Atomizers for Propulsion Devices-AE345

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1 Objective

To study the variation in breakup length, cone angle, and operating conditions for different gas and liquid volumetric flow rates in an atomizer system.

2 Theory

2.1 Injectors

It is a critical component that precisely sprays and mixes the fuel and oxidizer (propellants) into the combustion chamber, ensuring they atomize and thoroughly combine before ignition, thereby producing efficient and stable combustion to generate thrust; essentially, it's a specialized nozzle that meticulously delivers the fuel and oxidizer in a way that optimizes the combustion process within the engine.

2.2 Application of Injectors

Injectors are widely used to mix two initially separated streams into a uniform mixture, as seen in liquid rocket propellant engines (e.g., gas turbine, rocket engines, ramjet, scramjet). In such systems, the combustion chamber length is constrained by the injector's ability to break up and mix reactants efficiently for complete combustion. Typically, one reactant is liquid and the other gas, with coaxial geometry used to merge the streams. The gas phase, usually moving faster, must be in excess to ensure full vaporization and combustion of the liquid, as seen in $\frac{H_2}{O_2}$ rocket engines with liquid oxygen (LOX) and gaseous hydrogen.

2.3 Types of Injectors

Two types of injectors are used in liquid rocket engines:

- **Air-blast injector**: A liquid sheet is formed by a nozzle, and air is directed at the sheet to enhance atomization through kinetic energy transfer. The added air produces smaller droplets by increasing sheet instability and dispersing the droplets. This method, used in applications requiring fine atomization, involves a round liquid jet surrounded by a co-flowing air stream.

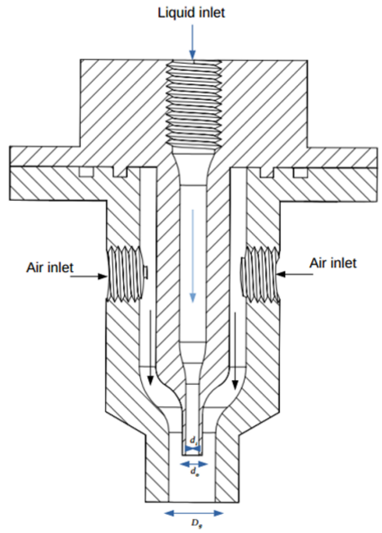
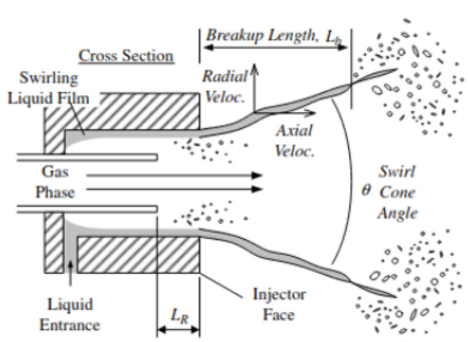
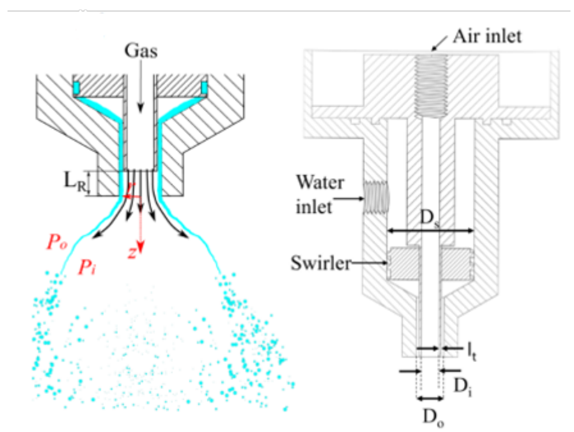


Figure 1: Air blast injector

- **Gas-Centered Swirl Coaxial injector**: A typical coaxial atomizer consists of concentric flow passages for both fuel and oxidizer. In a gas-centered swirl coaxial atomizer, a high-speed gas jet from the central orifice interacts with a swirling liquid sheet from the annular region, producing a spray. Swirl injectors offer good atomization and mixing efficiency. As the propellant enters through helical or tangential inlets, it forms a thin, swirling liquid sheet, with a gas-filled core along the center due to centrifugal force. The spray cone angle is determined by the ratio of circumferential to axial velocity. The breakup process involves thinning of the liquid sheet, forming ligaments and droplets, controlled by the interaction between gas and liquid, axial Reynolds number, and momentum flux ratio.



(a) Breakup Mechanism of GCSC injector



(b) Injector used in the experiment

3 Dimension of GCSC

Dimension for GCSC (mm)			
$D_i(gas)$	$D_0(liquid)$	$t_s(sheetthickness)$	$D_s(swirlchamber)$
3	5	0.5	22

Where, D_i diameter of orifice for gas flow, mm
D_o diameter of orifice for liquid flow, mm
t_s liquid sheet thickness, mm
$D_o = 2t_l + 2t_s + D_i$
Where t_l is lip thickness. Area for gas flow $= \frac{\pi D_i^2}{4} = \frac{3.14*3^2}{4} = 7.065\ mm^2$
Annular area for liquid flow $= \frac{\pi[D_0^2-(D_i+2t_i)^2]}{4} = 7.065\ mm^2$

4 Important Parameters

1. **Momentum Flux Ratio (MFR):** It is defined as the ratio of gas momentum flux to liquid momentum flux at the exit of the injector.

$$\text{MFR} = \frac{\rho_g U_g^2}{\rho_l U_l^2}$$

   where ρ_g and ρ_l are the densities of gas and liquid, and U_g and U_l are their respective velocities.

2. For a given liquid and gas volumetric rate, velocities can be calculated using mass conservation:

$$\dot{V} = A \cdot U$$

   where $\dot{V}$ is the volumetric flow rate, A is the cross-sectional area, and U is the velocity.

5 Sample Calculation and Observation Table

Let's take for $\dot{V}_f = 4$ lpm and $\dot{V}_g = 40$ lpm
$\dot{U}_g = \frac{\dot{V}_g}{7.065} * \frac{50}{3} = 94.36\ m/s$
$\dot{U}_l = \frac{\dot{V}_l}{7.065} * \frac{50}{3} = 9.44\ m/s$
$\text{MFR} = \frac{\rho_g * U_g^2}{\rho_l * U_l^2} = \frac{1.225*94.36^2}{1000*9.44^2} = 0.122$

$\dot{V}_g$	$\dot{U}_g$	$\dot{V}_l$	$\dot{U}_l$	MFR	L_b	Cone Angle
0	0	3	7.077	0	29.922	37.6
40	94.36	3	7.077	0.217	22.5	36.064
60	141.54	3	7.077	0.49	17.188	35.933
80	188.72	3	7.077	0.871	10.859	35.538
100	235.90	3	7.077	1.361	5.469	30.7
0	0	4	9.436	0	26.484	37.568
40	94.36	4	9.436	0.1225	19.375	35.2
60	141.54	4	9.436	0.276	14.844	36.146
80	188.72	4	9.436	0.49	10.781	35.629
100	235.90	4	9.436	0.766	5.156	31.957

Table 1: Observation Table

(a) Wave Assisted (b) Perforated (c) Segmented (d) Pulsation

Figure 3: Regimes of Sheet Breakup

6 Different Regimes in Air Blast Injector for $\dot{V}_f = 3$

7 Breakup Length Plot vs MSR for $\dot{V}_f = 3$ *and* $\dot{V}_f = 4$

8 Cone Angle vs MSR for $\dot{V}_f = 3$ *and* $\dot{V}_f$ = 4

9 Observations

1. The gas-centered swirl coaxial injector enhances mixing between the central gas stream and the surrounding liquid stream, creating distinct swirling patterns that result in a more homogeneous fuel-air mixture, which leads to improved combustion stability and affects flame shape and ignition behavior.

2. Although the breakup length follows a predictable decreasing trend, the cone angle appears more variable. However, it's reasonable to assume that the cone angle remains relatively constant across different MFR values, as the best-fit line for such a curve would be a straight horizontal line.

3. Key performance metrics, including flow rates, pressure drops, and emissions, serve as important indicators of the injector's overall effectiveness in various applications.

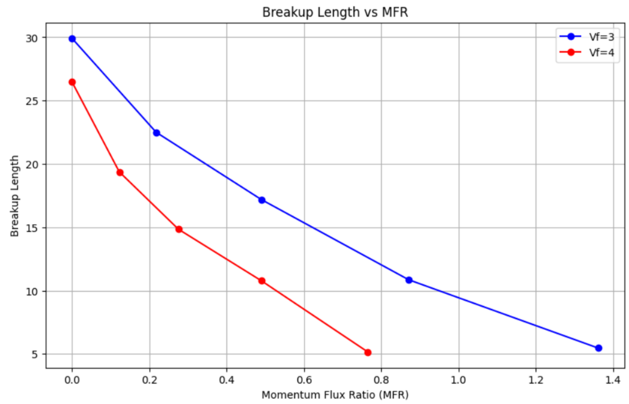


Figure 4: Breakup Length vs MFR

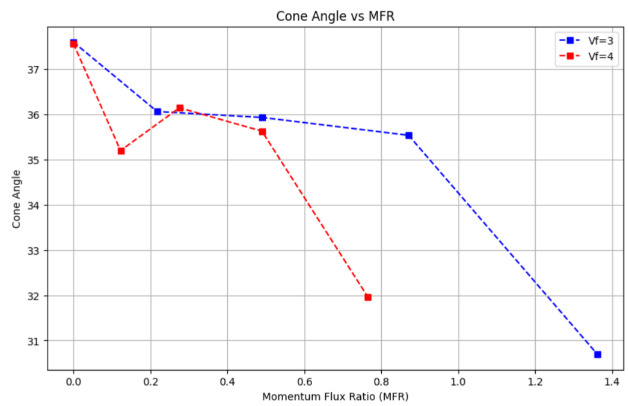


Figure 5: Cone Angle vs MFR

4. The enhanced mixing achieved by the gas-centered swirl coaxial injector generally contributes to more stable combustion, reflected in better ignition characteristics and flame control.

5. Despite variations in the momentum flux ratio, the cone angle remains largely unaffected, implying that the injector design maintains consistent spray characteristics across different operating conditions.

10 Conclusion

1. Enhancing injector geometry and refining computational models are key areas for future development to further boost efficiency and operational flexibility.

2. The gas-centered swirl coaxial injector significantly improves combustion efficiency and stability by promoting better fuel-air mixing.

3. Optimizing the injector's swirl intensity and design can lead to improved performance while reducing emissions in combustion systems.

4. Future efforts should focus on improving injector design and validating models to maximize operational flexibility and overall efficiency.

5. By adjusting swirl intensity and injector configuration, it is possible to enhance fuel mixing, which in turn improves combustion performance and lowers emissions.

11 Reference

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2. DSivakumar and V Kulkarni. “Regimes of spray formation in gas-centered swirl coaxial atomizers”. In: Experiments in fluids 51.3 (2011), pp. 587–596.