ISSN 2663-1563 Vol. 5, Issue 1: 14-20, DOI: 10.25236/AJAGE.2023.050103

Enrichment and Recovery of Lead-Zinc Tailings by Spiral Wall Cyclones

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Abstract: *In order to solve the problem of increasing the difficulty of sorting lead-zinc tailings in China, the re-separation of lead-zinc tailings is realized, the recovery efficiency is improved, and the sorting cost is reduced. Through the structural improvement of the traditional column conical cyclone, a spiral wall cyclone suitable for secondary sorting of lead-zinc tailings is proposed, and the lead-zinc tailings with different density are quickly separated by using the diversion of the spiral wall and the enrichment of mineral particles. The results showed that the recovery rate of heavy concentrate PbO increased from 55.55% to 85.25% by the spiral wall cyclone after structural optimization, an increase of nearly 30%, and the enrichment ratio of down-export PbO concentrate also increased from 1.321 to 1.762. It can be seen that the optimized spiral wall cyclone can effectively increase the secondary sorting efficiency of lead-zinc tailings, and provide a reference for the structural design of hydraulic cyclones in the same type of mine to a certain extent.*

Keywords: *Lead and zinc tailings; Structural improvements; Spiral wall*

1. Introduction

Hydrocyclones are devices that are based on centrifugal force to separate two-phase or multiphase fluids that have a difference in density and particle size and are not miscible with each other [1]. After the mineral particles are shot into the hydrocyclone through the feed port at a certain speed along the tangent direction of the cylinder, under normal circumstances, the dense solid mineral particles move towards the wall of the device, and the mineral particles with less density move towards the central axis, and then the overflow products and underflow products are obtained, and the separation of minerals according to different densities is realized.

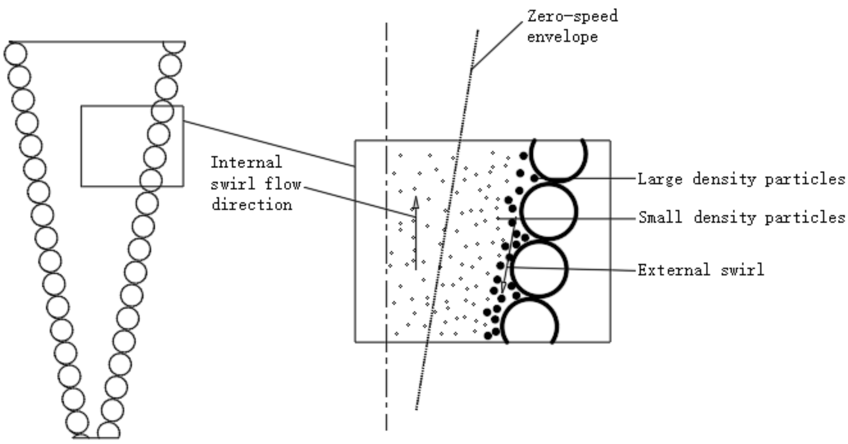


Figure 1: Spiral wall separation principle.

Mineral particles are injected into the inner cavity of the cyclone, and under the action of radial centrifugal force, dense particles are more likely to overcome fluid resistance to move towards the side wall, spiraling down the wall and discharged from the bottom flow outlet through the external swirl. In this process, due to the smooth and flat wall of the cyclone, the constraining effect of the wall of the cyclone, the mixed particles are enriched on the wall to form a stable bed, it is difficult to form relative movement between different particles, and it is impossible to produce a reaction similar to the Brazil nut effect, so that the small density particles are separated from the external swirl, so there is a part of the small density particles close to the side wall without separation, and continue to enter the bottom flow along the wall under the impetus of the mixed fluid particles, which is also the reason for the fine bottom flow of the cyclone. This makes the high-density mineral particles discharged from the underflow outlet taste low, the principle is shown in Figure 1.

In this paper, aiming at the problem that mixed particles are easy to stack into a stable bed on the wall, and it is difficult to produce relative motion between particles of each phase, which leads to the problem of fine bottom flow of cyclone, starting from the wall structure of the cyclone, adjusting the internal flow field characteristics of the cyclone by changing the wall form, and then affecting the movement trajectory of the particles, by breaking the balance and stability of the wall particle bed, increasing the relative movement between the particle phases, so that the small density particles settled on the wall leave the outer swirl of the wall, re-participate in the separation process, and accelerate the internal swirl to discharge from the overflow port. This improves separation performance.

2. Spiral wall cyclone structure design

When the mixed particles are separated in the traditional column cone hydrocyclone, the material particle group spirals downward on the inner wall under the action of radial centrifugal force, due to the interaction between the particles, the mixed particles will be settled and separated on the inner wall of the cyclone according to a certain law, coupled with the gradual contraction of the radius in the process of the downward migration of the particles in the axial direction, the light particles move in the axial direction and enter the overflow, and the heavy particles overcome the fluid resistance to reach the wall and continue to spiral down the wall under the push of the subsequent fluid, and then enter the bottom flow. In the whole process, the mixed particles continuously enter the interior of the cyclone, and due to the restraint of the wall, the light particles are enriched on the wall under the belt of heavy particles, forming an overall migration movement on the smooth and flat wall, resulting in a part of the light particles without the separation process entering the underflow with the heavy particles, resulting in the phenomenon of fine underflow of the cyclone[2].

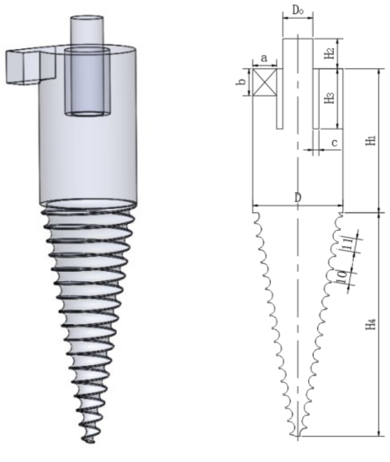


Figure 2: Structural model of spiral wall cyclone.

In this paper, the tapered wall of the main sorting area of the traditional cyclone is optimized and transformed, so that the smooth and flat inner wall surface forms a spiral sorting area, and the mixed particles are transitioned and fully mixed on the spiral wall to strengthen the relative movement between particles, thereby accelerating the separation process of multiphase particles and improving the separation efficiency. Through analysis and research, the structural model of spiral wall cyclone as shown in the figure 2 is preliminarily established, the spiral wire diameter of the spiral wall is 10mm, the pitch is 11mm, clockwise rotation, and other structural parameters are the same as that of the 75mm classical cyclone.

Mineral particles are injected into the inner cavity of the cyclone, and the particle group is enriched on the wall by the restraint of the wall, and it is difficult for particles of different densities to produce relative movement on the smooth and flat wall, resulting in the problem of fine underflow. In this paper, by improving the wall of the cyclone cone section, a spiral wall cyclone is established to break the relative stability of the particle group on the traditional smooth wall, strengthen the relative movement between different particles, promote the formation of internal swirl and external swirl, and then improve the separation efficiency.

3. Meshing and boundary condition setting

The Cartesian coordinate system is established at the origin of the interface center of the cyclone cylindrical segment and the cone segment, and the feeding direction is the reverse of the X axis and the Y axis is pointing to the direction of the overflow pipe. In order to accurately study the performance difference of cyclone structure, ICEM-CFD software is used to mesh the spiral wall cyclone by coupling "structured + unstructured", as shown in the figure 3, and the interface between structural and non-structural meshes is defined by "interface".

Figure 3: Meshing.

Due to the complexity of the spiral wall cyclone flow field, the flow field will be simulated step by step. Firstly, only the two-phase interaction of air and water is considered, and the VOF model and RSM turbulence model are used to obtain the stability process of the flow field in the cyclone and the basic characteristics of the flow field. After the flow field is stable, the mixed particles are introduced on the basis of the results of the previous calculation, and the DPM model is used to obtain the particle motion characteristics in the cyclone, and the separation performance is analyzed.

The inlet boundary condition of the spiral wall cyclone is the velocity inlet, and the size is 5m/s; Both the overflow outlet and the bottom flow outlet are pressure outlets and communicate with the atmosphere, and the air return volume fraction in the VOF model is 1; The mixed particles were SiO_2 and PbO particles, with densities of 2600kg/m^3 and 9530kg/m^3, respectively. In order to ensure that density is the only reference variable, according to the properties of lead-zinc tailings, the particle size of SiO_2 and PbO particles is set to 75μm. The wall surface adopts the non-slip boundary condition, the solution method is SIMPLE algorithm, the pressure discrete format is PRESTO, and the discrete format of other control equations adopts the second-order welcome style.

4. Analysis of simulation results

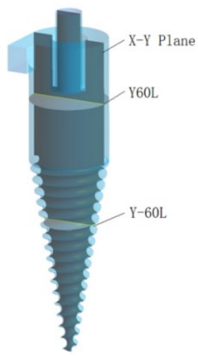
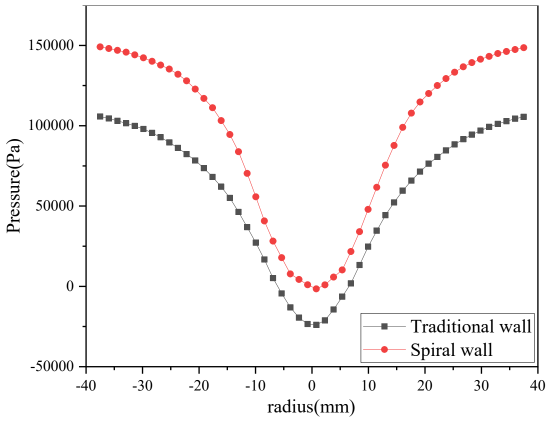


Figure 4: Eigenplane position.

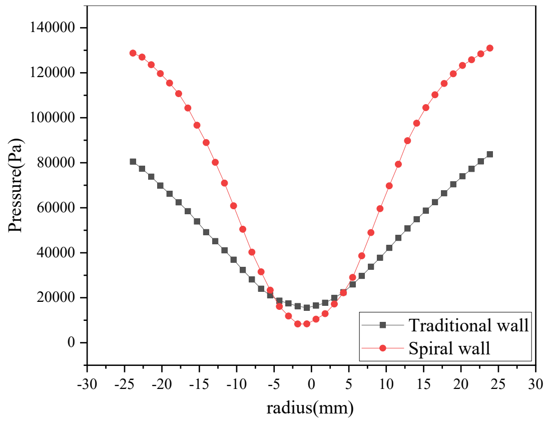
In order to better explore the influence of the inner spiral wall of the hydrocyclone on the internal flow field parameters, the simulation model structure is established based on the cone interface of the hydrocyclone column. Select the center section X-Y plane and Y-60 plane as the feature plane, the intersection of the X-Y plane and the Y60 plane as the feature line Y60L, and the intersection line of the X-Y plane and the Y-60 plane as the feature line Y-60L, its location is shown in Figure 4, the above two intersections can be used as the feature line to detect the column segment acceleration zone and the cone segment sorting area respectively, and the flow field change can be analyzed more clearly.

4.1. Pressure distribution

The pressure in the hydrocyclone has an important impact on energy consumption and equipment wear, when the flow field is stable, the static pressure distribution in the cyclone of the two structures is shown in the figure 5, the distribution law is basically in line with the characteristics of semi-free vortex and forced vortex pressure distribution, the pressure at the wall is the highest, the pressure from the wall to the axis gradually decreases with the decrease of the radius, and the overall pressure is symmetrically distributed by the central axis as the symmetrical axis. After the fluid medium enters the cyclone, due to the viscosity of the actual fluid, the flow between the fluid medium and the contact between the fluid and the wall will produce energy consumption, so there must be a pressure difference at the inlet and outlet of the cyclone [3].



(a) Y60L



(b) Y-60L

Figure 5: Change of pressure distribution.

The static pressure value is the value of the real pressure in the flow field relative to the operating pressure, and the intersection line Y60L and the intersection line Y-60L of the center section and Y=60mm plane Y=-60mm plane are selected as the monitoring line, and the change curve of pressure with radius on the two intersections is shown in the figure 5. It can be seen that the change of static pressure in the radial direction is significant, and the pressure distribution law of the spiral wall cyclone and the traditional column cone cyclone in the radius direction is the same, which is gradually reduced from the wall to the center and reduced to zero or negative pressure at the center position. The static pressure value of spiral wall cyclone on the characteristic line is basically greater than that of traditional column cone cyclone. At the same time, compared with the traditional column cone cyclone, there is a larger radial pressure gradient in the spiral wall cyclone, and it is precisely because of the existence of the pressure gradient that the force pointing to the center direction is generated in the cyclone, and the material particles have a tendency to move to the center, which is also one of the reasons why the cyclone makes the particles move in the radial direction and finally achieve the separation of the two-phase material medium. By showing the pressure change curve, it can also be shown that the spiral wall structure does increase the radial pressure gradient in the cyclone, thereby increasing the radial force of the material particles pointing to the axial direction.

4.2. Tangential velocity

Among the three velocity components of the fluid in the hydrocyclone, the tangential velocity has the greatest influence in the cyclone separation and is the direct cause of the static pressure. The tangential velocity causes the fluid to generate centrifugal force, which causes the fluid to move outward, while the presence of the cyclone wall prevents the fluid from moving outward, thus generating static pressure. Figure 6 shows the distribution of the tangential velocity in the radius direction on the characteristic line of the hydrocyclone of the two structures. It can be seen from Figure 6 that compared with the traditional hydrocyclone, the spiral wall cyclone has a larger tangential

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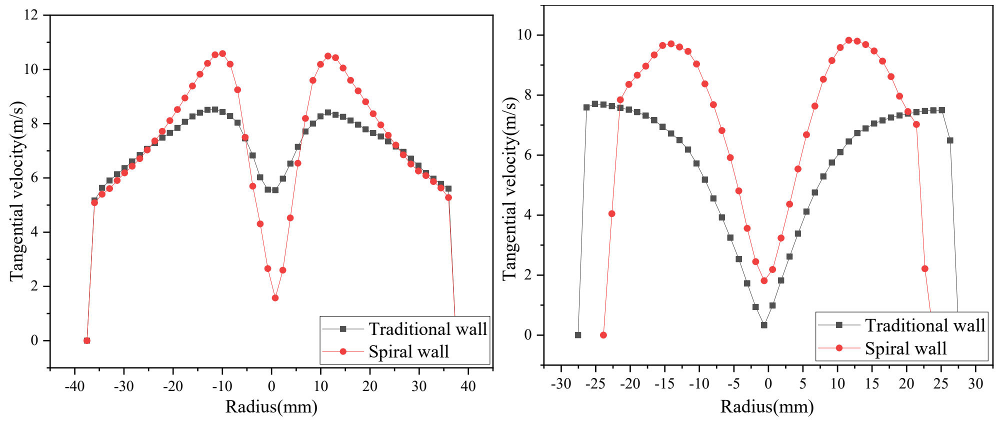
velocity near the overflow port, and the internal tangential velocity of the cyclone of the two structures has better axis symmetry in the X-Y plane and is distributed in an "M" shape. From the trend of tangential velocity, the internal flow field of the hydrocyclone can be divided into three regions [4]: boundary layer, free vortex region, and forced vortex region, the free vortex region helps particles to be captured by the wall, and the forced vortex region can help particles move outward.



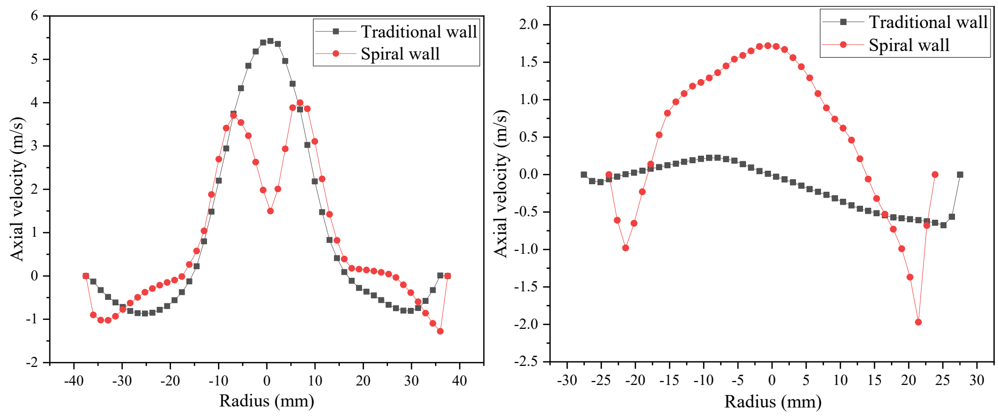
(a) Y60L *(b) Y-60L*

Figure 6: Change in tangential velocity.

From Figure 6, it can be seen that the change trend of the two cyclones at different positions is the same, the tangential velocity of the fluid is zero at the inner wall of the cyclone, and in the near-wall area, the tangential velocity increases rapidly, changes from laminar flow to turbulent flow, and reaches a maximum at the junction of free vortex and forced vortex, and then the velocity decreases rapidly. According to the separation theory, the greater the tangential velocity in the hydrocyclone, the greater the centrifugal force of the large-density particles themselves, which is more conducive to the movement of the large-density particles to the wall of the cyclone, so that they are brought into the bottom flow outlet by the downward external cyclone to be collected, so it also reflects the higher separation efficiency of the spiral wall cyclone than the traditional column cone cyclone.

4.3. Axial velocity

The distribution of material particles in the radial position is mainly determined by tangential speed and radial velocity, and the influence of axial velocity is small, but the axial velocity affects the residence time of the fluid in the cyclone, and also has an important influence on the distribution of material particles in the light phase and heavy phase [5].Figure 7 shows the axial velocity curves on the two characteristic lines Y60L and Y-60L.



(a)Y60L *(b)Y-60L*

Figure 7: Axial velocity.

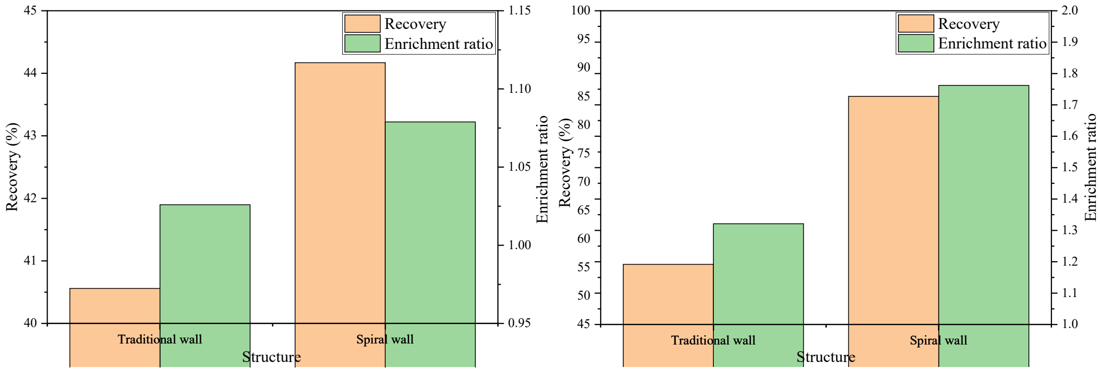
The axial velocity of the fluid is always downward in the direction of the cylindrical cylinder of the hydrocyclone, and the numerical magnitude of the axial velocity first decreases and then increases with the decrease of the radius. In the axial velocity direction of the cone section, it first goes upward, decreases with the decrease of the radius, until zero, and then changes to the downward velocity, the value of which is inversely proportional to the radial position, reaching a peak near the air column.

By analyzing the velocity flow field of mineral particles after entering the hydrocyclone, the motion trajectory and flow field motion law of the particles are further studied, and the prediction of the sorting effect of the cyclone and the study of the influencing factors can be realized.

4.4. Separation performance

The separation efficiency is a visual parameter of the external performance of the hydrocyclone, and the recovery rate and enrichment ratio of the material particles are used as important indicators to measure the separation performance of the hydrocyclone. Among them, the recovery rate refers to the proportion of the number of solid particles of a certain phase flowing out of the bottom flow port of the cyclone to the total number of particles of that phase entering the cyclone (that is, the recovery rate of particles of each phase by the bottom flow); The enrichment ratio refers to the proportion of a certain phase particles in the upper and lower outlets. In this paper, due to the separation of light and heavy two-phase particles with different densities, the light particles with lower density SiO_2 are mainly enriched at the upper outlet, while the heavy particles PbO with higher density are discharged at the lower outlet, so the enrichment ratio of SiO_2 particles refers to the proportion of SiO_2 particles in the total number of particles at the upper outlet, and the enrichment ratio of PbO particles is the proportion of PbO particles in the total number of particles at the lower outlet.

The PbO concentrate taste set in this paper is 10%, and it can be seen from Figure 8 that the recovery rate of PbO in the traditional column cone cyclone is 55.56% and the enrichment ratio is 1.321, and the recovery rate of SiO_2 is 40.56% and the enrichment ratio is 1.026 after the sorting and separation of the hydrocyclone. In contrast, after structural improvement, the recovery rate and enrichment ratio of both particles in the spiral wall cyclone were significantly improved, the recovery rate of PbO particles with higher density was 85.27%, an increase of about 40%, and the enrichment ratio increased to 1.762, while the recovery rate of SiO_2 particles with lower density was 44.17%, and the enrichment ratio was 1.079. It can be seen that it is feasible to control the internal flow field by changing the wall structure of the cyclone, so as to optimize the separation performance of the cyclone and increase its recovery rate and enrichment ratio.



(a) SiO_2 particles (b) PbO particles

Figure 8: Recovery and enrichment ratio of particles.

5. Conclusions

In this paper, the wall structure of the traditional hydrocyclone was optimized by CFD technology, and the internal flow field, particle motion trajectory, recovery rate and enrichment ratio were analyzed, and it was shown that the separation performance of the spiral wall cyclone after structural optimization was greatly improved when processing lead-zinc tailings resources. The design idea of this paper can solve the problem that multi-density minerals accumulate on the wall of traditional hydrocyclones to form a stable bed and it is difficult to achieve the ideal separation effect. At the same time, the research content of this paper also has certain reference significance for the same type of mineral sorting research.

ISSN 2663-1563 Vol. 5, Issue 1: 14-20, DOI: 10.25236/AJAGE.2023.050103

References

[1] Pang Xueshi. Technology and application of hydrocyclone[M]. Beijing Sinopec Press, 2011.
[2] JIANG Lanyue. Study on multiphase flow characteristics in W-type structure cyclone [D]. Sun Yat-Shandong University of Science and Technology, 2020.
[3] Xie Miao, Zhu Yun, Zhang Baoguo. Study on process parameter matching optimization of hydraulic grading cyclone [J]. Mechanical Science and Technology, 2023, 01, 29.
[4] LIU Yang, ZHAO Lixin, ZHANG Shuang, LIU Lin, XU Baorui. Research and application of filtration-swirl coupling technology in heterogeneous separation [J]. Journal of Mechanical Engineering, 2022, 58(04): 120-154.
[5] WEI Kefeng, ZHAO Qiang, KANG Changke, ZHANG Shuo, CUI Baoyu, LIU Keshuang. Effect of bipyramidal structure design on flow field characteristics and separation performance of cyclone [J]. Metal Mine:1-12,2023.