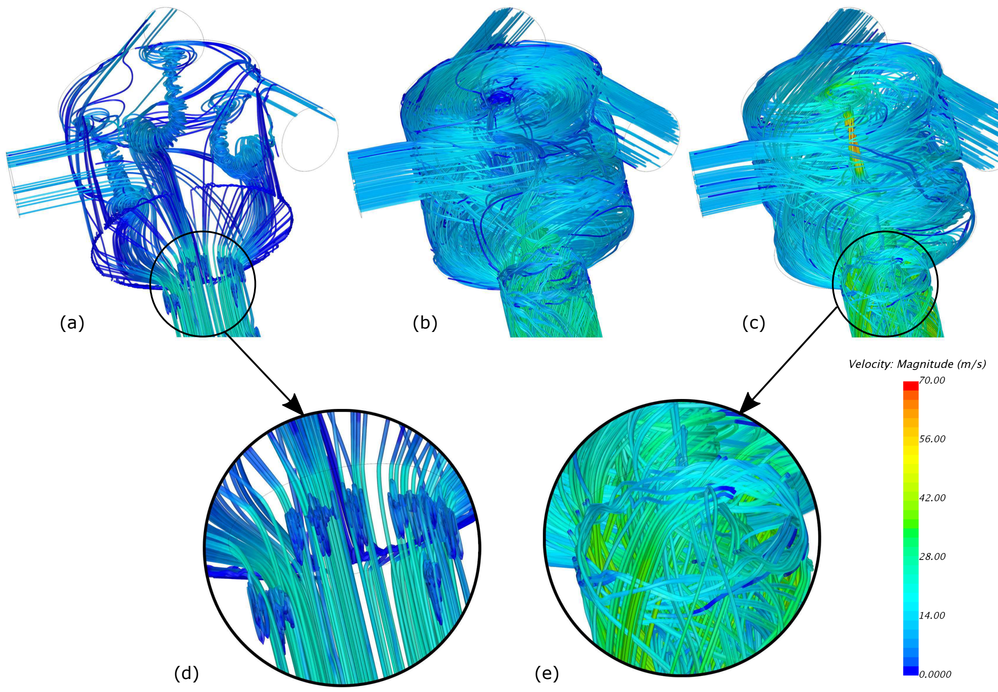


Figure 4: 3-D Streamlines inside atomizer at different times. (a) $T^* = 0.1$, (b) $T^* = 0.6$ and (c) $T^* = 1.0$. (d) orifice inlet at $T^* = 0.1$ and (e) orifice inlet at $T^* = 1.0$

Discharge coefficient variation in time

Due to the losses inside atomizer, actual mass flow rate is not equal to theoretical mass flow rate calculated by conventional fluid mechanics theory. Discharge coefficient is defined as this ratio,

$$C_d = \frac{\dot{m}}{A\sqrt{2\rho\Delta P}} \tag{2}$$

Large oscillations are obvious in the developing region till $T^* = 1$. After Flow establishment, large oscillations are wiped out and only small fluctuations are shown in figure 5.

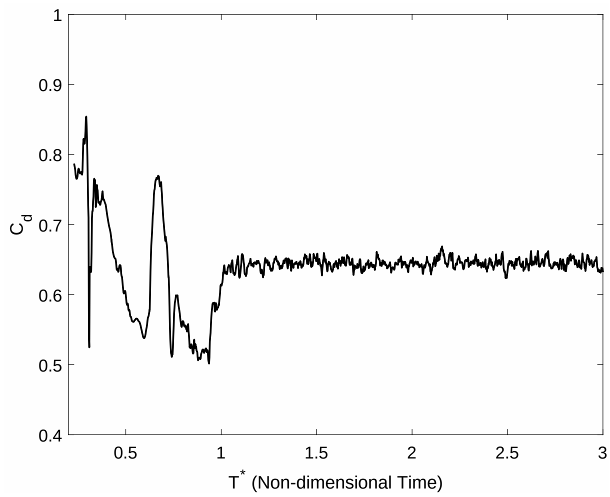


Figure 5: Discharge Coefficient

In the established region, the oscillations are around a mean value which is $\overline{C_d} \approx 0.64$. This shows nearly $\%36$ loss with respect to theoretical mass flow rate due to losses in the atomizer.

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References

Bazarov, V. G. & Yang, V. (1998). Liquid-Propellant Rocket Engine Injector Dynamics. *Journal of Propulsion and Power*, 14(5), 797–806.

Brennen, C. E. (2013). *Cavitation and bubble dynamics*. Cambridge University Press.

Horvay, M., and Leuckel, W. (1986). Experimental and Theoretical Investigation of Swirl Nozzles for Pressure Jet Atomization. *German Chemical Engineering Journal*, 9, 276–283.

Kenny, R. J., Hulka, J. R., Moser, M. D., & Rhys, N. O. (2009). Effect of Chamber Backpressure on Swirl Injector Fluid Mechanics. *Journal of Propulsion and Power*, 25(4), 902–913.

Kim, D., Im, J.-H., Koh, H., & Yoon, Y. (2007). Effect of Ambient Gas Density on Spray Characteristics of Swirling Liquid Sheets. *Journal of Propulsion and Power*, 23(3), 603–611.

Kim, S., Khil, T., Kim, D., & Yoon, Y. (2010). Effect of geometric parameters on the liquid film thickness and air core formation in a swirl injector. *Measurement Science and Technology*, 21(3), 039801.

Lefebvre, A. H. (1980). Airblast atomization. *Progress in Energy and Combustion Science*, 6(3), 233–261.

Lefebvre, a. H. & Ortman, J. (1985). Fuel distributions from pressure-swirl atomizers. *Journal of Propulsion and Power*, 1(1), 11–15.

Nouri-Borujerdi, A. & Kebriaee, A. (2012). Numerical simulation of laminar and turbulent two-phase flow in pressure-swirl atomizers. *AIAA Journal*, 50(10), 2091–2101.

Sauer, J. (2000). *Instationaer kavitierende Stroemungen - Ein neues Modell, basierend auf Front Capturing VOF und Blasendynamik*. PhD thesis, Universitaet Kalrsruhe.

Sauer, J. & Schnerr, G. H. (2000). Unsteady cavitating flow–a new cavitation model based on a modified front capturing method and bubble dynamics. In *Proceedings of 2000 ASME fluid engineering summer conference* (pp. 11–15).