Study on the influence of cyclone convex structure on copper separation

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ABSTRACT

China’s copper resources with small scale, associated ore, low grade, complex deposit material, affected by our environmental protection policy, some non-standard high pollution, energy intensive enterprises basic in a state of production, the possibility of recovery is low, the development of copper resources still cannot meet the demand for copper resources in our country, so the use of environmental protection machinery efficient rapid recovery of copper concentrate, can reduce economic costs, reduce energy consumption, do not add pharmaceutical sorting process can also reduce the harm to the environment, the human body. According to the physical characteristics of Qinghai copper mine, this paper proposes a hydrocyclone with a convex platform structure, which aims to increase the residence time of the polydensity particles in the flow field and improve the separation effect of the polydensity particles, so as to achieve the purpose of efficient recovery of copper concentrate in the copper ore. Research shows that the convex platform structure can disturb the cyclone field, prolong the particle residence time in the flow field, speed up the light particles in the inner flow to the flow tube velocity, can improve the effective separation efficiency, the final Cu particle enrichment ratio reached 10.351, is relative to the traditional cyclone increased 6.865, the recovery rate reached 87.45%, relative to the traditional cyclone increased by 11.38%.

KEYWORDS

Copper ore; Centrifugal separation; Hydrocyclone; Numerical simulation.

1. INTRODUCTION

Copper is an important mineral resource, second only to aluminum in the consumption of non-ferrous metals. It is an indispensable non-ferrous metal in modern industry, agriculture, national defense industry and science and technology[1][2][3]. Copper has made great contributions to China’s and global economic growth[4]. China is the world’s largest copper consumer. Driven by the development of new energy industry, the consumption of copper resources has maintained growing[5]. China’s copper ore is mainly copper sulfide, copper oxide and mixed copper ore. Good technical and economic indicators can be obtained according to the research of mineral processing process according to the properties of copper ore. At present, the recovery methods of copper separation are mainly the combined process of flotation, magnetic separation, reseparation and three methods. On the basis of the redressing method, the redressing equipment is further designed and optimized to adapt to the recovery of copper concentrate in copper ore and reduce the waste of copper resources. The secondary separation of pure physical method can implement the harmless recovery of copper ore, reduce the threat of copper tailings accumulation to the surrounding ecosystem and human health.
avoid environmental pollution, alleviate the shortage of land resources, and improve the economic benefits of enterprises. To realize the high-quality development of copper industry in the "new track" of practicing energy green development[5]At the same time, it provides a new reference for innovating the heavy processing equipment in China and improving the beneficiation efficiency.

2. STRUCTURE AND SEPARATION PRINCIPLE OF HYDROCYCLONE

2.1. Structural model of the hydrocyclone boss platform

![Convex structure cyclone model](image)

**Fig.1 Convex structure cyclone model**

Note: 1-feed pipe; 2-overflow pipe; 3-cylindrical section; 4-cone section; 5-bottom flow pipe; 6-platform

In the traditional cyclone, when the particles are separated in the conical section, the light and light particles are easy to mix to form a mixed particle layer, which is enriched in the smooth wall, which is difficult to separate. The structure of the traditional cyclone is changed, as shown in Fig.1, which is composed of feed tube, cylindrical section, conical section, convex table, overflow tube and bottom flow tube. In cone wall increase convex structure, the density of particles with the same tangential velocity into the cyclone, movement along the cylinder wall, the particles in the cyclone rotating movement after the platform, heavy particles bypass the platform, again in the cone wall enrichment, light particles and the platform wall collision, the movement trajectory is disturbed, most of the light particles will not be mixed with heavy particles accumulation in the wall of the cone, achieve the effect of destroying the mixed particle layer accumulation plate, make different density of particles produce different movement trajectory, as shown in Fig.2. Under the action of gravity, the heavy particles move down along the wall to the bottom flow outlet, and the light particles move up in the inner spiral along the overflow flow outlet, so as to improve the separation efficiency of the tailings.

![Separation of light and heavy particles on cone wall of cyclone with convex structure](image)

**Fig.2 Separation of light and heavy particles on cone wall of cyclone with convex structure**
2.2. Principle of particle separation in structural cyclone

When the particles move in the flow field, when the particle density is greater than the density of the fluid medium, the settlement movement is made under the action of gravity, the particle movement in the cyclone space is limited, and a variety of particles are squeezed in a limited range for settlement, which is interference settlement. For a single particle, particles will be centrifugal force, gravity, buoyancy, drag force, additional mass force, Basset force, Magnus force and Saffman force, these forces have little effect on the trajectory of the particles, so particles force mainly centrifugal force, gravity, buoyancy and drag force[6].

During the separation process, the particles are subject to collisions between the particles or between the particles and the wall[7]. In different concentrations of the pulp, the particles have different forces, and their transport speed and motion trajectory are different, as shown in Fig. 3. The Euler-Lagrangian method was used to describe the motion characteristics of the particles in a hydrocyclone. Specifically, the Euler method describes the flow field of the continuum, and the Lagrangian method describes the motion trajectory of the particles[8].

![Diagram of force analysis of particles in the convex structure cyclone](image)

**Fig. 3** The force analysis of particles in the convex structure cyclone

The equation of motion is:

\[
m \frac{du}{dt} = F_d + F_c + F_g + F_{br} + F_x
\]

In formula:

- \(m\) — Particle mass, kg;
- \(u\) — Particle velocity, m/s;
- \(t\) — Time, s;
- \(F_d\) — The owing force of fluid to particles, N;
- \(F_c\) — The centrifugal force of the particles, N;
- \(F_g\) — The gravity of the particles, N;
- \(F_{br}\) — The centripetal resistance applied to the particles, N;
- \(F_x\) — Other combined forces of the particle, N.

In the flow field of the particles, the buoyancy and drag force will hinder the particles' settlement. When the particles are in free settlement, the resultant force of the particles is zero. Particle centrifugal settlement is the centrifugal acceleration generated by particle centrifugal rotation instead of gravity.
acceleration. The particle separation in the centrifugal force field is mainly affected by the interaction of centrifugal force, radial buoyancy and drag force. According to the second law of particle settling, the settlement velocity of the particles is summarized as:

\[ V = \frac{(\rho_p - \rho_f)gd^2}{18\mu} \]  

among: \( V = v - u \)

In formula:

\( \rho_p \) — The density of the particles, kg/m\(^3\);
\( \rho_f \) — The density of the fluid, kg/m\(^3\);
\( v \) — Fluid velocity, m/s;
\( u \) — Particle velocity, m/s;
\( \mu \) — The dynamic viscosity of the fluid, Pa.s.

More dense particles receive more centrifugal force, settle faster in the flow field, and are easier to settle to the wall enrichment to form the bed; less dense particles receive relatively small centrifugal force and slower settlement speed, resulting in the separation of light and light particles. The range of centrifugal force field in the hydrocyclone flow field is limited. Some light particles can move upward by the drag and buoyancy in the axial direction, and some light particles harden after settling into the outer bed of heavy particles\(^9\), Affect the particle separation efficiency, thus reducing the ore enrichment ratio.

3. NUMERICAL SIMULATION OF STRUCTURAL CYCLONE

3.1. Model building and grid division

This paper to optimize the traditional hydrocyclone structure, cuboid as the initial structure, the inverted smooth transition on the cone wall, add the first vertical to the feed direction of the wall platform, the first platform structure, in the cyclone, cone wall position as shown in Figure 4, the platform in the center of the axis and the cylindrical and cone boundary length H 15mm. According to the spiral direction of the fluid inside and outside the cyclone, a platform is added for every 90° rotation at the cone wall to connect the center of the platform into a spiral line with a pitch of 120mm.

To investigate the separation performance of the convex structure, the model was built using SolidWorks software and fluid domain extraction, as shown in Fig.5 and 6. Compared with the traditional hydrocyclone with the same structure, the structural parameters of the two hydrocyclone are shown in Table 1. The fluid simulation software Fluent is used to study the internal flow field characteristics and separation performance of the spiral cyclone. Fig.4 The position of the first convex structure on
Fig. 4 The position of the first convex structure on the wall of the conical section of the cyclone

Fig. 5 Cyclone structure model

Fig. 6 Cyclone fluid domains
Note: (a) traditional; (b) convex platform
Table 1. Convex structure cyclone structure parameters

<table>
<thead>
<tr>
<th>structure</th>
<th>parameter</th>
<th>structure</th>
<th>parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>The diameter of the cylinder, D</td>
<td>75mm</td>
<td>Flow pipe diameter, D₀</td>
<td>8mm</td>
</tr>
<tr>
<td>The cylinder height, H₁</td>
<td>120mm</td>
<td>Cone angle, θ</td>
<td>16°</td>
</tr>
<tr>
<td>Feed port size, a×b</td>
<td>15×20mm</td>
<td>Convex platform length, L₁</td>
<td>10mm</td>
</tr>
<tr>
<td>Overflow pipe diameter, D₀</td>
<td>25mm</td>
<td>Convex platform width, L₂</td>
<td>4mm</td>
</tr>
<tr>
<td>Overflow tube insertion depth, H₂</td>
<td>30mm</td>
<td>Convex platform height, L₃</td>
<td>2mm</td>
</tr>
<tr>
<td>Overflow tube extension length, H₃</td>
<td>25mm</td>
<td>Convex platform number</td>
<td>4</td>
</tr>
<tr>
<td>wall thickness, c</td>
<td>5mm</td>
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<td></td>
</tr>
</tbody>
</table>

Due to the complex convex structure of the conical section of the cyclone, the combination of structured and unstructured grid is adopted, and the traditional cyclone uses I CEM for structured meshing. This paper mainly studies the convex structure of the cyclone, so the grid independence of the convex structure is verified, and the number of traditional cyclone grid is similar to the final number of the convex structure cyclone grid. The size of the adjusted hydrocyclone grid is 183496, 267646, 436241 and 833524 respectively, and the pressure curve is shown in Fig. 7. It can be seen that when the number of grids is above 436241, the pressure value is not very different and basically tends to agree, and the pressure is not restricted by the number of grids. Therefore, considering the accuracy of the simulation results and the calculation of computational resource saving, the hydrocyclone with a grid number of 436241 is used.

Fig. 7 Grid independence verification

3.2. Parameters of properties

Due to the different sources, mining methods and treatment processes of copper ore, the chemical composition of copper tailings is very complex, and the comparability between copper ore from different origins is poor. The main elements of copper ore are Mg, Al, Si, S, Ca, Fe, Cu, etc., accompanied by trace elements such as Mn, Ti, Zn, Sr and so on[10]. The main chemical composition of a copper polymetallic mine in Qinghai is shown in Table 2. The valuable minerals in this copper mine are mainly chalcopyrite, and the ore is mainly quartz.
Table 2. Main chemical composition of Qinghai copper tailings/%

<table>
<thead>
<tr>
<th>component</th>
<th>SiO₂</th>
<th>CaO</th>
<th>Al₂O₃</th>
<th>MgO</th>
<th>Fe₂O₃</th>
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<td>content</td>
<td>56.99</td>
<td>17.22</td>
<td>5.97</td>
<td>3.20</td>
<td>12.14</td>
</tr>
<tr>
<td>component</td>
<td>Na₂O</td>
<td>Cu</td>
<td>S</td>
<td>K₂O</td>
<td>MnO</td>
</tr>
<tr>
<td>content</td>
<td>0.35</td>
<td>0.8</td>
<td>2.60</td>
<td>0.27</td>
<td>0.46</td>
</tr>
</tbody>
</table>

This study mainly studies the recovery of copper concentrate in a copper polymetallic mine in Qinghai province. The copper mineral is mainly chalcopyrite, a small part of the glow copper, spot copper, copper blue and so on. The copper content in the copper ore is low, and the ore particles are ground for many times, which are fine particles. It is convenient for simulation calculation, the particles in the internal flow field of the cyclone are simplified, and the target mineral composition containing copper particles (Cu particles) and sand particles (SiO are setParticles) are the light and heavy particles in the flow field. The copper mineral is mainly a brass ore, so the parameter set is that the density of Cu particles is 4100 kg / m³, SiO₂The density of the particles was 2,200 kg / m³. In this paper, only the density difference was considered as the reference variable for two-phase particle separation, setting the mean particle size to 74 μm, liquid phase medium to water, and slurry concentration to 20%.

3.3. Setting of the boundary conditions

When considering only the role of air and water in the cyclone, the VOF model and RSM turbulence model are used, the water main phase is set, the air is the secondary phase, the air return volume fraction is set to 1, the initial air volume fraction of the fluid domain is 1, the inlet fluid is set to 1, and the water obtains the air column formation. After fluency and stability, particles were added and the particle separation was observed using the Mixture model and the RSM turbulence model. The numerical simulation object of this paper is incompressible fluid, and the incoming boundary condition selects the speed inlet, the incoming speed is set to 10 m/s, and the inlet hydraulic diameter is 17mm. Both the overflow outlet and the bottom outlet are connected with the atmosphere. The pressure outlet is selected. The outlet pressure is 0Mpa, the hydraulic diameter of the overflow outlet is 25mm, and the bottom drooling diameter is 8mm. The wall boundary conditions are the no-slip boundary conditions and the standard wall function. The pressure-velocity coupling algorithm employed SIMPLEC, PRESTO for pressure discrete scheme and Quick for other governing equations. The traditional hydrocyclone sets the same parameter steps as the convex platform structure hydrocyclone.

4. INTERPRETATION OF RESULT

4.1. Air column

Air column is a unique phenomenon in hydrocyclone, when the bottom flow port and overflow port is interlinked with the atmosphere, the cyclone inside is filled with water to form the screw vortex movement, when the fluid tangent velocity decreases, the pressure increases below the external space pressure, thus forming axial negative pressure, while the external air through the bottom and overflow port into the negative pressure area, the negative pressure area absorb outside air to form air column. The change of the air column can reflect the cyclone to reach a stable working state, which is an indispensable condition for the operation of the cyclone.

In this paper, the plane of axis section Z =0mm to observe the disappearance of cyclone air column, Fig.8 and 9. show the air column formation process of traditional and convex platform cyclone,
respectively. The red area in the figure is the air, The blue area is for the water. The air column of both cyclone first form the overall section upper width and narrow bottom, Complete air column with a ical shape, Then it gradually decreases, Because the entrance is full of water, The air column already formed will gradually decrease and eventually break, Since the air from the overflow and bottom ports enters the cyclone, Therefore, air columns are always present at the overflow and bottom ports, The air column is distorted by the turbulence of the bottom flow outlet.

![Fig.8 Air column change process of traditional cyclone](image)

In Fig.8, when the traditional cyclone is in 0.4 s, the air column at the axis of the cyclone is basically completely formed, and the air column gradually decreases at 0.6 s, and the air column disappears in the main separation area. In Fig.9, the convex structure cyclone basically forms a stable air column at the same time of 0.4 s, and the air column gradually decreases to the disappearance of the air column in the main swirl separation area at 0.7 s. This is due to the existence of the convex structure. The movement of the fluid in the cyclone is more complicated, resulting in a delay in the stability of the flow field of the convex structure cyclone. The air column is not involved in the separation process. The smaller the air column, the more effective separation space in the cyclone.

4.2. Pressure distribution

The static pressure is the value of the real pressure of the flow field relative to the operating pressure. When the flow field of the two gyrotors is stable, the static pressure distribution is shown in Fig.10. The static pressure distribution of the two cyclones is similar, which is combined by the semi-free vortex pressure distribution and the forced vortex pressure distribution. The overall pressure is symmetrically distributed in the central axis, and the wall pressure is positive and the maximum. From the wall to the axis, the pressure gradually decreases with the radius and becomes negative in the central area, and the negative pressure area at the axis leads to the formation of the air column.
In order to facilitate the analysis of the changes of the internal flow field of the cyclone, the cross section of $Y = 0$ L, $Y = -70$mm and the $Y - 70$L, $Y - 170$L and $Y - 270$L, $Y = -170$mm and $Y - 170$ mm and $Y = -270$mm are taken as characteristic lines. As shown as Fig.11, the three feature lines are taken for the flow field analysis below.

The fluid is actually viscous. After the fluid enters the cyclone, the flow between the media and the contact with the wall of the cyclone will produce energy loss, so the pressure difference will appear at the inlet and outlet of the cyclone. As can be seen from Fig.12, the distribution of static pressure along the radial direction is similar, and the pressure drop of the convex platform structure cyclone is less than that of the conventional cyclone, and the processing pressure is larger under the same feeding conditions. With the decrease of the axial position, the maximum pressure difference of the convex platform structure and the traditional cyclone decreases, and the maximum pressure difference is gradually presented higher than that of the traditional cyclone, which is conducive to particle separation. In Fig.(b) The pressure of the cyclone at the wall is sudden, because there is a bump at the axial position-170mm, the particle collides with the bump, and the pressure changes, resulting in a sudden decrease in the pressure at this position.
4.3. Tangential velocity

The tangential velocity has the greatest influence on fluid separation in the hydrocyclone flow field, and the centrifugal force is the premise of multi-phase flow separation. The greater the tangential velocity, the greater the centrifugal force, the tangential velocity will also affect the radial velocity and axial velocity, which is an important factor in the analysis of hydrocyclone separation. Fig. 13 for the two kinds of hydrocyclone internal tangential velocity distribution cloud diagram, tangential velocity in the central axis for symmetry line distribution, along the radius direction from the axis to the wall, with the radius increases, the tangential velocity increases, conform to the forced vortex distribution rule, when reaching the maximum tangential velocity with the increase of radius, at the wall speed to zero, conform to the distribution within the free vortex.

Fig. 13 Tangential velocity distribution cloud

Note: (a) traditional; (b) convex platform

Fig. 14 shows the tangential velocity distribution of different positions of traditional cyclone and convex platform structure. The tangential velocity of both cyclones is "M" type distribution with good
symmetry. Both the radial position of the maximum tangential velocity of the cyclone in Fig. (a) and (c) are basically the same, that is, the dividing line between the forced vortex and the free vortex is basically the same, and the interface of the free vortex is basically the same as the interface. As can be seen in the figure, the maximum tangential velocity value of the convex structure cyclone is slightly lower than that of the traditional spiral, and the velocity gradient along the wall is avoided, and the flow field increases.

4.4. Axial velocity

The axial velocity has less influence on the flow field separation than the tangential velocity, but it affects the time of the fluid stays in the cyclone, which determines the direction of the axial movement in the flow field. It is an important factor for analyzing the separation of particles in the hydrocyclone. Fig. 15 shows a cloud diagram of the internal axial velocity distribution of the two gyrols. The axial velocity divides the flow field into the inner cyclone region with positive velocity and the negative velocity, and the interface of the inner and outer cyclone regions is the zero envelope formed by the point with zero axial velocity. There are obvious positive and negative areas near the axis of the overflow pipe, which are caused by air entering down from the overflow port into the cyclone. The formation and dissipation of the air column can also be explained from the axial velocity distribution.

Fig. 15 Axial velocity distribution cloud

Note: (a) traditional; (b) convex platform

From figure 16, the distribution of axial speed is basically similar, near the wall axial speed direction down, along the radius, the radial position of the smaller, the absolute value of axial speed down to zero, and then the axial speed direction up, the radial position the greater near the speed at the speed, to the maximum, in figure (a) and (c) the axial speed near the central axis, this is because the air from the overflow and bottom flow into the flow field. Figure (b) and Figure (c) are the axial velocity distribution of the cone section, which is the main separation area of the cyclone. The axial velocity of the cyclone is slightly higher than that of the traditional cyclone, which can make the separated light particles move quickly to the overflow pipe and reduce the possibility of reconfusion after the separation of light and light particles.

Fig.16 Axial velocity in different sections
4.5. Separating property

In this paper, after the multiple density particles move for a certain time under the combined action of various forces in the flow field, the more dense Cu particles exit along the bottom flow mouth by the outer spiral movement, and the density SiO$_2$ is relatively light. The particles are mainly discharged along the overflow port. The enrichment ratio for Cu particles is the content of Cu particles monitored in the bottom flow port and SiO$_2$ in the raw ore. The ratio of the particle content, and the recovery rate is the ratio of the mass of Cu particles in the bottom flow mouth to the mass of Cu particles in the raw ore. The monitoring surface is set at the feed inlet, bottom flow outlet and overflow outlet to monitor the change of mass flow of light and light particles on each monitoring surface over time after a period of separation in the two kinds of rocyclone. Fig. 17 (a) shows the mass flow of Cu particles at the inlet and bottom flow over time, and Fig. 17 (b) shows SiO$_2$ the mass flow rate of particles at the inlet and the overflow port changes with time.

From Fig. 17 (b) know two particles in the early into the cyclone, a small part of the particles is affected by the feed pipe, energy loss, such as formation from the overflow pipe, so the particles at the overflow port mass flow after surging with particles in the flow field, mass flow with time change slow and stable trend. According to Fig. (a), the movement of the two particles was not stable in the early stage of separation, so a small part of Cu particles did not separated in the conical segment, and directly flow out along the bottom flow mouth under the action of their own gravity.

As can be seen from Fig. (a) and (b), two kinds of cyclone in 3s, the flow field two particles stable separation, the convex structure bottom flow and overflow monitoring particle mass flow time slightly later than the traditional structure, that the two particles in the convex structure movement separation time is slightly longer than the traditional structure, making Cu particles and SiO$_2$ particles are better than separation.

![Fig.17 Time-dependent of particles mass flow rate](image)

This paper mainly studies the structure of convex platform, the enrichment ratio and recovery rate of copper concentrate in copper ore, and SiO$_2$. The particles are not mainly studied, so the enrichment ratio and recovery rate of Cu particles in the numerical simulation are mainly analyzed. Fig. 18 shows the enrichment ratio and recovery of Cu particles after the separation of the two cyclones. The enrichment ratio of Cu particles in the traditional cyclone is 3.486 and the recovery was 76.07% and the enrichment ratio of Cu particles in the cyclone is 10.351 and the recovery was 87.45%. By comparative analysis, the enrichment ratio and recovery rate of the recovered copper concentrate in the convex platform structure cyclone are significantly improved.
In order to solve the problem of particle separation in the traditional hydrocyclone, because the action of strong centrifugal force makes the light and light particles quickly enriched in the cone wall into a mixed bed, which leads to the poor separation effect, this paper proposes to add a convex structure in the smooth cone wall surface. According to the numerical simulation analysis, the structure can regulate the state of the internal flow field and the movement of the particles, and improve the separation performance of the cyclone, so it is feasible to improve the enrichment ratio and recovery rate of tailings sorting recovery concentrate.

5. CONCLUSION

In this chapter, the initial numerical simulation model of the convex structure cyclone and the traditional numerical simulation model of the flow field and separation performance of the two kinds of cyclone are proved to improve the efficiency of copper separation.

(1) from the aspects of air column, pressure, speed, the comparative analysis of platform structure and the traditional cyclone flow field, it is concluded that the platform structure flow field is more complex than the traditional cyclone, in the cone of the main separation of the pressure difference is bigger, multiple density particles in the convex structure cyclone stay longer, spiral region axial velocity is larger, is conducive to the particle separation, SiO$_2$ particles do internal spiral movement through the overflow outlet.

(2) By analyzing the volume concentration distribution of Cu particles and SiO$_2$ particles in the two cyclone, the convex structure can disturb the relative movement of the light particles. The enrichment of Cu particles at the lower part near the bottom outlet of the convex rotor is better than the traditional cyclone; More SiO$_2$ particles in the convex cyclone enter the internal spiral area and move upward to the overflow outlet. By calculating the separation performance of the two kinds of cyclone, the enrichment ratio of the convex platform structure cyclone reached 10.351, which increased 6.865 compared with the traditional cyclone, the recovery rate reached 87.45%, and 11.38% compared with the traditional cyclone.

REFERENCES


