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THE INVESTIGATION OF FLOW FIELD IN SWIRLER

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ABSTRACT

In this paper the flow field in swirler is measured by five-hole probe, hotwire and LDV（Laser Doppler Velocimetry）. These results would be much the same .It can provide some ideas for design of swirler.

KEY WORDS

swirler, five-hole probe, hotwire, LDV, vortex

NOMENCLATURE

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γ	specific weight of liquid
h_2	height of liquid
ρ	density of air
V_∞	velocity of air
$K_2^{'}$	coefficient of total pressure
λ	wavelength of laser
f_d	Doppler frequency
k	cross angle of dual-beam
K_1	yaw-factor
K_2	pitch-factor

INTRODUCTION

Swirler is widely used in industrial manufacturing. For example, dedusting, increasing the stability of blast chamber, measuring of flowrate, burnishing treatment of tiny drill way, and non-touch sucking disk of delivery system. Its structure is simple, manufacture with low cost, operating with little loss, so it is paid more attention to .The inner flow field appears different feature with the difference of structure. .Investigation of flow field in swirler is helpful for design various swirler with different purpose.

In this paper the experimental investigation for the inner flowfield of a cylinder swirler was done. Using five-hole probe, hotwire and LDV to measure velocities, total pressure, static pressure of the inner flow field, we can get much the same results. This can provide supports for the design and improvement of swirler.

1 EXPERIMENTAL MODEL AND MEASURING METHOD

As described by figure 1, air flows in from two sides tangentially and forms vortex. Flowrate is controlled by upstream valve; therefore the flowrates of two sides are the same. Air is discharged from outlet. Because the flowfield of swirler is complicated, three methods of measurement were used.

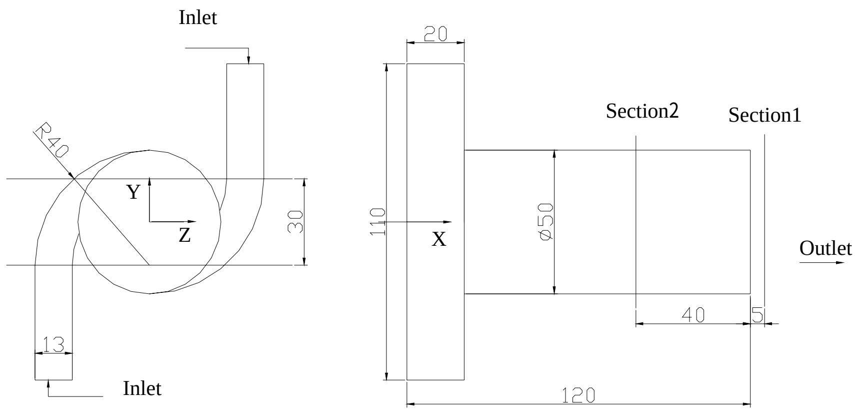


Figure 1 The model of swirler

1.1 Measurements with five-hole probe

The theory of measurement with five-hole probe is based on flow over a sphere.

Velocity component can be calculated by the following equations:

$$\begin{cases} U_x = V_\infty \sin\beta \\ U_y = V_\infty \sin\alpha\cos\beta \\ U_z = V_\infty \cos\alpha\cos\beta \end{cases}$$

Where

V_∞ is the velocity of the coming flow .

U_x, U_y and U_z are axial, radial and tangential velocity respectively.

In addition static pressure is:

$$P = \Upsilon h_2 - \frac{1}{2}K_2^{'}\rho V_\infty^2$$

Total pressure is

$$P_0 = \Upsilon h_2 + \frac{1}{2}(1 - K_2^{'})\rho V_\infty^2$$

1.2 Measurement the inner flow field of swirler with hotwire.

The basic theory of hotwire is to measure the heat loss of the hotwire with flow over it.

Heat loss is related with fluid temperature ,velocity , pressure, density and thermotics feature of fluid and hotwire’s temperature and geometry .If only one parameter is changed , heat loss can be explained as directly measurement varied parameter.. Usually this parameter is velocity or temperature of fluid. If more than one parameter is changed, we must use compensation technique to remove the affect of other variance.

When the turbulence of flow is very low, using single probe we can consider only average velocity is affecting heat loss of the hotwire. At a certain point, we measure three effective cooling velocities respectively when hotwire is set on three planes; horizontal, vertical and oblique plane at the angle to horizontal plane. Therefore we have three equations about cooling velocity and the average velocity of axial direction, radical direction and tangential direction.

$$\begin{cases} U_{1eff}^2 = U_x^2 + K_1^2 U_y^2 + K_2^2 U_x^2 \\ U_{2eff}^2 = U_x^2 + K_2^2 U_y^2 + K_1^2 U_x^2 \\ U_{3eff}^2 = U_x^2 + K_1^2 (U_y \sin\theta - U_x \cos\theta)^2 + \\ K_2^2 (U_y \cos\theta + U_x \sin\theta)^2 \end{cases}$$

U_x , U_y and U_z are average velocity along axial direction, radial direction and tangential direction respectively.

1.3. Measurement by LDV

The basic theory of LDV is that the difference of frequency between incoming ray and scattered ray of moving particle is direct ratio with the moving velocity of particle. This is;

$$V = \frac{\lambda}{2\sin\frac{k}{2}} f_d$$

Essentially, LDV measures the velocity of particles. We use home-made particle producer to seeding oil drop with micron size into the air flow. In swirling flow field, particles are forced with centrifugal force, so the number of particles in the center of the model is few. Hence the data rate will be reduced. In order to get good signal to noise ratio and data rate, the frequency range should be compressed and laser power would be increased. So the experimental results will be much better

2 EXPERIMENTAL RESULTS

Experimental condition: The flowrate at inlet was Q=220,350, 470 L/min respectively; at outlet the pressure was atmosphere pressure

$$P_0 = 0.1MPa$$

The distribution of tangential velocity in swirler is shown in figure.2.From the above figures it can be found that the tangential velocity in the center of the swirler is about zero., and along the radial direction from center to outside it becomes bigger and bigger .There is a point having maximum tangential velocity. From the point with maximum tangential velocity, to wall, the tangential velocity reduces gradually. It can be used the maximum tangential velocity as boundary to divide the flowfield of the swirler into forced vortex region and free vortex region. The forced vortex region is the dominant.

The axial and radial velocity distribution in swirler is shown in figure 3. The distribution of radial velocity in swirler can also be divided into two parts; in external region the direction of flow is outward while in the center region the direction of flow is inward. Radial

Velocity compared with other two components is smaller. The radial velocity is almost only 1/10 of the tangential velocity.

The distribution of pressure is shown in figure 4. With different flowrates, the intersection of positive and negative pressure for static pressure and total pressure in swirler is almost the same position. It means that negative pressure area doesn't change with the increase of flowrate, However magnitude of negative pressure and positive pressure changes with flowrate.

Negative pressure area in the center of the swirler occupies about 2/3 of the transverse section .Due to the existence of the negative pressure area in the outlet of the swirler the reverse flow occurs. Correspondingly there is negative value of axial velocity.

In addition, local tangential turbulence intensity measured by LDV is:

$$T_\omega = \frac{\sqrt{\overline{\omega'^2}}}{\omega}$$

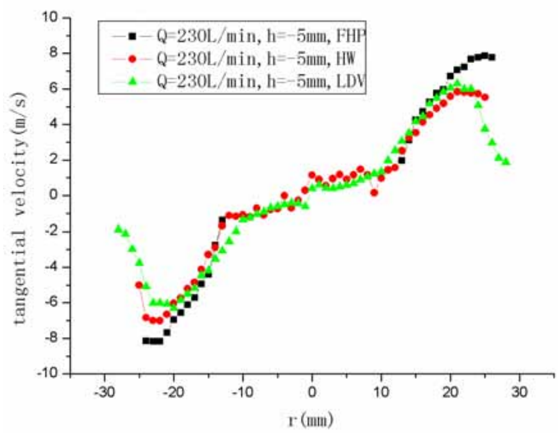
where

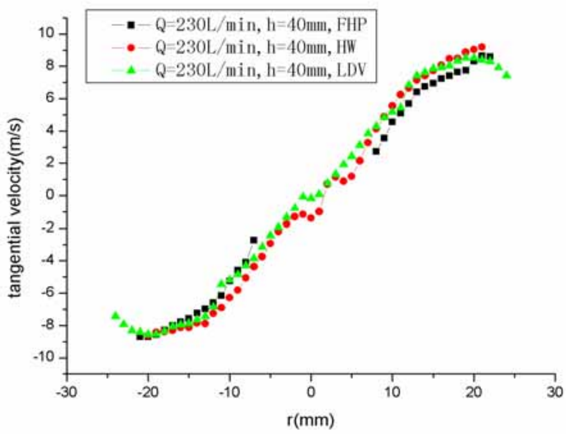
ω is local mean velocity;

ω' is tangential fluctuation velocity

The experimental results are shown as figure 5:

Local Turbulence intensity is very high in the central region of swirler, while turbulence intensity is relative low in the outer region.





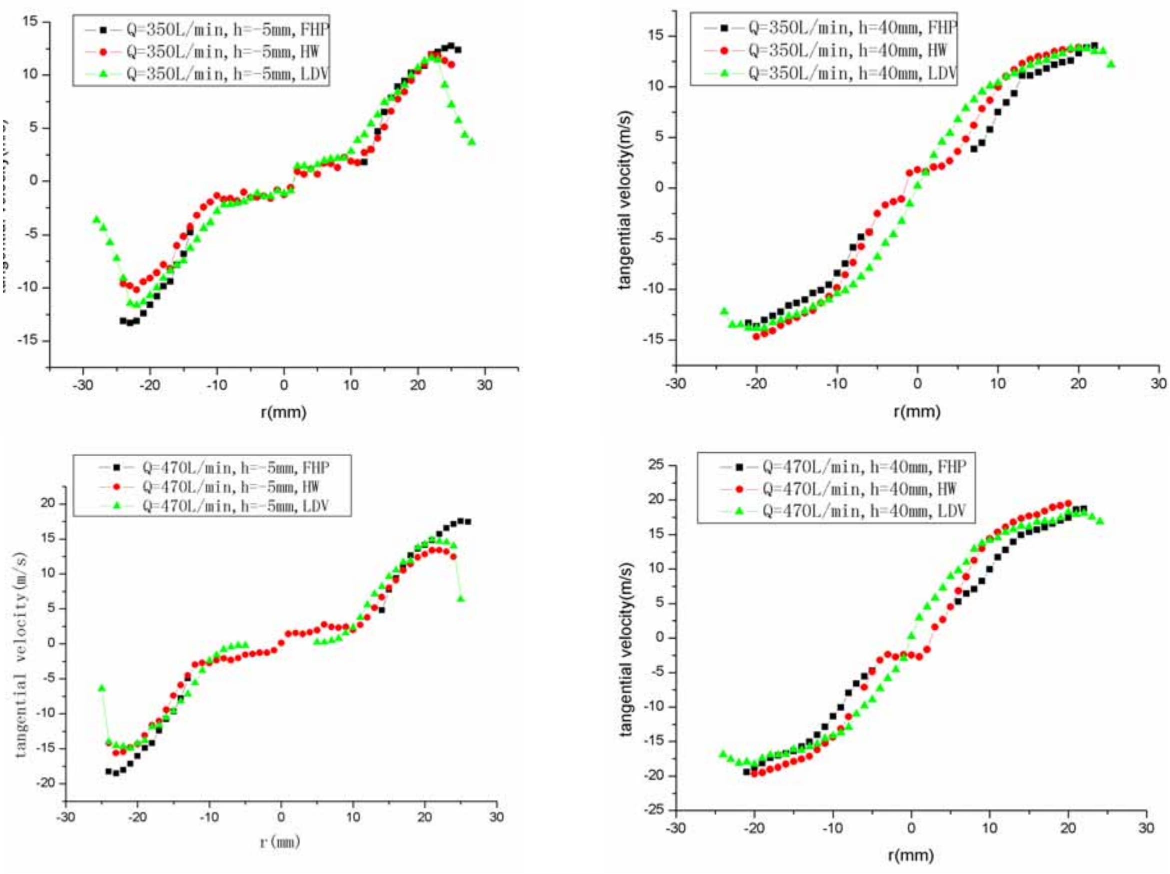


Figure 2 The distribution of tangential velocity

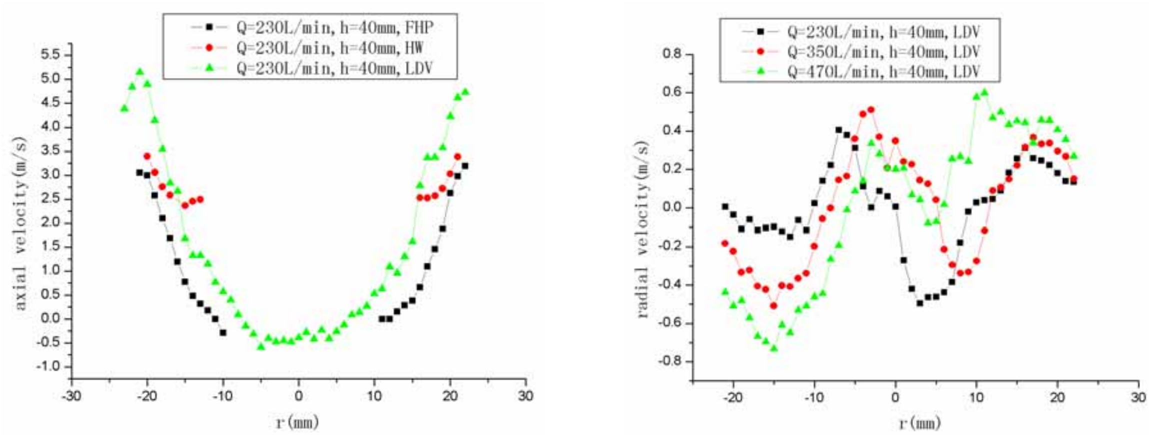


Figure 3 The distribution of axial and radial velocity

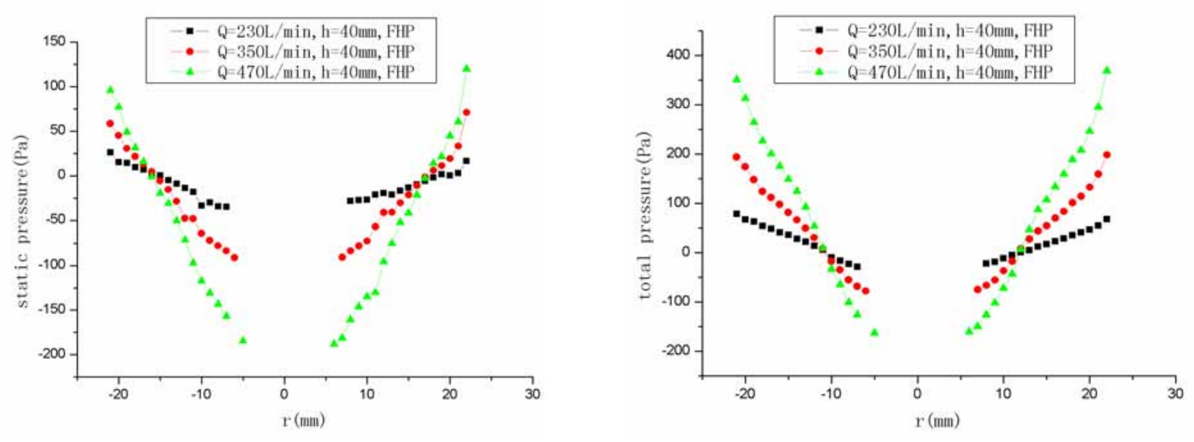


Figure 4 The distribution of pressure

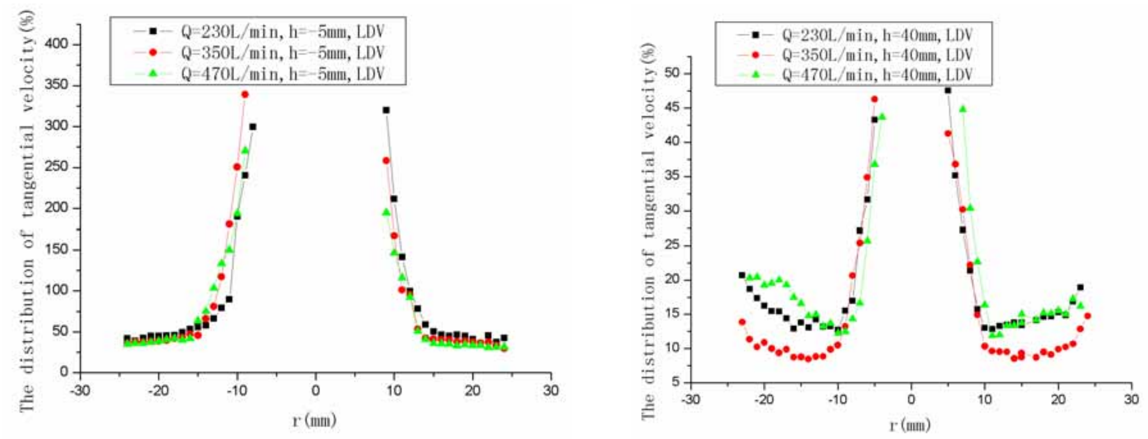


Figure 5 The distribution of tangential velocity

3 NUMERICAL SIMULATIONS

Differential equations of flow field for swirler (mass conservation equation and momentum conservation equation) are

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0$$

and

$$\frac{\partial(\rho u_i)}{\partial t}+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i$$

Where: p is static pressure; τ_{ij} is stress tensor and g_i is body force of gravity.

Using RNGK- ε turbulence model to calculate, RNGK- ε is a kind of empirical mode.

Figure 6 shows the comparison between experimental and numerical simulation results of tangential velocity. The numerical simulations show good agreement with experimental data

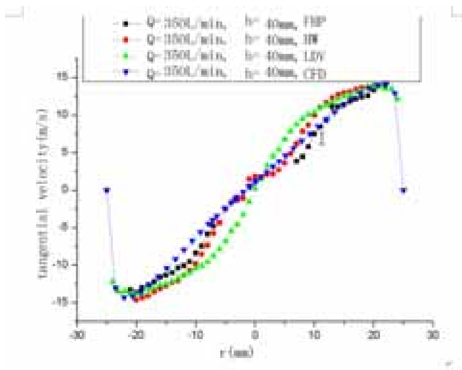
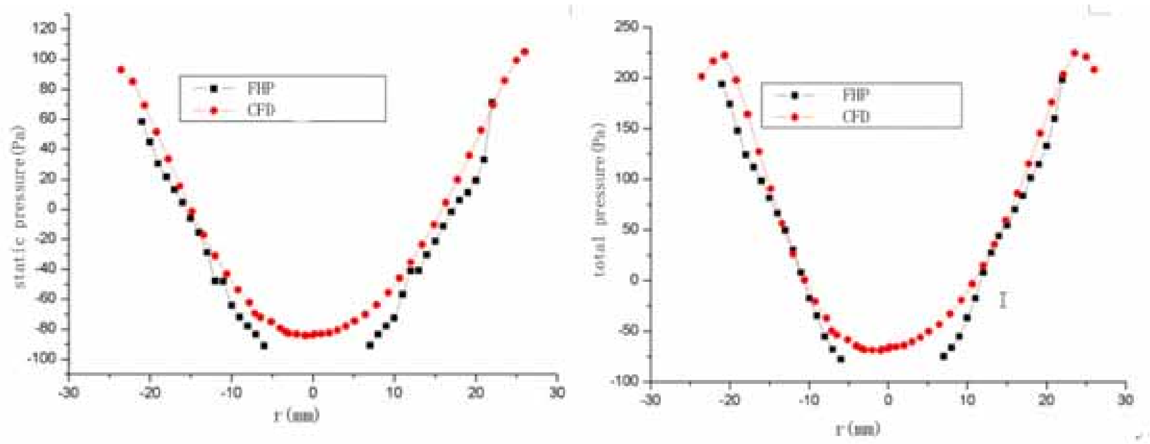


Figure 6 The distribution of tangential velocity

The results of experiment about the static and total pressure measurement and the numerical simulation are shown in the figure 7.



Q=350L/min, h=40mm Q=350L/min, h=40mm

Figure 7 The distribution of pressure

The result of numerical simulation indicates that the experimental data get from five-hole probe are almost the same with numerical simulation. From the above two results there are both negative pressure region in the center part and positive pressure in outer part. The experimental results and numerical simulation can provide us reliable basis for the design of swirler.

4 CONCLUSIONS

1、We can measure distribution of total and static pressure with five-hole probe . But it can interfere flow field seriously. The velocity is low and turbulence intensity is high in the center part, therefore, the error of measurement is bigger here. Measurement with hotwire has many merits, such as high frequency response, little interference to flow field, and easily collecting data and doing statistictical processing with computer. But when the measured value is near to zero, measuring error is very big. LDV is a kind of non-contact measurement technique. It can measure velocity with a wide range. It can measure reverse flow and it has a relatively high spatial resolution and a quick dynamic response .But its measurement is limited by the seeding particles.

2、The tangential velocity in the swirler is dominant The axial velocity is smaller. The radial velocity is the least. .

3、The results of measurement indicates that there are two kinds of flow pattern in the swirler There are forced vortex in the center region and free vortex in the outer part. . From experiment, It can be found that the region of forced vortex is dominant .The region of free vortex is relatively small.

4、There is the phenomenon of reverse flow around the outlet of the swirler.. There are negative pressure region both in total pressure and static pressure. And the range of negative pressure area is almost the same with variation of flowrate. The negative value in the central part increases with the increase of flowrate.

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