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Internal flow analysis of a Pintle injector

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Abstract. *Injectors are devices responsible for breaking a portion of fluid into a spray of small droplets in order to promote fast vaporization, mixing and combustion of propellants in a chamber. A pintle injector contains a movable rod which allows control of the mass flow rate and presents good stability characteristics. This paper investigates the influence of the inner geometry of a pintle injector on the exit flow uniformity. Geometries with and without perforated walls were analysed. Computational fluid dynamics simulation using the ANSYS Fluent code with the SST k-ω turbulence model have shown that internal perforated walls can enhance the exit flow homogeneity in terms of turbulence kinetic energy, an important parameter to promote combustion stability.*

Keywords: Pintle injector; Injector design; Numerical simulation.

1. Introduction

Propulsion systems using liquid propellants can produce high thrust levels with high specific impulses. Recently, green propellants have regained attention for application in rocket propulsion systems since they present lower toxicity, less environmental impact, lower cost and better storage, handling and safety characteristics than conventional propellants (AGGARWAL; PATEL; SHARMA, 2015).

Small droplets are required to achieve rapid evaporation, mixing and ignition and to establish a flame front adjacent to the injection head. Large droplets take longer to burn and therefore define the length of the combustion chamber (KHAVKIN, 2004).

Injectors are responsible for the breakup of bulk fluid into a spray of small droplets for further vaporization, mixing and burning into the combustion process. Such breakup process is frequently called atomization. Efficient atomization significantly increases propellant surface area, ensuring high rates of evaporation, mixing and burning (DIAS et al., 2019).

Pintle injectors have variable internal parts that allow better thrust control compared to impinging jet injectors and swirl injectors (SONG; HWANG; KOO, 2021). Besides that, a single Pintle injector is sufficient to promote high thrust levels, a hard task to other injector types.

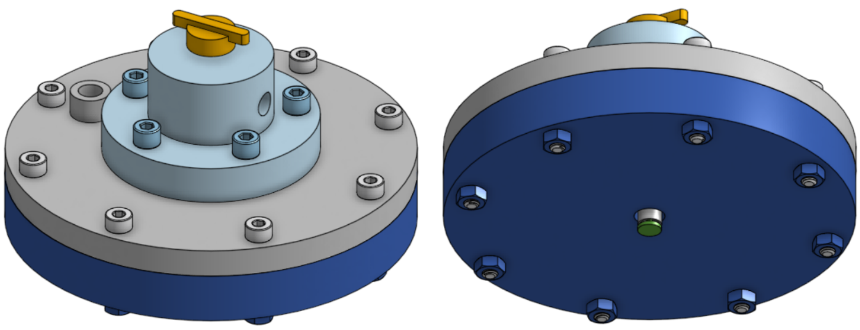

Figure 1. 3D view of the pintle injector assembly.

A pintle injector is being designed to atomize ethanol and hydrogen peroxide for application in a 200 N thruster (Figure 1), this work describes a preliminary analysis of the internal oxidizer flow using Computational Fluid Dynamics (CFD). Inner geometries with and without perforated walls are considered in the present analysis.

2. Methodology

In general, internal flows through injectors are turbulent, due to high flow velocities and complex inner geometries. Consequently, it is required the adoption of a turbulence model in order to perform the numerical simulation of inner flows through injectors. For example, Tahmasebi et al. (2015) have used a k-ω Shear-Stress Transport (SST) two equation turbulence model to solve the Reynolds-averaged Navier-Stokes (RANS) equations for numerically simulate a diesel injector internal flow field.

The CFD code with the SST k-ω turbulence model was utilized for the present simulations. Initially, a numerical simulation of a single jet injector was performed to validate the CFD code, since experimental data were available (DIAS, 2020).

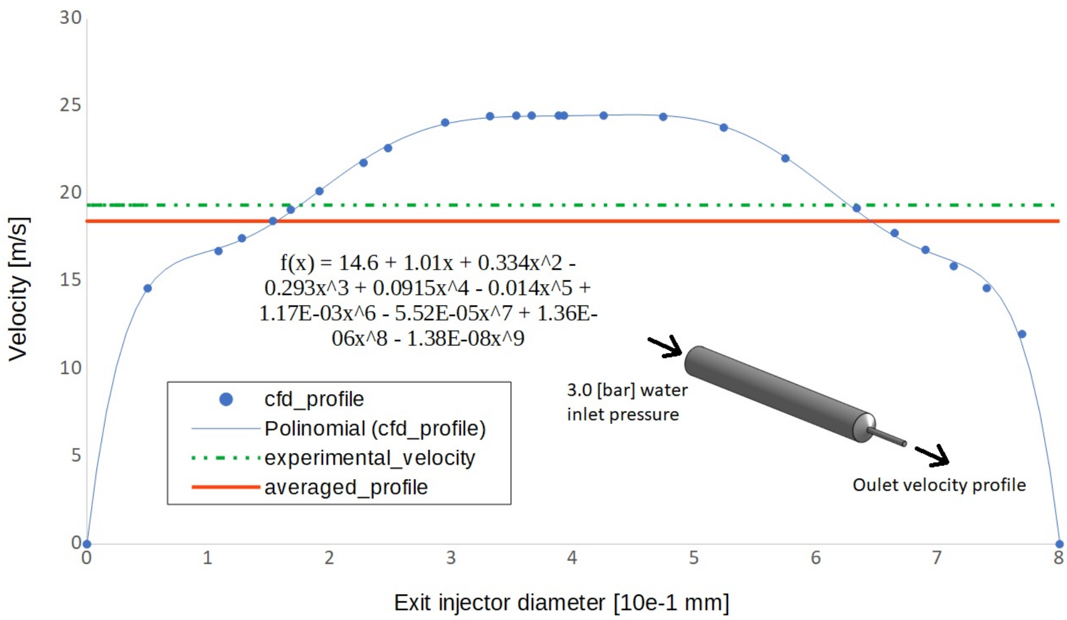

Figure 2. Velocity exit profile for the jet injector and comparison with average experimental velocity.

Figure 2 shows the exit velocity profile for a 0.8 mm diameter jet injector using water as test fluid with inlet pressure of 3 bar. The numerical result is characteristic of a turbulent profile (SALAMA, 2021). The profile was fitted into a polynomial function and then integrated. The average velocity from CFD data was similar to the experimental mean velocity.

Figure 3 shows the internal geometries of the pintle injector to be analysed. Water was also used as test fluid with a pressure of 1 bar in the inlet channel.

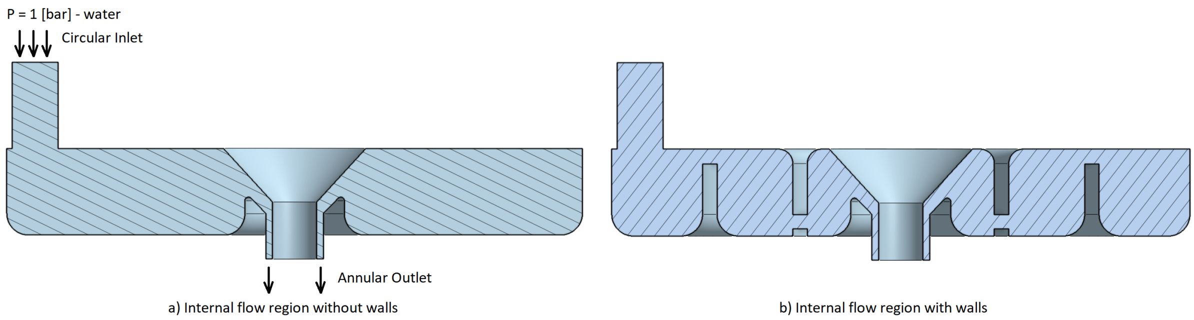

Figure 3. Oxidizer flow region, a) with and b) without internal walls

3. Results and Discussion

A satisfactory injector must promote a homogeneous flow distribution around the exit orifice, besides breaking the bulk material into droplets. Such homogeneity is important to avoid hot points around the chamber and to avoid combustion instabilities.

The flow homogeneity in the exit channel was estimated by the distribution of turbulent kinetic energy which depends on the root-mean-square (RMS) velocity fluctuations (RUBENSTEIN; YIN; FRAME, 2015).

Figure 4 presents the distributions of Turbulent Kinetic Energy in the annular exit channel for the two inner geometries considered.

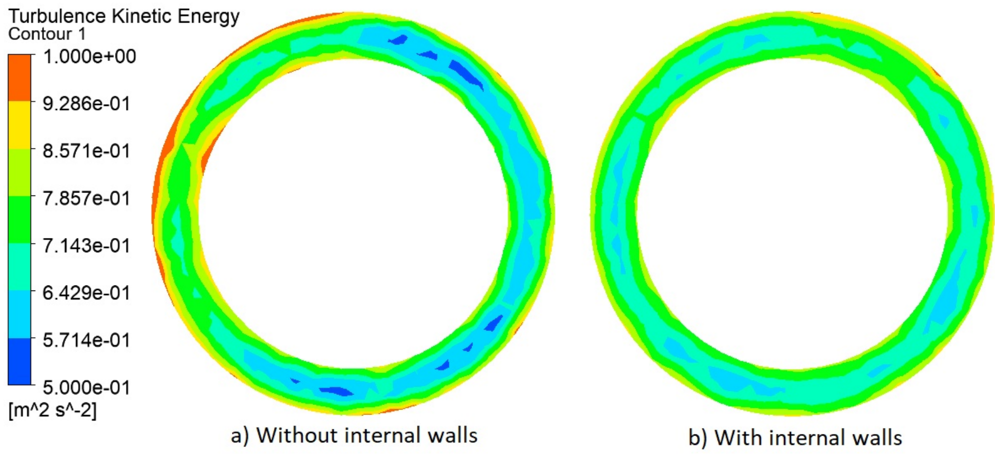

Figure 4. Turbulence Kinetic Energy over the annular exit for the geometry a) without internal walls and b) with internal walls.

A more homogeneous distribution of turbulent kinetic energy is verified for the injector geometry with internal perforated walls. The internal walls force the fluid pass trough obstacles and perforations, reducing the preferential flow paths. As a result, the flow streamlines become more uniformly distributed over the exit channel.

A drawback of adding internal walls, besides a cost increase and difficulties in manufacturing, is the reduction of the discharge coefficient, thus requiring a higher inlet pressure to achieve a certain mass flux.

4. Conclusion

Numerical simulations using the ANSYS Fluent code with the SST k-ω turbulence model allowed to determine the best inner geometry of a pintle injector. The utilization of inner walls with perforations increased the uniformity of turbulent kinetic energy distribution in the exit channel and reduced preferential paths in the inner flow.

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