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The spray characteristic of gas-liquid coaxial swirl injector by experiment

Chen Chen[1,2], Yan Zhihui[2], Yang Yang[2], Gao Hongli[1], Yang Shunhua[2] and Zhang Lei[2]

[1]*School of Mechanical Engineering, Southwest Jiaotong University, 610031Chengdu, China*
[2]*Air-breathing Hypersonic Technology Research Center, China Aerodynamics Research and Development Center, 621000 Mianyang, China*

Abstract. Using the laser phase Doppler particle analyzer (PDPA), the spray characteristics of gas-liquid coaxial swirl injector were studied. The Sauter mean diameter（SMD）, axial velocity and size data rate were measured under different gas injecting pressure drop and liquid injecting pressure drop. Comparing to a single liquid injection, SMD with gas presence is obviously improved. So the gas presence has a significant effect on the atomization of the swirl injector. What's more, the atomization effect of gas-liquid is enhanced with the increasing of the gas pressure drop. Under the constant gas pressure drop, the injector has an optimal liquid pressure drop under which the atomization performance is best.

1 Introduction

As the combustion performance and the uniformity of the flow field are closely related to the structure and working parameters of the injector, injector is a key part of the combustion chamber. By studying the breakup length and particle size distribution, it could provide basis for the ignition and combustion optimization, high or low frequency instability analysis and combustion performance prediction [1]. So it is necessary to conduct a comprehensive and systematic study.

At present, the gas-liquid coaxial swirl injector has been widely used in liquid rocket engine due to its excellent atomization and mixing performance. Wu et al. [2] found that the injection pressure drop change of will lead to different flow and mixing ratio distribution. There is an optimal value, at which the atomization performance is best [3-8]. The injection pressure drop of propellants has a big effect on the droplet diameter and size distribution [9-12]. Li et al. [13] contrasted atomization characteristics under cold and hot conditions. Some results have obtained as mentioned above, which systematically investigated the influence of structure parameters and working parameters on atomization characteristics. But most of them tried to describe the distribution characteristics by the average value of each measurement plane or points in a plane. So they lack of a detailed study of the spatial distribution of the whole flow field.

In order to determine whether the atomization performance of the injector can meet the requirement of application, it is necessary to carry out some experiments. Air and water were chosen as the propellant. Under different gas injection pressure drop and liquid injection pressure drop, the spray flow field was measured by PDPA. It analyzed the spatial distribution of gas-liquid coaxial injector in detail. And typical measuring plane were picked to investigate the effect of gas injection pressure drop and liquid injection pressure drop on the atomization characteristics, which is helpful to the gas-liquid coaxial injector fine design, ignition location selection, spray flow field calculation and analysis.

2 Experimental methods

The test gas-liquid coaxial swirl injector model is shown in Fig.1. Water and air were chosen as the simulation mediums. Water flows into the injector through the tangential hole. And the gas flows from the loop into the outer injector. It exists a recessing value L between the inner and outer injector.

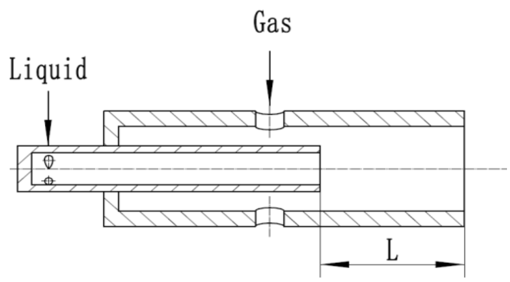


Figure 1. Schematic of gas-liquid coaxial swirl injector.

Figure 2 is the schematic diagram of the test system. The laser phase Doppler particle analyzer (PDPA) was used to measure the droplet diameter and axial velocity. The measurement range of speed is -150~1000 m/s, whose accuracy is 0.1%. And the measurement range of droplet diameter is 0.5-4000μm, whose accuracy is 0.5%.

The exit of outer injector is treated as the starting point. The measurement plane is XY plane while the Z direction is along the injection direction. Optical measurement conducted at Z = 15, 50, 100, 150, 200 and 300 mm in turn as shown in Fig. 3. In order to guarantee the accuracy of the test results, the number of collected droplets at each measured point is more than 5000 [14-15].

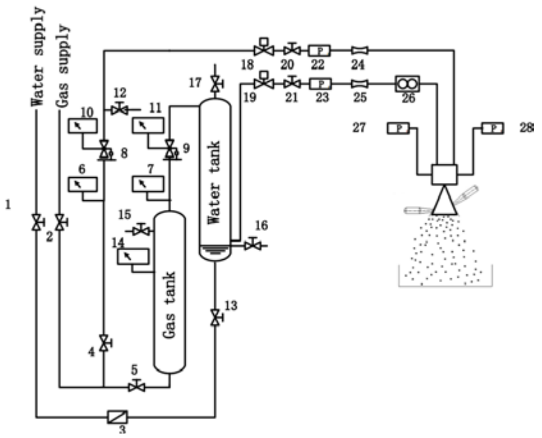


Figure 2. Test system schematic diagram.

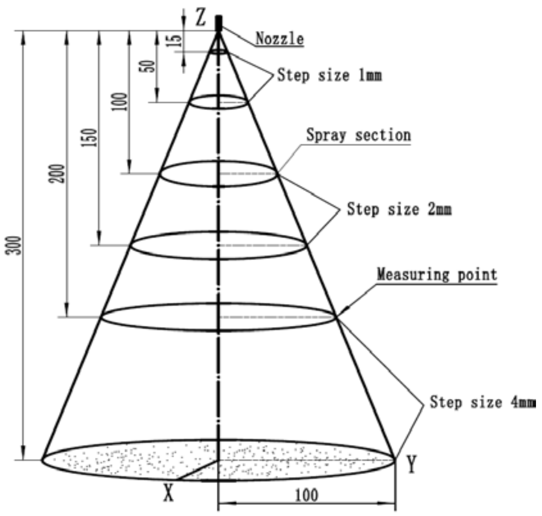


Figure 3. Measuring planes and points.

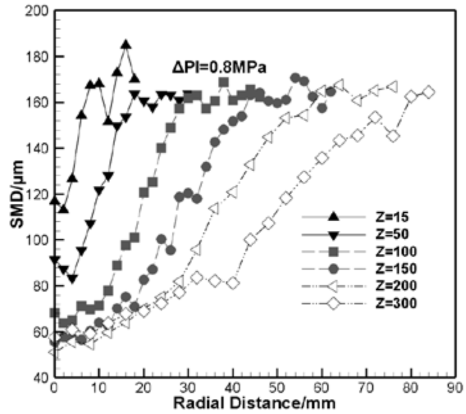
3 Results and discussion

3.1 The spatial distribution of a swirl injector

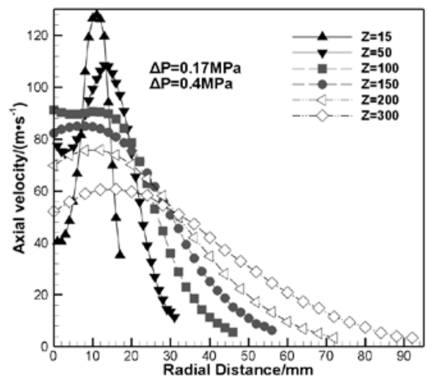
In order to better understand the distribution characteristics of gas-liquid coaxial swirl injector, it is essential to research the spatial distribution of inner injector. Figure 4 is the spatial distribution of diameter, axial velocity and data rate (particles number collected at the measurement points per second) under 0.8MPa. In literature, the use of liquid water content is usually adopted to reflect the density of the flow field. However, the liquid water content is calculated by particle number and particle size. And the particle number at the measurement point is related to the breakup and coalescences. So data rate is used to characterize the density at the measurement point in this paper.

After a series of test, we found that: (1) On the whole, the droplet size was larger while the axial velocity and the data rate are very low. So the atomization effect is poor. (2) With the increase of the axial distance, the amplitude of diameter variation in the curve plane increase. And axial velocity and data rate curve tend to smooth. Under the continuous interaction of ambient gas, the droplet keeps breaking. So the droplet diameter and velocity decreased. As the spray spread out, the data rate reduced. (3) The droplet size shows a rising trend along the radial direction. The formation of this phenomenon can be explained as follows:

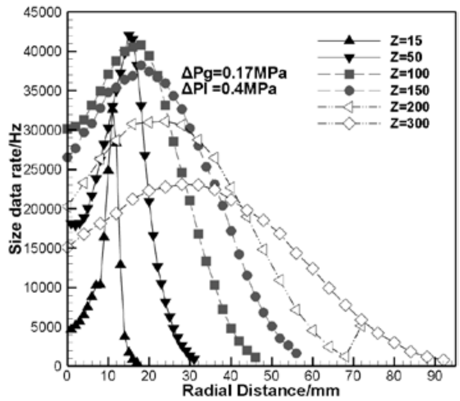
The inertia force of large droplets is greater. So they were thrown to the spray periphery. It increased the coalescence probability, which leads to the increase of droplet diameter along the radial direction.



(a) SMD



(b) Axial velocity

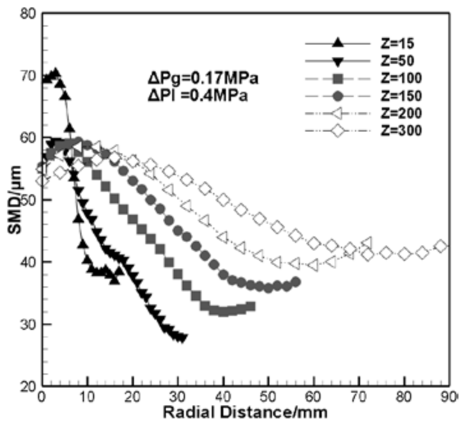


(c) Size data rate

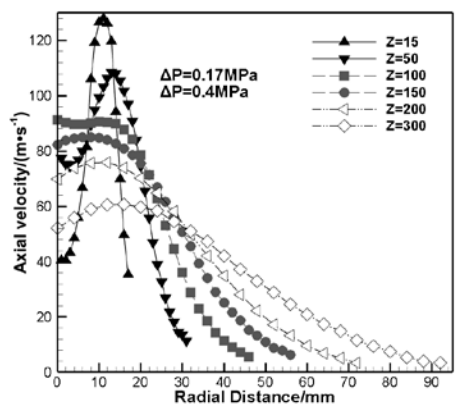
Figure 4. Spatial distribution of the swirl injector.

3.2 The spatial distribution of a gas-liquid coaxial swirl injector

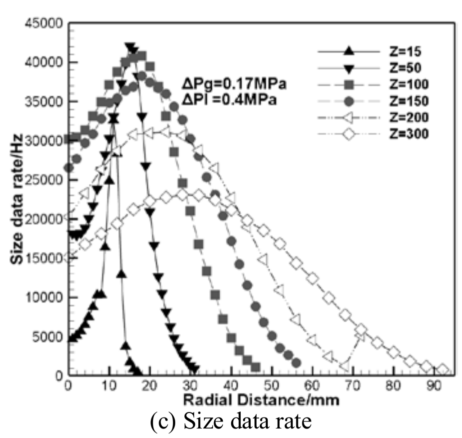
The spatial distribution of gas-liquid coaxial swirl injector is shown in Fig.5 when the gas and liquid injection pressure drop were 0.17MPa and 0.4 MPa respectively. With the increase of axial distance, the characteristic curves becomes more and more gently. At Z = 15 mm plane, the variation amplitude of SMD and axial velocity are 33.4 and 92.7 respectively. And at Z = 300 mm plane, the variation amplitude of SMD and axial velocity are 15.5 and 57.4 respectively. So the amplitude of SMD and axial velocity reduced by half. So the distribution is more uniform.



(a) SMD



(b) Axial velocity

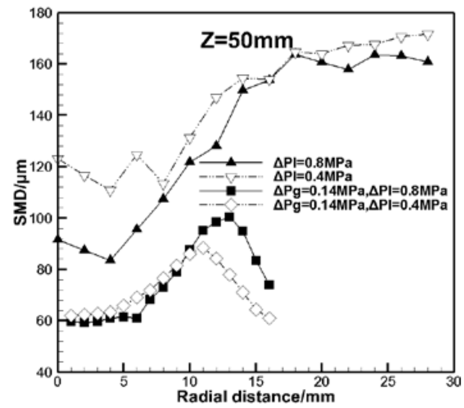


(c) Size data rate

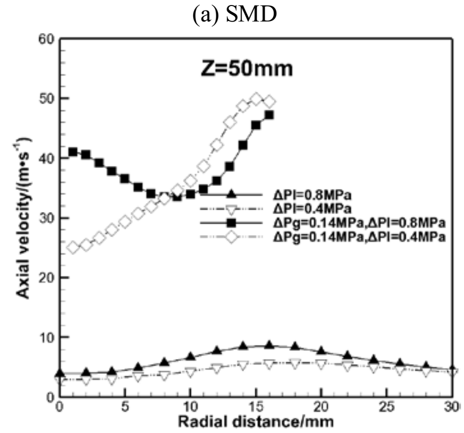
Figure 5. Spatial distribution of gas-liquid coaxial swirl injector.

3.3 The effect of gas injection pressure drop

In order to better understand the influence of gas pressure drop, it is better to study the effect of gas existence to the atomization quality firstly. In order to avoid the randomness of single working condition, two groups of tests were conducted. And SMD is adopted to evaluate the atomization quality. As shown in Fig.6a and 6b, atomization quality was very poor when only the liquid injected. Most of the droplets are more than 100μm, and the peak is up to 170μm. The diameter variation amplitude in a plane is more than 100μm. And the maximum speed is less than 10m/s. When the gas injected, all the droplet diameter is less than 100μm with maximum amplitude of 50μm. And the minimum velocity is 20 m/s. The formation of this phenomenon can be explained as follows: The pneumatic nebulization and pressure atomization worked at the same time. In Fig. 6a and 6b, the radial measurement range obviously decreased. So it could be assumed that the spray was suppressed by the gas, which is consistent with the experiment observations.



(a) SMD



(b) Axial velocity

Figure 6. Gas presence on SMD and axial velocity.

As shown in Fig7a and 7b, the SMD decreased while the axial velocity increased at the same position with the increase of gas injection pressure drop. And the shape of the SMD and axial velocity curve are basically identical. When the gas injection pressure drop rises, the gas-liquid ratio increases. What's more, the relative velocity between gas and liquid increased. So it would increase the aerodynamic force. As a result, the droplet is more easily to break. So with the increase of injection pressure drop, the atomization effect strengthened.

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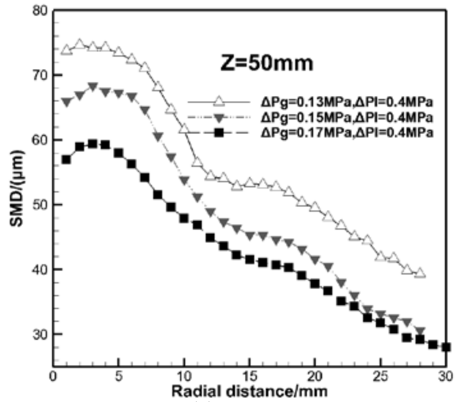
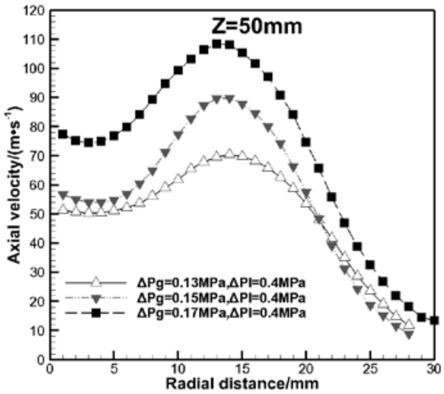


(a) SMD



(b) Axial velocity

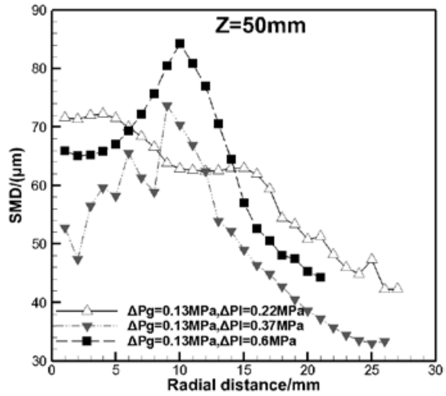
Figure 7. Spatial profiles of SMD and axial velocity under different gas pressure drop.

3.4 The effect of liquid injection pressure drop

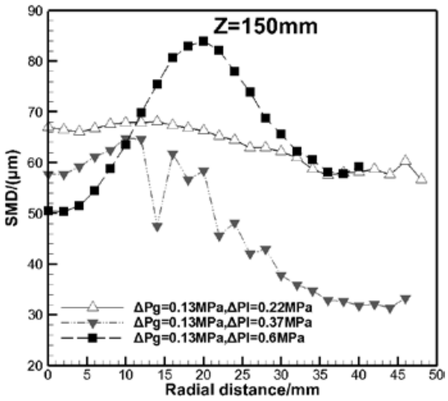
As the liquid injection pressure drop rises, it would produce some effects. First of all, it would enhance the atomization effect of internal swirl injector. However, the relative velocity between air and water in the recess region decrease, which increase the initial droplet diameter. What's more, it lowers gas-liquid ratio. As a result, pneumatic atomization becomes poor as the liquid injection pressure drop increases. As shown in Fig. 8a and 8b, SMD showed a decreased trend with the increase of radial distance. On the whole, the droplet diameter and velocity value under 0.37 MPa are less than those under 0.22 MPa. The formation of this phenomenon can be explained as follows: Though the pressure atomization and pneumatic nebulization effect at the same time, the pressure atomization dominated. The higher is the liquid injection pressure drop, the smaller is the droplet diameter.

The curve shape of droplet diameter under 0.37 and 0.6 MPa is similar in Fig. 8a. But the droplet diameter under 0.6 MPa is bigger. The formation of this phenomenon can be explained as follows: On the one hand, excessive liquid injection pressure drop would lead to worse pneumatic atomization. On the other hand, with the increase of liquid injection pressure drop, the pressure atomization turns better. However, the improvement of atomization effect is not significant when the liquid injection pressure drop increases to a certain extent. It could be assumed that the pressure atomization under 0.6 MPa and 0.37 MPa is similar while the pneumatic atomization of 0.6MPa is far worse than 0.37MPa. So the droplet diameters under 0.6MPa are bigger.

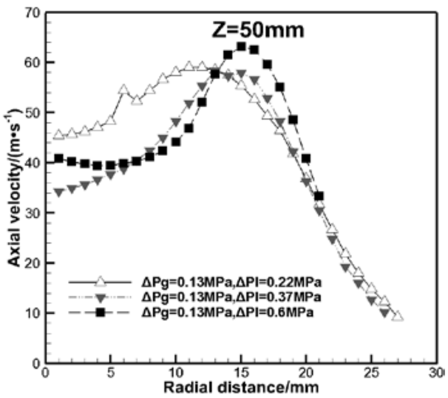
Fig. 8c shows the droplet distribution of z=150 mm, at which the spray is fully developed. It is obviously that the atomization effect under the injection pressure drop of 0.37MPa is better than those under 0.22 MPa and 0.6 MPa. So it exist an optimal liquid injection pressure drop within the scope of 0.37 MPa and 0.6 MPa, at which the atomization effect is best with a minimum SMD. Further study would be conducted to investigate the effect of liquid injection pressure drop on the atomization model.



(a) SMD-Z=50mm



(b) Axial velocity



(c) SMD-Z=150mm

Figure 8. Spatial profiles of SMD and axial velocity under different liquid pressure drop.

4 Conclusion

The unique spatial distribution of a gas-liquid coaxial swirl injector was investigated. On the study of centrifugal injector has Further research of the external flow field would be carried out with the aid of PIV.

(1) Comparing to the single liquid injection, the droplet diameter rapidly decreased while the axial velocity greatly increased after the gas was injected. The existence of the gas has obvious optimization effect to spray atomization. What's more, it suppressed the expansion of the spray.

(2) At a fixed liquid injection pressure drop, injector, atomization quality was optimized as the gas injection pressure drop increase.

(3) An a fixed gas injection pressure drop, it exist a optimum liquid injection pressure drop, in which the atomization is best.

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