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旋流式气液同轴式喷油器在加压空间中雾化特性的试验研究

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Experimental Study on Atomization Characteristics of Gas/liquid Coaxial Swirling Nozzle in Pressurized Space

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ABSTRACT: The atomization characteristics of a gas/liquid coaxial swirling nozzle in pressurized space were investigated. Under different background pressures, the Sauter mean diameter (SMD) affected by the background pressure, the relative velocity of atomization gas to oil and the oil velocity were studied through measuring the size distribution of the droplets with 70 mm to the exit orifice by Phase Doppler Particle analyzer(PDPA). The results show that when the relative velocity of atomization air to oil and oil velocity are fixed, SMD decreases as the background pressure increases; when the background pressure and oil velocity are fixed, SMD decreases as the relative velocity of atomization air to oil increases; under the condition of fixed atomization air pressure and background pressure, the affection rule of the oil velocity on the SMD has an inflexion. SMD increases firstly and decreases lately as oil velocity rises. Based on the experiments, the inflexion value is 9.91 m/s. Correlations between SMD and background pressure, relative velocity of atomization air to oil and oil velocity were analyzed according to the examination data.

KEY WORDS: gas/liquid coaxial swirling nozzle; pressurized space; Sauter mean diameter (SMD); atomization characteristics

摘要：在增压条件下对一种旋流式气液同轴喷油器的雾化特性进行研究。在不同的环境背压条件下，采用PDPA测量距离喷口处70mm的液雾分布，研究了环境背压、气液相对速度、以及燃油流速对索特平均直径(Sauter mean diameter，SMD)的影响规律。结果表明：当保证燃油流速一定、气液相对速度一定的条件下，SMD随环境背压的增大而减小；当环境背压及燃油流速一定的条件下，SMD随气液相对速度的增大而减小；当保证雾化空气压力以及环境背压一定的条件下，燃油流速对SMD的影响规律存在一个拐点，随着燃油流速的增加，SMD先增加后减小，在文中的试验条件下，燃油流速拐点值约为 9.91m/s。根据试验数据整理出SMD与环境背压、气液相对速度及燃油流速的拟合公式。

关键词：气液同轴喷油器；加压空间；索特平均直径；雾化特性

0 INTRODUCTION

The benefits of supercharged boilers include larger volumetric heat release rates，lower weights，smaller dimensions，better dynamic and economic characteristics, and higher reliability and maintainability. Therefore，they can be widely used in power plants[1]. This also requires a shorter burner torch and a larger load adjustment. Among all existing nozzles，the gas/liquid coaxial swirling nozzle delivers the best performance. It is the best to choose the gas/liquid coaxial swirling nozzle[2].

The gas/liquid coaxial swirling nozzle has the benefits of pressure-swirl and air assistant atomization nozzles simultaneously. The liquid phase structure adopts the pressure-swirl nozzle，and the air phase also adopts the swirl flow way to assist the oil atomization. In this case of higher pressure of injecting oil or larger load condition，the oil supply pressure can ensure the good atomization; when the injecting oil pressure is lower，the swirl assistant air with certain velocity can ensure the good atomization of the oil. Therefore，gas/liquid coaxial swirling nozzle has a better load adjustment ability，as much as 1:7. In the same time，the swirl assistant air can cool the oil injector to protect the nozzle from burnout.

At present，the research on air-liquid coaxial nozzle is concentrated on the fields of coal water slurry gasification，Pharmacy and Aircraft Engine[3-9]. Due to the procedure complexity for gas-liquid coaxial type of oil injector，by far the research method is mainly experiment[10-15]. The research on the air blast atomization showed that under the fixed velocity of air and liquid flux，the correlation between the background pressure and (Sauter mean diameter，SMD, D_{SM}) was as follows[16]：

$$D_{SM} \propto p_e^{-1} \tag{1}$$

In the formula：p_e was the background pressure. Under the same condition，the correlation between the background pressure and SMD was as follows[17-18]：

$$D_{SM} \propto p_e^{n} \tag{2}$$

n was between –0.4 and –1. According to the research on atomization performance of air blast three-channel nozzle under high background pressure, when air/liquid ratio was not changed，SMD made negative exponential power function with the background pressure，as follows[19]：

$$D_{SM} \propto p_e^{n} \tag{3}$$

n was between –1.3 and 1.0. It has been concluded that the background pressure had little influence on the SMD in the research about the air blast atomization under the high pressure; and the background pressure and gas/liquid ratio had the correlation as follows[20]：

$$D_{SM} = 48 p_e^{-0.05} (1 + A_{LR}^{-1})^{0.5} \tag{4}$$

In the formula：A_{LR} was the gas/liquid quality rate. Experimental study on twin-fluid air-blast nozzle atomization under high background pressures showed that when gas/liquid ratio was not changed SMD presented direct proportion with the background pressure’s n power; n was between 0.3 and 0.9. Moreover，n increased as the increasing of gas/liquid ratio; and the background pressure and gas/liquid ratio had the correlation as follows[21]：

$$D_{SM} \propto p_e^{n} \tag{5}$$

$$n = 0.853 A_{LR}^{0.376} \tag{6}$$

At present there are a few researches about atomization characteristics of the gas/liquid coaxial swirling nozzle in pressurized space. Moreover，because the nozzle framework and the condition of research are different，the results are different with each other. There is no report on the research about the atomization characteristics of gas/liquid coaxial swirling nozzle in the pressurized space. Therefore it is imperative to research about the atomization characteristics of gas/liquid coaxial swirling nozzle in the pressurized space.

A phase doppler particle analyzer (PDPA) was adopted to study the atomization characters of the gas/liquid coaxial swirling nozzle in the pressurized space through measuring the size distribution of the droplets with 70 mm to the exit orifice. The influences of the background pressure，relative velocity of atomization air to oil and oil velocity on the SMD were investigated. Moreover，correlations between SMD and background pressure，relative velocity of atomization air to oil and oil velocity were analyzed according to the examination data.

1　EXPERIMENTAL METHOD

1.1　The gas-liquid coaxial swirling nozzle

The gas/liquid coaxial swirling nozzle can be referred to Figure 1. It comprises a baffle，an atomization plate，a compression nut and a multi-hole oil dividing plate. The atomization plate has the double face swirl flow of tangential slots，as oil routine and assistant air routine respectively. From the multi-hole oil dividing plate，the oil enters the tangent

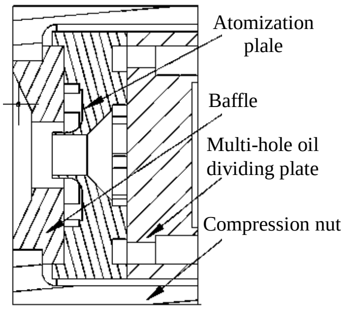


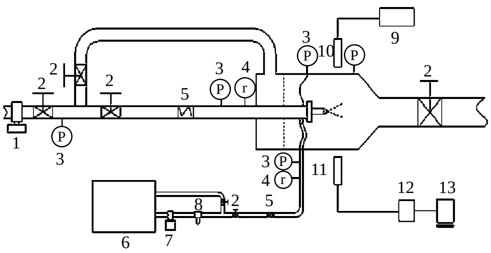
图 1 旋流式气液同轴喷油器

Fig. 1 Gas-liquid coaxial swirling nozzle

slots of atomization plate，and then will be injected from the nozzle. The assistant air enters other tangent slots of atomization plate，and will be injected from the ring-like gap between the atomization plate and the baffle. Lastly，the mixture of oil and assistant air will be injected as tapered atomization body from nozzle. The oil impacted by the aerodynamic force of atomization air can ensure the better atomization results.

1.2 Experimental system

The experiment was done under normal temperature and the background pressure condition. The system diagram for experiment equipment can be referred to Figure 2. During the experiment period，firstly the atomizing air pressure and background pressure were adjusted to the rated value，and the turbo flow meter was used to measure the gas flux. Secondly the oil pressure was adjusted to the rated value through adjusting valve，and the liquid flux was measured with turbo flow meter. When atomizing was steady，the liquid droplets' size characters were measured by PDPA in a line with 1.4 mm diameter in the section located at 70 mm to the exit orifice downstream. The distance of sampling cross section to exit orifice was 70 mm，because the size distribution of the droplets at this position can represent the atomization characteristic of the characteristic torch[22].



1-Compressed air pump; 2-Control valve; 3-Pressure meter; 4-Thermometer; 5-Flow meter; 6-Oil tank; 7-Oil pump; 8-Oil filter; 9-Laser; 10-Transmission probe; 11-Receiving probe; 12-Signal processor; 13-Computer.

图 2 试验装置系统图

Fig. 2 System diagram for test equipment

The experimental instruments underwent a special calibration and the scope and accuracy of the instruments are shown in Table 1.

表 1 测量范围及精度

Tab. 1 Scope and accuracy of the experimental instruments

Code	Description	Accuracy	Test scope
1	Pressure transmitter	0.25%	0-800 kPa
2	Platinum resistor	B class	0-100°C
3	Air turbo flow meter	1.5%	2-11 L/s
4	Liquid turbo flow meter	1%	55-333 mL/s
5	Particle diameter measurement	1%	1-800 μm
6	Particle velocity measurement	0.1%	–600-600 m/s

The liquid medium used in this experiment was the RP3-type aviation kerosene with the density of 802 kg/m^3，the stickiness of 1.25 mm^2/s and the temperature of 20℃.

To avoid the influence of visible window pollution caused by droplet mist on the measure accuracy，a part of dry air was disposed to the inner of visible window to blow off the atomization droplets near the window.

The experimental condition range：the atomization pressure：100-200 kPa; the oil velocity：7-15 m/s; the background pressure of the atomization room：50-150 kPa. The pressure in this work is referred as gauge pressure. The atomization pressure is denoted as Pa with a unit of kPa; The background pressure is denoted as p_e with a unit of kPa; The oil velocity is denoted as v_f with a unit of m/s; The relative velocity of atomization air to oil is denoted as v_{re} with a unit of m/s.

2 RESULTS AND DISCUSSION

2.1 Atomization mechanism analysis

Atomization，and especially air-blast atomization，is a complex multi-parameter problem. At present many researches consider that the atomization includes two stages： primary atomization and secondary atomization. The primary atomization is the forming and breaking up of the liquid film. The instability disturbing on the surface of the liquid film，liquid surface tension and liquid viscosity force affect the primary atomization. The secondary atomization is the liquid threads and big droplets broken up into small droplets. The assistant atomization air kinetic energy，liquid surface tension and liquid viscosity force affect the secondary atomization[22]. The liquid surface tension and liquid viscosity force belong to the atomization liquid properties. The instability disturbing on the surface of the liquid film and the assistant atomization air kinetic energy are affected by the experimental operation parameters，such as the background pressure，the relative velocity of atomization air to oil and the oil velocity.

2.2　The influence of background pressure on SMD

The influence of the background pressure on SMD under the fixed oil velocity and the relative velocity of atomization air to oil is presented in Figure 3. As can be seen，SMD decreases as the background pressure rises. When the oil velocity is fixed，the oil kinetic energy keeps constant. When the relative velocity of atomization air to oil is constant，the density and the kinetic energy of the assistant atomization air rise with the increasing of background pressure，which makes the frictional resistance of the interphase between oil and air augment and instability disturbing to oil increasing，enhancing atomization. With the increasing of background pressure，air density of the atomization room and air resistance of the injected oil rise，so the superficial instability disturbing on the oil is enhanced，which promotes atomization. Consequently，SMD decreases under the comprehensive influences of the above factors while the background pressure changes from 50 kPa to 150 kPa.

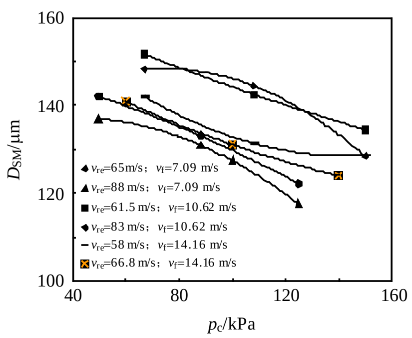


图 3　环境背压对 SMD 的影响

Fig. 3　Influence of ambient pressure on SMD

2.3　The influence of the relative velocity of atomization air to oil on SMD

The influence of the relative velocity of atomization air to oil which is adjusted by the atomization air pressure on SMD under 7.09m/s oil velocity and 100 kPa background pressure is presented in Figure 4. As shown in figure 4，SMD decreases as the relative velocity of atomization air to oil increase. When the oil velocity keeps constant，the oil kinetic energy keeps constant. While the background pressure is fixed，air density of the atomization room and air resistance of the injected oil is fixed，which makes the superficial instability disturbing on the oil constant. As the atomization air pressure rises，the air flux and air velocity rise，leading to the relative velocity of atomization air to oil as well as the air kinetic energy increasing，which makes the frictional resistance of the interphase between oil and air augment and instability disturbing to oil increasing，favoring atomization. Consequently，SMD decreases under the synthesis influences of the above factors.

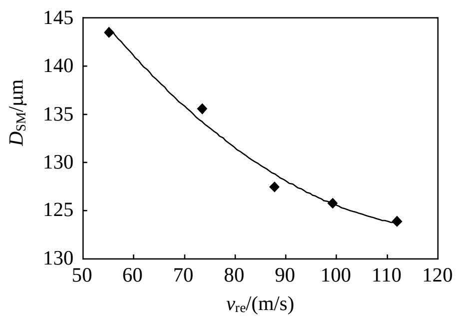


图 4　气液相对速度对 SMD 的影响

Fig. 4　Influence of the relative velocity of atomization air to oil on SMD

2.4　The influence of the oil velocity on SMD

Figure 5 shows the effects of the oil velocity on SMD with specific assisted air pressure and

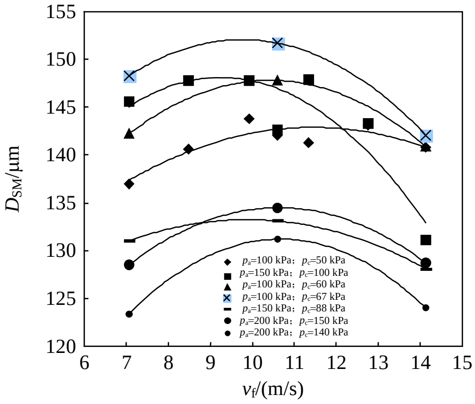


图 5 燃油流速对 SMD 的影响

Fig. 5 Influence of the oil velocity on SMD

background pressure. As shown in Figure 5, the SMD increases at first and then decreases as oil velocity increases. This is because the assisted air velocity keeps steady when the pressure of assisted air and background pressure is constant. While the background pressure keeps fixed, air density of the atomization room and resistance of the injected oil keep constant, which makes the superficial instability disturbing on the oil constant. When the oil velocity increases, the oil kinetic energy increases, favoring oil atomization. On the other hand the relative velocity between oil and air will decreases, leading to the frictional resistance of the interphase between oil and air and instability disturbing to oil weaken, which lowers atomization. Consequently, there is an inflexion of the SMD under the synthesis influences of the above factors when the value of oil velocity is around 9.91 m/s. When oil velocity is less than 9.91 m/s, air kinetic energy of assisted air have a decisive effects on the SMD which will rise as the oil velocity rises. While oil velocity is larger than 9.91 m/s, the kinetic energy of oil has a dominant effect on the SMD which will decrease as the oil velocity increases.

2.5 Correlation and analysis

According the relationship between SMD and oil velocity shown in Figure 5, there is an inflexion of 9.91 m/s. Therefore the relationships between the SMD and background pressure, relative velocity of atomization air to oil, oil velocity in two parts were simulated respectively based on the least square method.

If $v_f \le 9.91$ m/s,

$$D_{SM} = 200\left(\frac{p_e}{1\,000} + 0.101\right)^{-0.25} v_{re}^{-0.18} \left(\frac{v_f}{9.91}\right)^{0.1} \quad (7)$$

If $v_f > 9.91$ m/s,

$$D_{SM} = 206\left(\frac{p_e}{1\,000} + 0.101\right)^{-0.31} v_{re}^{-0.21} \left(\frac{v_f}{9.91}\right)^{-0.19} \quad (8)$$

As shown in Figure 6, when $v_f \le 9.91$ m/s, all the errors between the calculational values of SMD from the formulas (7) and experimental values are in ±10%. The max error is 8.6% and the average error is 3.7%. As shown in figure 7, when $v_f > 9.91$ m/s, all the errors between the calculational values of SMD from the formulas (8) and experimental values are in ±10%. The max error is 5.0% and the average error is 2.0%. Therefore, it can be concluded that the formulas (7) and the formulas (8) can predict the SMD reasonably for this nozzle.

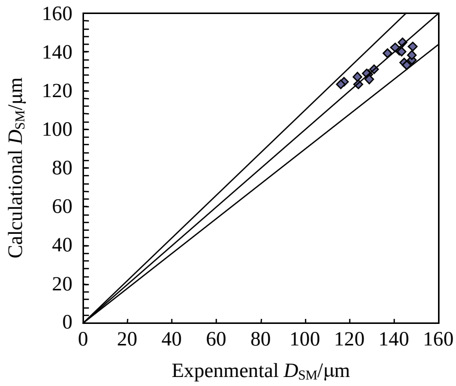


图 6 $v_f \le 9.91$ m/s 时 SMD 比较

Fig. 6 Comparison of SMD($v_f \le 9.91$ m/s)

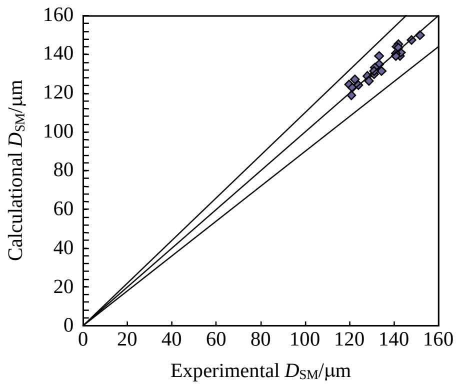


图 7 $v_f > 9.91$ m/s 时 SMD 比较

Fig. 7 Comparison of SMD($v_f > 9.91$ m/s)

3 CONCLUSIONS

The gas/liquid coaxial swirling nozzle has the combined benefits of the pressure-swirl and the air assisted atomization nozzles. Its atomization characteristics were synthetic affected by the background pressure, the relative velocity of atomization air to oil，and oil velocity. Atomization characteristics of a gas/liquid coaxial swirling nozzle in a pressurized space were studied. The conclusions are as follows：

1）SMD decreases as environment background pressure increases within the range from 50 kPa to 150 kPa with specific oil velocity and relative velocity of atomization air to oil.

2）SMD decreases as the relative velocity of atomization air to oil increases with constant oil velocity and background pressure.

3）At a constant assisted air pressure and background pressure，when the oil velocity is no more than 9.91 m/s，the SMD increases while oil velocity increases. The SMD decreases as the oil velocity increases when oil velocity is larger than 9.91 m/s.

4）According to the data obtained in experiments，relationships between the SMD and background pressure，relative velocity of atomization air to oil，and oil velocity were summed up as follows：

If $v_{\mathrm{f}} \le 9.91$ m/s，

$$D_{\mathrm{SM}} = 200\left(\frac{p_e}{1\,000} + 0.101\right)^{-0.25} v_{\mathrm{re}}^{-0.18} \left(\frac{v_{\mathrm{f}}}{9.91}\right)^{0.1}$$

If $v_{\mathrm{f}} > 9.91$ m/s，

$$D_{\mathrm{SM}} = 206\left(\frac{p_e}{1\,000} + 0.101\right)^{-0.31} v_{\mathrm{re}}^{-0.21} \left(\frac{v_{\mathrm{f}}}{9.91}\right)^{-0.19}$$

The above results are important in predicting the atomization characteristics of gas/liquid coaxial swirling nozzle in a pressurized space.

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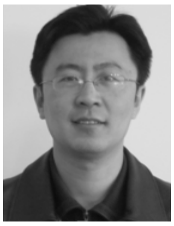
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