

Numerical Simulation Study on Flow Field Characteristics and Separation Efficiency of Micro Cyclone by Shunt Ratio

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Abstract

In this study, based on the current situation of waste drilling fluid treatment, the operating parameters of micro cyclones are investigated. A 10-mm micro cyclone used to separate ultrafine particles was designed and the effect of the split ratio on the pressure and axial velocity in the micro cyclone as well as the total separation efficiency was investigated using CFD techniques. The conclusions obtained are that the pressure gradient in the microcyclone increases with the increase of the splitting ratio; the axial velocity decreases with the increase of the splitting ratio; the total separation efficiency increases with the increase of the splitting ratio.

Keywords

Waste Drilling Fluid; Micro Cyclones; Separation Efficiency; Axial Velocity.

1. Introduction

In oil and gas exploration drilling operations, drilling fluids are used to control formation pressure, suspend rock cuttings, stabilize the wellbore, cool and lubricate drilling tools, and seal the formation[1]. Drilling fluids can be categorized into water-based drilling fluids (WBDF), oil-based drilling fluids (OBDF), and synthetic-based drilling fluids (SBDF) according to their composition[2]. Currently, water-based drilling fluids are widely used (about 80% of all drilling fluids used) due to their low price, easy-to-control performance, and simple production process[3]. And this has led to the fact that most of the waste drilling fluids generated today are waste water-based drilling fluids. Moreover, water-based drilling fluids are composed of freshwater or brine, a weighting agent (usually barite BaSO₄), clay, various types of organic polymers, inorganic salts, inert solids and organic additives[4]. Therefore, the waste water-based drilling fluid will contain not only large rock debris, fine suspended particles of clay, inorganic salts, a small portion of oil, but also a large number of organic chemical treatment agents and heavy metal ions (such as Cr³⁺, Hg²⁺, Cd²⁺, Pb²⁺)[5]. Since waste water-based drilling fluids are mainly composed of large rock chips, small suspended solids, oil, organic chemical treatment agents, inorganic salts and heavy metal ions. Therefore, if it is discharged without treatment, it will cause serious impact on the environment. Currently, the commonly used treatment methods for waste water-based drilling fluids include in-pit landfill, formation reinjection, electrochemical method, stabilization/curing method, microbial degradation method, heat treatment method, and chemical demulsification method. However, all these methods have drawbacks, such as secondary pollution or the inability to reuse the treated fluid phase[6~13].

Solid-liquid separation method refers to the solid-liquid separation of waste water-based drilling fluids using gravity sedimentation, centrifugation, filtration and other techniques. Solid-liquid separation method has received more and more attention due to its low cost, high efficiency, scalable application, and the ability to improve the recycling rate of the liquid phase after the treatment of waste water-based drilling fluids and reduce the secondary use of

chemicals in the treatment process. At present, the commonly used solid-liquid separation equipment such as vibrating screens, centrifuges, etc. have the disadvantages of requiring long-time supervision by technicians, high installation and maintenance costs, and large installation footprints[14]. As a typical high-efficiency separation equipment, hydrocyclone is widely used in solid-solid, solid-liquid, liquid-liquid and other separation processes due to its simple structure, low maintenance cost, large treatment capacity, small footprint and other advantages. However, the current research on cyclone for waste water-based drilling fluid treatment mainly focuses on large-diameter and medium-diameter desander and deslugger, while the research on the application of micro cyclone for waste water-based drilling fluid treatment is still rare. And in recent years, with the development of Computational Fluid Dynamics (CFD) technology, the application of CFD research method has been widely used in the study of hydrocyclone internal flow field characteristics and particle separation process. Therefore, this study is based on the fluid simulation software Fluent, using the RSM model to calculate turbulence and the Mixture model to simulate the particle separation results, and systematically investigated the influence of the change of the shunt ratio of the micro cyclone with a diameter of 10mm on its internal flow field characteristics and separation efficiency.

2. Model Construction and Boundary Condition Setting

2.1. Model Construction and Meshing

The particle distribution of the waste water-based drilling fluid after vibrating screen and subsequent processes and the corresponding physical parameters are shown in Table 1. Therefore, this study based on the corresponding parameters to design a 10 mm diameter micro-cyclone as a simulation object for simulation, micro-cyclone model and grid as shown in Fig. 1. The geometric model is built by SOLIDWORKS software, and the meshing is done by ICEM software for hexahedral structured meshing. When meshing, the grid should be refined at the wall, and a total of 5 boundary layer meshes are divided in this paper to further improve the calculation accuracy.

Table 1. Physical parameters of waste water-based drilling fluids

Particle size range(μm)	Average particle size(μm)	D90 particle size(μm)	solid content(%)	densities(Kg/m^3)
0.186~244.9	5.44	32.19	17%	1425

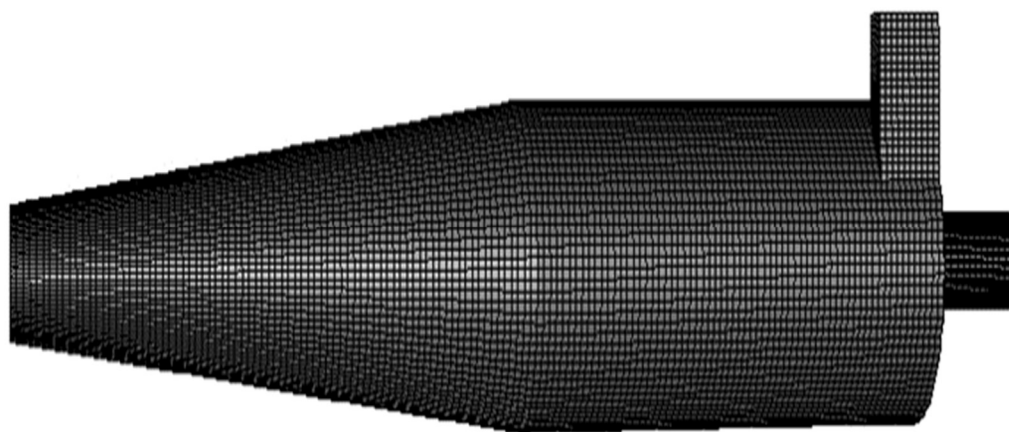


Fig. 1 Mini-hydrocyclone geometric model and structured mesh

2.2. Boundary Condition Setting

First the mathematical model is determined. In the simulation of the microcyclone, the energy conservation equation is ignored since the microcyclone usually operates at room temperature, but the energy-momentum conservation equation as well as the continuity equation need to be obeyed. The energy conservation equation is Eq. (1) and the continuity equation is Eq. (2). Meanwhile, since the flow field inside the microcyclone is a complex flow field with three-dimensional strong cyclonic flow, the Reynolds stress model (RSM) is chosen as the turbulence model in order to ensure the accuracy of the calculation. The transport equation of the Reynolds stress model is Eq. (3).

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = \rho g_j + \frac{\partial}{\partial x_j} \left(\mu_t \frac{\partial u_i}{\partial x_j} \right) - \frac{\partial p}{\partial x_i} \quad (1)$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u_k)}{\partial x_k} = 0 \quad (2)$$

$$\frac{\partial}{\partial t} \left(\overline{\rho u'_i u'_j} \right) + \frac{\partial}{\partial x_k} \left(\overline{\rho u_k u'_i u'_j} \right) = D_{ij} + P_{ij} + G_{ij} + \Phi_{ij} - \varepsilon_{ij} + F_{ij} + S_{user} \quad (3)$$

Where ρ is the fluid density; p is the pressure exerted on the fluid; μ_t is the hydrodynamic viscous coefficient; u_k is the component of the velocity in the k -direction, i.e., the velocity $U=\{u_k\}$ or $\{u,v,w\}$; D_{ij} is the sum of turbulent diffusion term and molecular viscous diffusion term, P_{ij} is the shear term, G_{ij} is the buoyancy-generating term, Φ_{ij} is the pressure-strain term, ε_{ij} is the viscous dissipative term, F_{ij} is the system rotational term, and S_{user} is the user-defined source term.

Secondly, since this paper studies the microcyclone applied to solid-liquid separation of waste water-based drilling fluid, and the solid phase particles are greater than 10%, the mixture model is selected as the multiphase flow model, the water phase is set as the main phase, and the particle phase is set as the second phase. The inlet of the microselector is set as velocity inlet, and the inlet velocity is 9 m.s⁻¹. The overflow and underflow ports are set as free flow out, and the diverter ratio is controlled by setting Flow rate weighting, and the diverter ratio is set to five variables, 5%, 15%, 25%, 35% and 45%, and the wall surface is adopted as the no-slip wall condition. The QUICK format is used as the discrete phase format, PRESTO! format is used as the pressure interpolation format, and SIMPLEC algorithm is used as the pressure-velocity coupling algorithm to calculate the model.

2.3. Methods of Analyzing Simulation Results

(1) Flow field analysis. Four different radial sections Z1=25mm (column-cone interface), Z2=43mm (lower part of cone section) were selected to extract data. Based on the data, the relationship between the variation of different splitting ratios and the three-dimensional velocity field, pressure field, turbulent kinetic energy, pressure drop and separation efficiency are analyzed.

(2) Total Separation Efficiency Analysis. The total separation efficiency of ultrafine particles is calculated for different diversion ratios, and the corresponding total separation efficiency curve is derived. The total separation efficiency is calculated as Eq (4).

$$\mu = m_u / m_i \quad (4)$$

where μ is the mass flow rate at the bottom flow inlet and m_i is the mass flow rate at the inlet.

3. Result

3.1. Effect of Shunt Ratio on Pressure Field

The effect of the shunt ratio on the pressure distribution inside the microcyclone is shown in Fig. 2. As a whole, the pressure curve inside the microcyclone is mainly presented as a "V" structure with high sides and low center. With the increase of the shunt ratio, in the microcyclone near the wall, the pressure value shows a first decrease and then increase, and does not change with the change of axial position; in the center of the microcyclone, the pressure value of the cylindrical section (Z1 section) with the increase of shunt ratio shows a first decrease and then a small increase in the state, while the pressure value of the conical section (Z2 section) is negatively correlated with the shunt ratio, i.e., the pressure value is decreasing with the increase of the shunt ratio. The pressure value of the conical section (Z2 section) is negatively correlated with the shunt ratio, i.e., it decreases with the shunt ratio. Specifically, with the increase of manifold ratio, especially when the manifold ratio is increased from 25% to 35%, the maximum pressure at the wall of Z1 section increases by 36.13%, and the maximum pressure at the center of the shaft increases by 77.15%; the maximum pressure at the wall of Z2 section increases by 37.21%, and the maximum pressure at the center of the shaft decreases by 92.69%; the maximum pressure at the wall of Z3 section increases by 32.01%, and the maximum pressure at the center of the shaft decreases by 92.81%; and the maximum pressure at the center of Z3 section increases by 32.01%, and the maximum pressure at the center of the shaft decreases by 92.81%. 92.81%; Z4 cross-section wall at the maximum pressure increase of 38.77%, the maximum pressure drop in the center of the axis of 76.96%; and when the manifold ratio increased to 35%, the pressure distribution is basically no significant change.

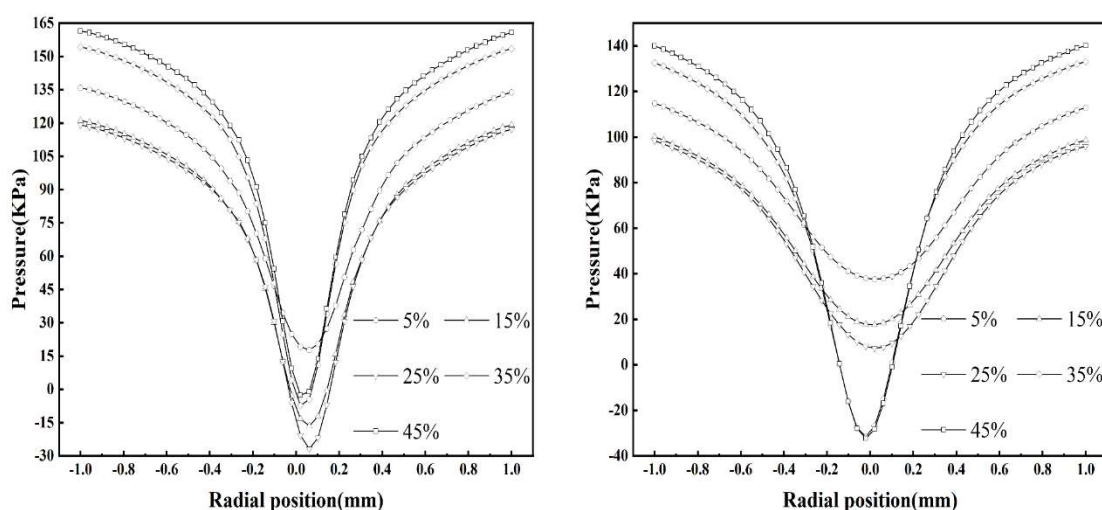


Fig. 2 The influence of shunt ratio on pressure distribution

3.2. Effect of Shunt Ratio on Axial Velocity

In the cyclone separation process of the cyclone, the axial velocity generally affects the time of solid-liquid phase separation in the cyclone because both the overflow and underflow ports of the cyclone are located in the axial direction. In the case of the rest of the conditions are the

same, generally speaking, the larger the axial velocity, the shorter the time required for the separation of materials in the cyclone. The effect of the shunt ratio on the axial velocity distribution inside the microcyclone is shown in Fig. 3. From the figure, it can be seen that the increase of the diversion ratio does not change the axial velocity of the external rotating flow significantly, but it mainly affects the axial velocity of the internal rotating flow. And no matter how the diversion ratio changes, the axial velocity near the radial position $x/R=\pm 0.7$ in the Z1 cross-section shows a weak positive and negative change phenomenon, which indicates that there is a certain degree of circulating flow in this part of the region. However, when the shunt ratio is greater than 35%, the phenomenon of positive and negative changes in axial velocity occurs in the vicinity of $x/R=\pm 0.2$ in both Z1~Z2 sections, which also proves that when the shunt ratio is greater than 35%, a greater degree of circulating flow is generated in the axial region. With the increase of the splitting ratio, the largest change in the peak axial velocity of the internal cyclonic flow occurs at the Z1 section, where the peak axial velocity decreases from -16.74 m.s^{-1} to -8.03 m.s^{-1} , with a decrease of 52.03%, and the largest change in the peak axial velocity of the external cyclonic flow occurs at the Z2 section, where the peak axial velocity decreases from 2.11 m.s^{-1} to 1.63 m.s^{-1} , with a decrease of 22.74%.

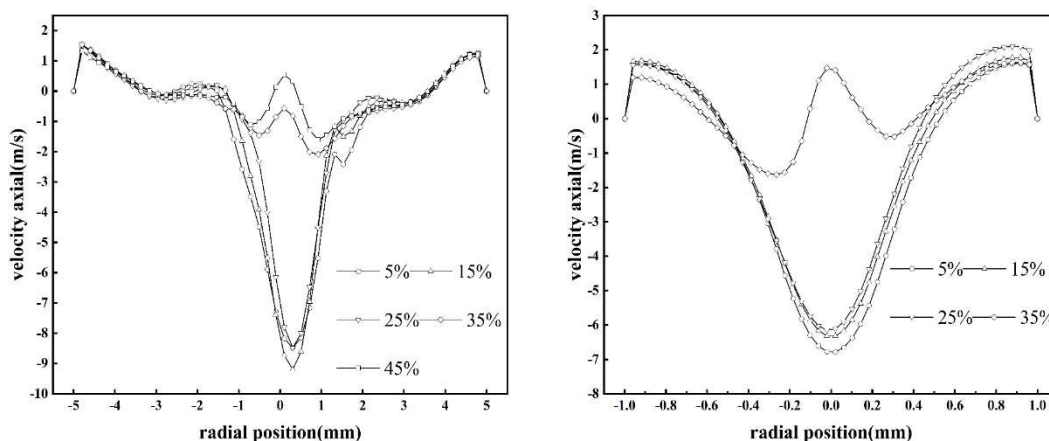


Fig. 3 The influence of shunt ratio on axial velocity

3.3. Effect of Split Ratio on Separation Efficiency

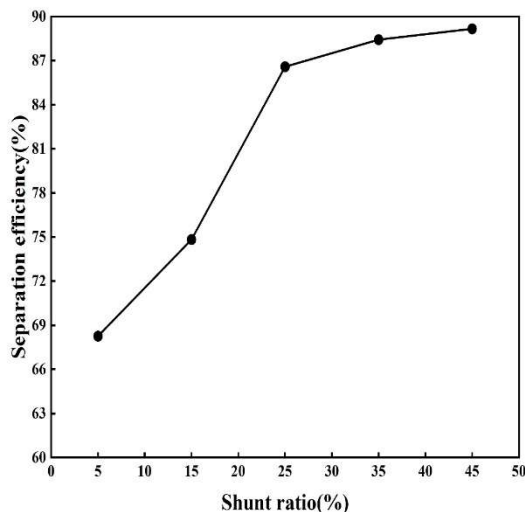


Fig. 4 the influence of shunt ratio on separation efficiency

The effect of shunt ratio on the total separation efficiency is shown in Fig. 4. From the figure, it can be seen that the total separation efficiency shows a gradual increasing trend with the increase of the manifold ratio. However, the increase in separation efficiency slows down after the square shunt ratio increases to a certain extent. When the manifold ratio increases from 5% to 25%, the increase in total separation efficiency is 28.31%, but when the manifold ratio increases from 25% to 45%, the increase in total separation efficiency is only 1.81%.

4. Summary

In this paper, the effect of split ratio on the flow field as well as the total separation efficiency of a cyclone for the separation of ultrafine particles from waste drilling fluids was investigated. The following conclusions were drawn.

- (1) The pressure gradient in the microcyclone increases with the increase in the split ratio, and the maximum increase in wall pressure occurs at the Z2 cross section.
- (2) The change of the split ratio mainly affects the axial velocity at the cyclone in the microcyclone, which decreases with the increase of the split ratio, and the decrease can be up to 52.03%.
- (3) The total separation efficiency of the microcyclone increased as the split ratio increased, but the increase in total separation efficiency slowed down when the split ratio increased to a certain level.

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