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Pressure analysis of a Multi-tube Cyclone Separator

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ABSTRACT

In order to study the pressure drop changing in multi-tube guide vane cyclone at the gas transmission station, the model of 21-tube guide vane cyclone was established, and the static pressure, dynamic pressure and total pressure distribution were analyzed in the interior of cyclone separator and cyclonic tube. The results show that the multi-tube pressure drop is mainly composed of single pipe, being about 80% ~ 90% of total pressure drop. In the interior of cyclone separator, the distribution of total pressure and static pressure is very similar, namely that the pressure of inlet chamber is maximal, and the gas-collecting chamber is minimum, and the maximum static pressure is about 6000 ~ 7000 Pa. The dynamic pressure in most regions of 21-tube is the same, being about 500Pa. The variation gradient of dynamic pressure is mainly concentrated on the exit of the exhaust pipe and the interior of single cyclone tube. In the interior of cyclone tube, the distribution of static pressure and dynamic pressure is symmetrical, and the maximum static pressure is in the inlet of cyclonic tube, being 6000 Pa, besides the maximum dynamic pressure is in the inlet of gas exit tube, being 4500 Pa. The symmetry of total pressure along the axis is very good, and its value decreases gradually from surface to center, the inlet value is maximum, being about 6000 Pa.

Key Words: Multi-tube cyclone separator; Numerical simulation; Static pressure; Dynamic pressure; Turbulence

1 Introduction

Multi-tube cyclone separator as a gas-solid separation equipment is widely used in the particle separation process of petrochemical, coal-fired electricity generation, metallurgy, light industry and environmental protection industry etc., because it has some advantages, such as, simple structure, convenient operation and maintenance, large amount of gas processing, high separation efficiency, little space taking and so on [1]. Multi-tube cyclone separator is generally composed by the multiple paralleled guide vane cyclone tube whose diameter is between 50mm and 150mm. Besides, compared with the tangential inlet structure, the guide vane inlet structure has the advantages of little space taking and large amount of gas processing [12].

At present, the separation efficiency and pressure drop of cyclone Separator has been carried out on a lot of research at home and abroad. Luo Xiaolan [3] etc Studied that the solid concentration makes the effect on the separation efficiency and pressure drop, pointing out that the interaction between particles should be valued, and putting forward the interactional calculation formula and the concept of turning point concentration. Li Qi [4, 5] etc studied pressure drop changing of multi-tube dry separator at gas transmission station, and studied the effect of the taper on flow field of cyclone separator at natural gas purification. Xiong ZhiYi [6] etc studied the flow field in the interior of cyclone separator under different pressure. Han ChuanJun [7] etc studied the effect of the blade structure parameters on flow field distribution and separation efficiency of guide vane cyclone tube. Wan GuJun etc [8] analyzed the gas phase flow field of cyclone separator under different temperature and pressure by using the RSM model, and established tangential velocity formula including the temperature and pressure. Trond and Priestman[9, 10]studied the flow field of multi-tube cyclone separator that is used for gas liquid separation by numerical simulation method, finding that the particles re entrainment phenomenon will affect the separation performance, and put forward an improving structure. Wu XiaoLin [11] etc studied separation performance of multi-tube cyclone separator. Han ChuanJun [12]etc studied the effect of inlet velocity, particle density, particle total flow rate and operating pressure on the separation efficiency of multi-tube cyclone separator and pressure drop changing. But most studies are about that of single pipe cyclone tube or a few of multi-tube cyclone separator. Therefore, the model of a 21-tube guide vane cyclone separator was established in this paper, and pressure distribution in the interior of cyclone separator and cyclone tube was done systematic study.

2 Calculation model

2.1 Turbulence mode

There is three-dimensional strong swirling flow movement inside the cyclone separator, thus choosing the appropriate turbulence model to simulate is very important. K-epsilon model is an eddy viscosity hypothesis model based on the isotropy, including the Standard k - epsilon model, the RNG k-epsilon model and Realizable k-epsilon model. The RNG k-epsilon model that is an improved model on the basis of the Standard k-epsilon model by using the Renormalization group theory is widely applied. Besides it comes from the strict statistical techniques [13], and it can effectively improve the calculation accuracy and credibility. RNG k-epsilon model closes fluid basic equations by solving k and epsilon two equations, specific as follows:

（1）

（2）

Where, is turbulent kinetic energy produced by the average velocity gradient, (m^2/s^2). is turbulence kinetic energy produced by buoyancy. is coefficient of thermal expansion. is turbulence compressibility. is turbulent Mach number. is velocity of sound, (m/s). ,, —k， ε is the effective prandtl number. — ε is the additional term of the equation to adapt to computing needs of the rapid flow of the strain rate and flow-path curvature change. is user-defined source conditions. Constant. t — Time, (s). — Fluid density, (kg/m^3). x_i, x_j — Position coordinates, (m). u_i — Velocity component, (m/s). $_{eff}$ — Effective viscosity, (Pas). — Turbulent dissipation rate, (m^2/s^3).

2.2 Geometric model

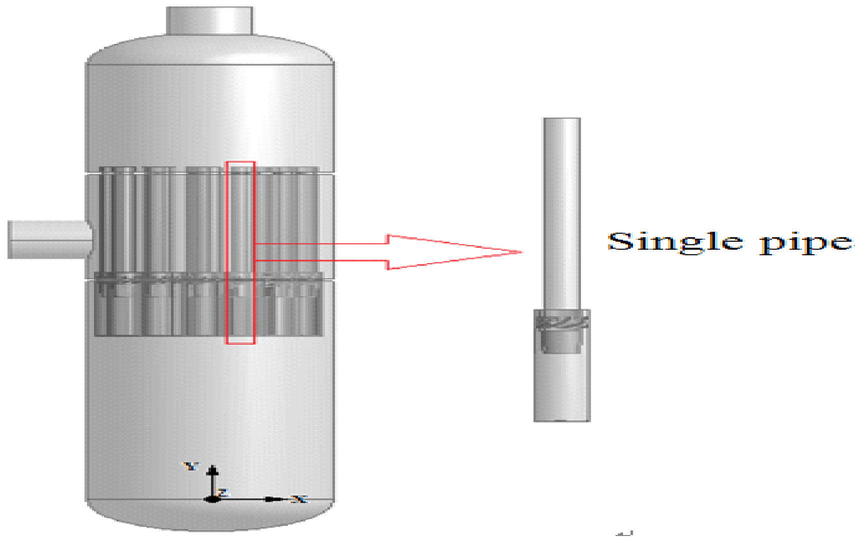

Figure 1 Multi-tube cyclone separator fluid domain model

In this paper, the multi-tube cyclone separator is composed of 21 paralleled cyclone tubes, and it is divided into three parts through two kinds of separator that are formed by welding the master cylinder of single pipe and gas exit tube, namely inlet chamber, dust chamber, gas collecting chamber, as shown in figure 1. The gas with some dust enters into the inlet chamber from the side entrance of the separator, and it is gathered and compressed in the inlet chamber and then flows into the single cyclone tube. At last, the separation process is done.

Cyclone tube that consists of guide vane, gas exit tube and master cylinder is the main separation components of multi-tube cyclone separator, and the guide vane has the orientation and acceleration role. The gas with some dust enters into cyclone tube from the axial-entrance, and under the function of guide vane, the downward movement of the fluid along the axis is converted into tangential movement, and then solid particles are thrown toward the wall by taking advantage of the density difference of the gas phase and solid phase, and after the gas purification reaches the bottom of the main cylinder, the gas flows in reverse and at last it is vented from the gas exit tube.

2.3 Boundary condition

There is the strong swirling flow movement inside the cyclone separator, thus the turbulent model of gas phase flow field selects the RNG k-epsilon model, while after the solid phase particles join, the DPM discrete phase model is selected, and then gas-solid two-phase flow field was simulated at the same time. The momentum equation and turbulence intensity equation are solved based on the finite volume method, the SIMPLEC algorithm, PRESTO interpolation format, the QUICK format and the couple method of pressure and velocity.

According to operation conditions of the multi-tube cyclone separator in service, boundary conditions in the regions are set in the Fluent, as follows:

①Fluid inlet: The inlet boundary was set as velocity inlet, and fluid inlet velocity is 7 m/s, and the operating pressure is 4 MPa and normal temperature. The gas medium is the methane whose density ρ is 0.67 kg/m^3, dynamic viscosity μ is 1.087 x 10-5 Pa·s under the standard condition, approximate instead of natural gas.

②Gas outlet: It was set as outflow, and flow-weighted is 1, namely that all gas flows from the export.

③Solid outlet: It was set as outflow, and flow-weighted is 0。

④Wall: The wall boundary is no slip, and the standard wall function is calculated near surface.

3 Results and analysis

3.1 Static pressure distribution

The static pressure distribution of 21-tube cyclone separator is shown in figure 2. From the Figure 2, we can know that the static pressure is mainly distributed in three obvious regions, the gas collection chamber, inlet chamber and dust chamber respectively. There is not the gas-solid separation process in the inlet chamber, thus the turbulence intensity is weak, and energy consumption is low, so its static pressure is maximum, being about 6000 ~ 7000 Pa (in this paper, all pressure is the change value in the cyclone separator, so its real value should be add the corresponding operating pressure). The dust chamber is mainly used to collect the impurities of solid particles that are expelled from the conical bottom of single cyclone tube. There are a lot of solid particles colliding each other, and there is a channeling and back-mixing phenomena in the conical bottom of the single pipe, thus the turbulence intensity is strong, and the static pressure is about 0 Pa. The static pressure in the gas collection chamber is the lowest, and the pressure of the top exit is about -3000 Pa. This is because that after the gas purification, the gas is vented from the gas exit tube, and the gas is collected and compressed in the gas collection chamber. Besides, because the flow rate of gas phase is much larger more than that of solid phase, the amount of fluid compression of the gas collection chamber is much greater than that of dust chamber, thus the turbulence intensity is stronger, and the loss of pressure is the largest.

From the drawing of partial enlargement, we can know that the static pressure in the interior of cyclone tube is symmetrical, and the pressure decreases gradually from the surface to the center, which is the same as the single cyclone tube when the single cyclone tube was analyzed alone. At the same time, the static pressure in the entrance of cyclone tube is the maximum, being about 6000Pa, and the static pressure in the center of vortex core is minimum, being -5000 Pa.

In general, the value that the static pressure of fluid inlet subtracts that of gas outlet can expressed as the pressure drop approximatively. Under the given operation condition, the pressure drop of 21-tube cyclone separator is about 6500 – (-3500) = 10000 Pa, and the pressure drop of signal cyclone tube is about 6000 – (-2000) = 8000 Pa, which is the 80% of multi-tube pressure drop. That is consistent with the literature[11], namely that the pressure drop of multi-tube is main from the pressure drop of signal tube, and it is about 80%～90% of total pressure drop.

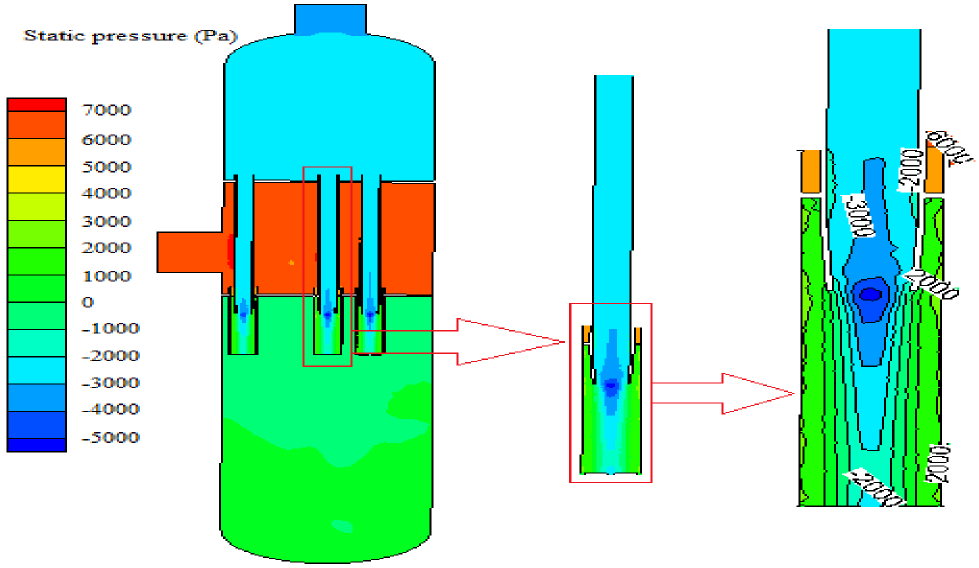

Figure 2 the static pressure distribution of 21-tube cyclone separator

3.2 Dynamic pressure distribution

Dynamic pressure can be expressed as. The dynamic pressure is bigger, the velocity is bigger, and turbulence intensity is stronger, and the energy loss is greater. There is the interconnection between dynamic pressure and static pressure, and when the fluid flow is steady, the famous Bernoulli equation can be expressed as:

（3）

In the equation，the static pressure is the first item, and the dynamic pressure is the second. When discussing the cyclone separator, the second item can usually be ignored, because compared with the rest of second items, the fluid height difference is small, and density ratio is low. Therefore, the static pressure and dynamic pressure can be mutual transformation, namely that when the speed is high, static pressure is low, while when speed is low, static pressure is high. What’s more, there is friction in the actual flow of fluid, thus Mechanical energy loss caused by friction will reduce the sum of three items of Bernoulli along the flow direction, namely that the sum of three items will not be a constant. However, for the cyclone separator, the frictionless flow is still a reasonable approximation method, because the sum of three items of Bernoulli just has a little change.

The dynamic pressure distribution of 21-tube cyclone separator is shown in figure 3. The dynamic pressure in the most regions of 21-tube is the same, being about 500Pa. The variation gradient of the dynamic pressure is main concentrated on the exit of the exhaust pipe and the interior of signal cyclone tube, which indicates that turbulence intensity of two regions is strong. The structure of the exhaust pipe exit is simple, so the turbulent motion is mainly caused by the structure mutation. While the structure of signal cyclone tube is complicated, so the dynamic pressure distribution in the interior of cyclone tube can’t be visually look, and the single pipe cyclone tube was the local enlarged image. From the picture, we can know that dynamic pressure distribution is the same as that of the static pressure, and it is also symmetrical. The dynamic pressure of single pipe inlet is minimum, being about 500Pa, while the dynamic pressure of the gas exit tube inlet is maximum, being 4500Pa.

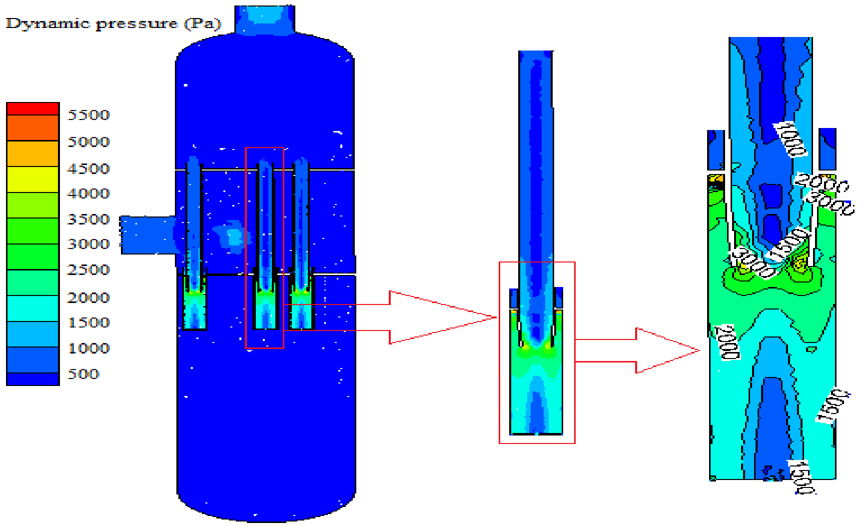

Figure 3 the dynamic pressure distribution of 21-tube cyclone separator

3.3 Total pressure distribution

In the Fluent, total = static pressure + dynamic pressure, which denotes total energy. The total pressure distribution of 21-tube cyclone separator is shown in figure 4. The total pressure distribution is the similar with the static pressure, namely that the pressure of the inlet chamber is maximum, and that of the gas collection chamber is minimum. For the single cyclone tube, the symmetry of total pressure along the axis is very good, and its value decreases gradually from the surface to the center. The inlet value is maximum, being about 6000 Pa, and the total pressure in the center of vortex core is minimum, being -3000 Pa. What's more, the total pressure of the guide vane is smaller, because the guide vane has the effect of acceleration, the pressure can convert into the kinetic energy after the fluid flows around the guide vane.

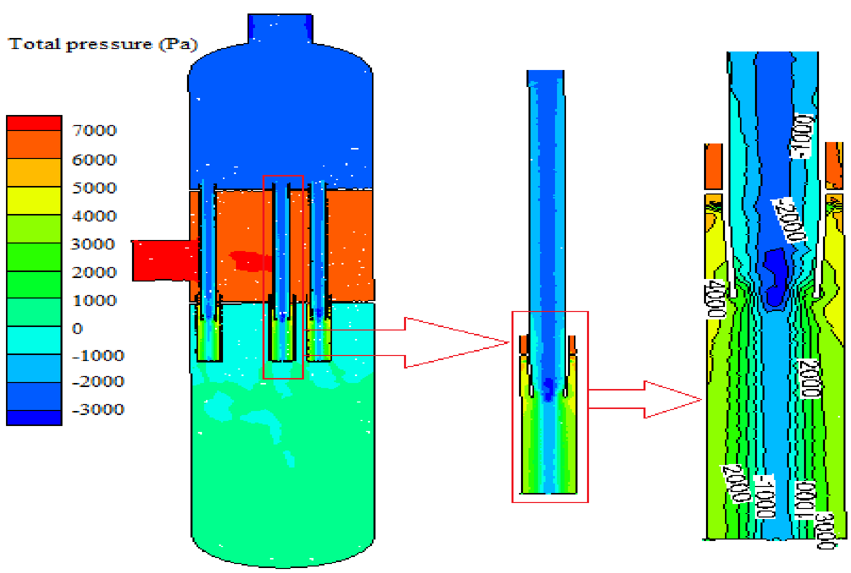

Figure 4 the total pressure distribution of 21-tube cyclone separator

4 Conclusion

- In the interior of cyclone separator, the static pressure is mainly distributed in three obvious regions, the gas collection chamber, inlet chamber and dust chamber respectively. The static pressure of the gas collection chamber is maximum, being about 6000 ~ 7000 Pa, and the static pressure of the dust chamber is about 0 Pa. The static pressure in the gas collection chamber is the lowest, and the pressure of the top exit is about -3000 Pa. The dynamic pressure in the most regions of 21-tube is the same, being about 500Pa, and the variation gradient is main concentrated on the exit of the exhaust pipe and the interior of signal cyclone tube. The total pressure distribution is the similar with the static pressure, namely that the pressure of the inlet chamber is maximum, and that of the gas collection chamber is minimum. the pressure drop of multi-tube is main from the pressure drop of signal tube, and it is about 80%～90% of total pressure drop.
- In the interior of cyclone tube, the distribution of static pressure is symmetrical, which is the same as the single cyclone tube when the single cyclone tube was analyzed alone. The static pressure in the entrance of cyclone tube is the maximum, being about 6000Pa, and the static pressure in the center of vortex core is minimum, being -5000 Pa. The dynamic pressure is also symmetrical. The dynamic pressure of the gas exit tube inlet is maximum, being 4500Pa, while the dynamic pressure of single pipe inlet is minimum, being about 500Pa. The total pressure distribution is the similar with the static pressure, the symmetry of total pressure along the axis is very good, and its value decreases gradually from the surface to the center. The inlet value is maximum, being about 6000 Pa, and the total pressure in the center of vortex core is minimum, being -3000 Pa.

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