Separation performance of hydrocyclone on emulsified oil wastewater floc

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Abstract. In order to improve the separation effect of emulsified oil wastewater flocs, a new separation method was proposed, which used a hydrocyclone to separate emulsified oil flocs. In this paper, the velocity field, pressure loss and floc volume distribution of the two hydrocyclones were studied by numerical simulation, and the difference of the separation performance of two different structures was investigated. The results show that the separation efficiency reaches to 81.7% and 78.9% respectively; the single cone cyclone has smaller pressure loss and energy loss under the same processing capacity; as the particle size of the floc increases, the separation efficiency of the two hydrocyclones increases. This simulation provides a reference for deep treatment of emulsified oil wastewater.

1. Introduction
The emulsified oil wastewater, one of the most difficult types of wastewater to dispose, consists of small particle and it’s hard to be degraded. If the emulsified oil wastewater is directly discharged or not properly treated, it will cause serious damage to the natural environment. The separation methods of emulsified oil wastewater mainly include adsorption separation, filtration separation, flocculation separation and air flotation separation. Activated carbon used in adsorption separation is costly and difficult to recycle [1]. Both filtration separation and air-floating separation require special structures, which requires a large footprint, long separation time and low efficiency. The flocculation method is widely used because of its wide application range, mature technology and good deoiling effect. However, it is difficult to separate the flocs, which are obtained after flocculation. The separation effect of the traditional gravity sedimentation and filtration method is not ideal [2]. In order to improve the separation effect of emulsified oil wastewater floc, a new separation method, hydrocyclone separation of emulsion oil floc, is proposed in this paper. A double-cone spiral double inlet hydrocyclone and a single-cone rectangular single-entry hydrocyclone were designed respectively. Based on previous studies and numerical simulation, the separation performance of two hydrocyclone separators for emulsion oil flocs was investigated.

2. Calculation model

2.1. Structural Design of the Hydrocyclone
Symmetrical placement of the two feed tubes mitigates the asymmetry of the flow field distribution and it can reduce the inlet pressure required for hydrocyclone operation [3]. The cross section shape of the double-cone hydrocyclone of this simulation is rectangular, the inlet flow channel is selected as a spiral type, and the double inlet is symmetrically arranged; the inlet cross section of the single-cone
hydrocyclone is rectangular, and the inlet flow channel is an equal section linear tangential to single inlet form. The structural parameter values of the two hydrocyclones are shown in Table 1.

| Specifications of cone hydrocyclone separator |
|-----------------------------------------------|
| Double cone hydrocyclone                      | Single cone hydrocyclone                     |
| Cylinder diameter /mm                         | 60                                            | 60                                            |
| Import size /mm                               | 7×4                                           | 14×8                                          |
| Overflow diameter /mm                         | 18                                            | 18                                            |
| Underflow diameter /mm                        | 10                                            | 12                                            |
| Barrel height /mm                             | 300                                           | 385                                           |
| Overflow tube insertion depth /mm             | 40                                            | 42                                            |

2.2. Simulated Materials

A kind of emulsified oil wastewater, compounded with PAFC and APAM, was prepared in the laboratory. The mass ratio of the additive was 50:1[^1]. Diatomite was selected as coagulant aid, and it was used after necessary purification and activation. The strength of flocs can be improved by using the pore structure of diatomite as the absorption center. The particle size of the prepared flocs was tested, and the flocs were tested for strength on a digital constant speed paddle mixer, and then the floc size distribution was measured again by a laser particle size analyzer. Separation of flocs is a key factor affecting the efficiency of cyclonic separation. If the floc strength is low, it will be broken during the separation process, and it is also possible to desorb the oil molecules, leading to reduce oil removal rate. The greater strength of the flocs are, the less likely the flocs will break. The average particle size of the flocs before strength test was 62.88 μm. And the distribution of the flocculant floc size after strength test is shown in Fig. 1. It can be seen from the figure that after the strength test, average particle size after fracture is 51.67 μm and strength factor is 82.2. The high-strength flocs can avoid breakage during the hydrocyclone separation process. From the particle size distribution test results, it can be seen that the particle size of the flocs ranges from 3 μm to 121 μm. In addition, the density of the flocs was 1150 kg/m^3 and the total mass flow rate was 0.7728 kg/s.

![Figure 1. Compound flocculant particle size distribution](image)

2.3. Boundary Conditions and Simulation Parameter Settings

The simulations of six micro-hydrocyclones were carried out using Fluent 18. The multiphase flow model is the Mixture model, the turbulence model selects the RSM Reynolds stress model[^5], and the solid wall is assumed to be a non-slip solid wall boundary condition. Considering that the flow state at the wall surface is quite different from that in the turbulent core region, the standard wall function method is adopted to solve the flow near the wall. In the calculation, the convection term of each governing equation is discretized by the QUICK difference scheme, and the pressure equation and velocity equation are coupled by the SIMPLEx algorithm. Inlet boundary condition is set to the speed inlet, capacity of 6.72×10^-4 m^3/s, and the overflow outlet and the bottom flow outlet are outflow outlets.
The water density is 998 kg/m$^3$ and the floc density is 1150 kg/m$^3$. The outcome of two structures are shown in Tab. 2.

| Type         | Upper cone angle | Lower cone angle | Separation efficiency | Pressure loss (pa) |
|--------------|------------------|------------------|-----------------------|--------------------|
| Double cone  | 30               | 12               | 0.765186              | 82913.62           |
|              | 30               | 10               | 0.79087               | 87126.17           |
|              | 30               | 8                | 0.81724               | 90903.44           |
| Single cone  |                  | 12               | 0.73571               | 57478.25           |
|              |                  | 10               | 0.76943               | 61477.06           |
|              |                  | 8                | 0.78945               | 65858.76           |

After the simulation, it was found that the hydrocyclone separator with 30°-8° double cone combination and single cone 8° has the highest separation efficiency, but pressure loss increases correspondingly with the decrease of the cone angle. Considering the separation efficiency and the energy consumption of the hydrocyclone, the two-cone combination of 30°-8° and the single cone of 10° were selected for comparative study.

### 3. Results and analysis

Because flow field of hydrocyclone changes in barrel section and the cone section are different, and for the double cone hydrocyclone, there is also a difference between the large cone section and the small cone section flow field [6]. Therefore, this paper selects Z=-40mm, Z=-90mm and the Z=-150mm cross section respectively to explore the differences in velocity field.

#### 3.1. Tangential Speed

The liquid flow inside the solid-liquid hydrocyclone is a three-dimensional turbulent flow, and its velocity field can be decomposed into three sub-speeds; tangential velocity, axial velocity and radial velocity. The tangential velocity, premise of generating the inertial force field and prerequisite for separation of solid phase particles in solid-liquid separation, is the most important velocity component in hydrocyclone separator, and it determines centrifugal acceleration and centrifugal force generated in the hydrocyclone separator [7].

Figure 2 is a comparison of the tangential velocities on the cross sections of different characteristic lines of the hydrocyclone separator of the two structures. It can be seen from the figure that the tangential velocity of the two hydrocyclones has a good symmetry in the radial distribution. The velocity value reaches a maximum near the center of the hydrocyclone separator and gradually decreases along the radial direction, and the velocity value decreases to zero at the wall position.

![Comparison of tangential velocities](image)

(a) Z = -40mm  
(b) Z = -90mm
3.2. Pressure Loss
The energy loss during the operation of the hydrocyclone separator is also the focus of attention \cite{8}, so the magnitude of the pressure loss during the hydrocyclone separation process also needs to be paid attention to. The static pressure distribution of the inlet cross sections of the two structures is shown in Fig. 3. It can be clearly seen from the cloud diagram that the pressure gradient and pressure loss of the hydrocyclone are the largest at the junction of the inlet tube and the swirl chamber. Inside the swirl chamber, the static pressure at the wall surface is the largest, and decreases gradually along the radial direction. There is an annular region between the overflow tube and the cylindrical swirl chamber, in which pressure loss along radial direction is small and there is a negative pressure.

In addition, the rectangular single inlet hydrocyclone has asymmetrical pressure distribution at the inlet section, while the spiral double inlet hydrocyclone has a good symmetry in the static pressure distribution at the inlet section, but the pressure loss is significantly greater than that of the single inlet hydrocyclone. However, as the symmetry of the velocity field and the pressure field distribution is improved, the turbulent energy loss of the fluid flowing inside is reduced.
3.3. Solid Phase Volume Distribution

In order to compare the solid-phase volume distribution of two kinds of hydrocyclone separators when separating flocs with different particle sizes, the flocs with floc size of 25μm, 50μm, 80μm and 115μm were selected for simulation, and the corresponding volume fractions were 0.017, 0.025, 0.012 and 0.006 respectively. The simulation results are shown in Figure 4.

It can be seen from Figure 4 that the distribution of the 25μm flocs has undergone a concentration shift and the flocs is enriched from axial direction toward conical bottom region. In addition, the floc distribution also shows a spatial deviation, and volume distribution of the flocs in the cone section and the cylindrical swirl chamber is gradually away from the center of the hydrocyclone in the radial direction; as the floc size gradually increases from 50μm to 115μm, the flocs gradually approach the inner wall surface of the hydrocyclone in the radial direction, and also begin to move toward the bottom portion of the cone in the axial direction. The larger particle size of floc, the higher its concentration near the inner wall of hydrocyclone and the cone bottom. From this cloud diagram, it can be seen that the separation efficiency of solid-liquid hydrocyclone increases with the increase of the floc size, and the flocs flow out from the bottom outlet during the separation process, without obvious fracture.

Figure 4. Floc volume distribution contour of the two structures
4. Conclusions
The technology of separating emulsified oil flocs by hydrocyclone has great application prospects. In this paper, the following conclusions can be drawn from the simulation and analysis of two structures:

(1) For the separation of floc with a particle size of 51.67μm, separation efficiency of the double-cone spiral double inlet hydrocyclone can reach to 81.7%, and that of the single-cone single-entry hydrocyclone can reach to 78.9%, double-cone spiral double inlet has better separation effect;

(2) Tangential velocity have good symmetry in radial direction. It generally exhibits symmetric "M" distribution. The velocity value is zero at the central axis, and increases first and then decreases along the radial direction.

(3) The designed spiral double inlet hydrocyclone separator has less pressure loss and higher separation efficiency

(4) Separation efficiency of the flocs increased with the increase of the floc size, and the flocs flowed out from the bottom outlet during the separation process, without no obvious fracture phenomenon.

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