

Numerical Study of Gas-liquid Micro-cyclone Separator Flow Field

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Abstract—Based on Reynolds stress model (RSM), the three-dimensional flow field of a gas-liquid micro-cyclone separator with a diameter of 75 mm have been simulated with the computational fluid dynamics (CFD). The distribution of gas tangential velocity of the inside flow field and its effects on the movement of liquid droplets are presented in this paper. The results suggest that the micro-cyclone accords with the vortex motion rules and the droplets fractional efficiency change with the inlet flow rate. Also, an efficient separation zone of the micro-cyclone have been found.

Keywords- CFD; Micro-cyclone; Numerical study; Tangential velocity

I. INTRODUCTION

The gas-liquid micro-cyclone is used to implement gas-liquid separation by centrifugal force with a simple structure and without moving parts. The 3D turbulent flow of micro-cyclone is a very complicated. To investigate the flow characteristics, the mechanism of separation and set up mathematical models of the internal flow field, theoretical analysis, tests and numerical simulation were generally used. In recent years, the micro-cyclone had undertaken extensive research by CFD simulation [1-15], because the research of theoretical analysis and tests hasn't applied to the separation of complex turbulent flow. Recent studies show that RSM turbulent models are in very good agreement with the measured value by used in simulating the mean velocity and static pressure.

In this article, CFD simulation technology was used to simulate the flow field inside the gas-liquid micro-cyclone separator with a diameter of 75 mm. Simulation with established models shows that the flow field and tangential velocity inside the micro-cyclone separator were changed. Similarly, the areas with different tangential velocities changed under different processing volumes.

II. EXPERIMENTAL

A. Computing Models

1) *The mass and momentum conservation equations of incompressible fluid at mean-time Reynolds number:*

$$\frac{\partial u_j}{\partial x_i} = 0 \quad (1)$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j} (u_i u_j) = \frac{\partial p}{\partial x_i} + \nu \frac{\partial}{\partial x_j} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) + \frac{\partial \tau_{ij}}{\partial x_j} + f_i \quad (2)$$

$$\tau_{ij} = \mu_t \left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) - \frac{2}{3} \mu_t \delta_{ij} \frac{\partial u_j}{\partial x_j} \quad (3)$$

2) *The transport equation of the RSM model:*

$$\begin{aligned} \frac{\partial}{\partial t} \left(\overline{\rho u_i u_j} \right) + \frac{\partial}{\partial x_k} \left(\overline{\rho u_k u_i u_j} \right) &= \frac{\partial}{\partial x_k} \left(\overline{\rho u_i u_j u_k} + \overline{p u_i \delta_{kj}} + \overline{p u_j \delta_{ik}} \right) + \\ & \frac{\partial}{\partial x_k} \left[\underbrace{\mu \frac{\partial}{\partial x_k} \left(\overline{u_i u_j} \right)}_{D_{L,ij}} \right] - \rho \left(\underbrace{\overline{u_i u_k} \frac{\partial u_j}{\partial x_k} + \overline{u_j u_k} \frac{\partial u_i}{\partial x_k}}_{P_{ij}} \right) - \rho \beta \left(\overline{g_i u_j \theta} + \overline{g_j u_i \theta} \right) \\ & \rho \left(\underbrace{\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}}_{\phi_{ij}} \right) - 2 \mu \frac{\partial u_i u_j}{\partial x_k \partial x_k} - 2 \rho \Omega_k \left(\underbrace{\overline{u_j u_m \epsilon_{ikm}} + \overline{u_i u_m \epsilon_{jkm}}}_{F_{ij}} \right) \end{aligned} \quad (4)$$

In the formula, the first term is transient phase, C_{ij} is convection phase, $D_{T,ij}$ is turbulent flow diffusion phase, $D_{L,ij}$ is molecular viscosity diffusion phase, P_{ij} is shear stresses part, G_{ij} is buoyancy part, ϕ_{ij} is pressure strain term, ϵ_{ij} is viscous dissipation, F_{ij} is system rotates

B. Geometrical Model and Mesh Dividing

The cyclone separator have been studied by many researchers with different structures and sizes [16-18], but it is rare for the micro-cyclone separator with the cylindrical section diameter of 75mm. As shown in Figure 1, the structure dimension of the micro-cyclone separator involves: diameter of the cylindrical section is 75mm, and ordinate is origin, and the origin of coordinates in the central axis of the top cover of micro-cyclone separator, positive direction is down.

Owing to the sharp degree of connection pipe and cylinder, take method of block grid generation. In different regions were using a structured grid, grid node number is 370000.

C. The Mathematical Model and Boundary Conditions

Based on the Reynolds stress model (RSM), unsteady incompressible turbulent flow in the micro-cyclone separator under different flow was simulated by establishing the discrete equations and using QUICK difference scheme and SIMPLE algorithm for solving the control equation. In addition, the motion trajectory of droplets was simulated using a discrete phase model (DPM).

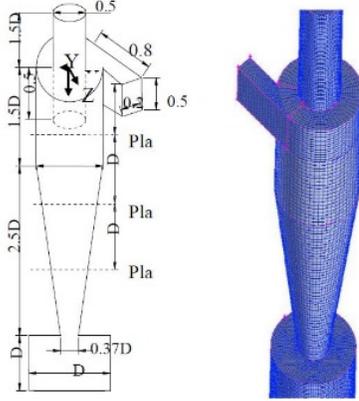


Figure 1. (a) Geometric figure of the micro-cyclone separator, (b) Grids layout of the micro-cyclone separator.

a) *Inlet boundary conditions*: inlet flow is normal temperature air, Entrance velocity is 4m/s, 8m/s, 12m/s, 16m/s. The inlet boundary condition for DPM is the Escape boundary conditions. In other words, the droplets return to the surface to break away from the boundaries. Thus, the computational domains were not to be calculated.

b) *Outlet boundary conditions*: according to the fully developed tube flow conditions, the gradient of all variables is 0 in normal of the exit section. DPM export settings is escape (Escape) boundary conditions. When the droplet reaches the surface, stop tracking the droplet. Track results are marked as "Escape".

c) *Wall condition: using nonslip velocity condition*. DPM wall settings is trap boundary conditions. This is, once the droplet collision the wall, the droplet is trapped and termination of orbit calculation of the droplets.

III. RESULTS AND DISCUSSION

A. Flow Field Distribution

It can be concluded that tangential velocity plays an important role in the three dimensional gas-liquid movement of the micro-cyclone separator because of the faster speed moving than axial velocity and the imperative condition of producing centrifugal force. Therefore, tangential velocity is the most important performance metric for micro-cyclone separator.

The tangential is consistent basically with the combination vortex movement. The radius of micro-cyclone

separator is divided into three vortex regions: forced vortex region, quasi-free vortex region and boundary layer. The region that radius is from 0 to half- radius of exit tube is the forced vortex region with a linear distribution. And the tangential velocity intensifies sharply and maximum value is approximately twice than the inlet. The next region, to the boundary layer, is the quasi-free vortex region, which tangential velocity is slowly decreasing. In the figures we can deduce the variation tendency of tangential velocity is basically the same.

B. Droplets Fractional Efficiency

According to the simulation of the discrete phase, the droplets fractional efficiency can be obtained by

$$\eta = \frac{\text{The number of particles trapped}}{\text{The number of particles released}} \times 100\% \quad (5)$$

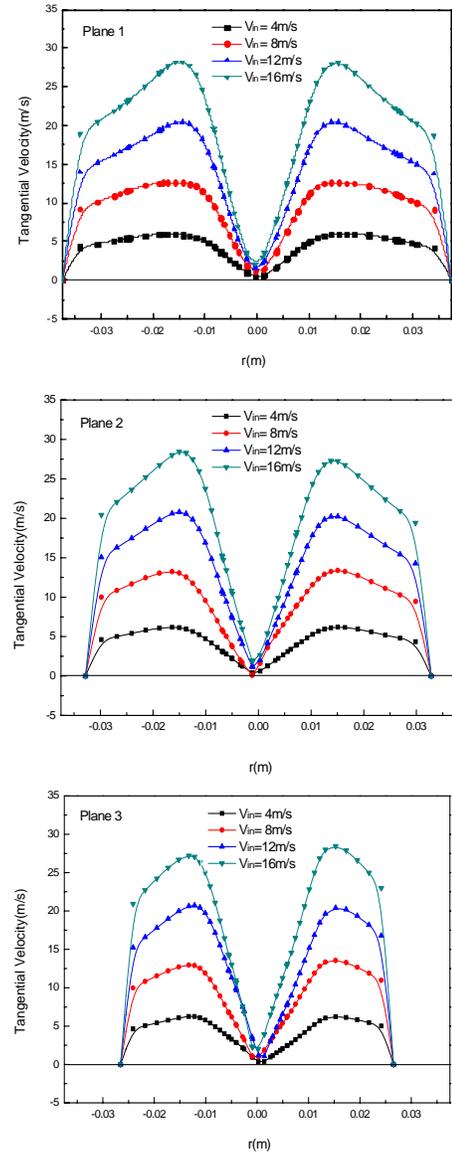


Figure 2. Tangential velocity profiles with different flow rates.

In this study, the separation properties of four different flow rates were simulated under droplets diameters of 0.5 to 10 μm , as Figure 3 shows. It shows how different flow rates impact the droplets fractional efficiency. It is clearly observed that the droplets capture efficiency of micro-cyclone separator rises with the increase of droplets diameter. The droplets diameter greater than 7 μm were almost completely captured. For the 75mm micro-cyclone separator, when the flow rates was 12m/s, the droplets fractional efficiency is highest, and the maximum efficiency is close to 100%. And when the flow rates was 8m/s or 16m/s, the efficiency remains high. Based on this simulation data, if the flow rate is low, it's not enough to generate the centrifugal force to separate the droplets from gas out the micro-cyclone separator. The alternative to this is excessive flow rate, the settle time of droplets in micro-cyclone separator is too short to be captured. In such conditions, it adds the short-circuit flow and increases the gas turbulence, and thus the droplets are brought again. Thus, it shows that if the flow rate is too large or small, the droplets capture efficiency is greatly reduced.

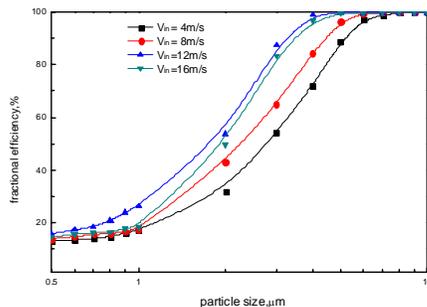


Figure 2. Droplets fractional efficiency with different flow rates

IV. CONCLUSION

In this paper, the numerical simulation of the flow distribution in micro-cyclone separator with RSM model was performed by using CFD. And the droplets fractional efficiency of micro-cyclone separator was calculated using DPM model.

The following conclusions were reached: the tangential degree in micro-cyclone separator basically line with the combination vortex motion, from the axis to the wall, the tangential velocity first increases rapidly to nearly twice of the inlet flow rate, then decreased slowly, and when arrive in the boundary layer region, it dropped sharply to 0. For the 75mm micro-cyclone separator, the droplets diameter greater than 7 μm were almost completely captured. And there is an effective separation area within the flow rates range with 8m/s to 16m/s.

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