Influence of main structural parameters of spiral chute on sorting flow pattern and mineral sorting behavior

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Abstract. Spiral chute is an efficient equipment for gravity separation. A numerical simulation model concerning sorting flow pattern and particle trajectory of the spiral chute was built using Computational Fluid Dynamics (CFD) technology to study the effect of the diameter and pitch to diameter. trajectory of the spiral chute was built using Computational Fluid Dynamics (CFD) technology to study the effect of the diameter and pitch to diameter ratio on the sorting performance. The trajectories of the mineral particles with different particle sizes and specific gravities were modeled. results show that the small-diameter spiral chute with a constant pitch to diameter ratio for the 5μm fine-grained heavy minerals; the spiral chute with a diameter of 1200mm and a pitch to diameter ratio of 5μm was modeled. The results show that the small-diameter spiral chute with a constant pitch to diameter ratio for the 5μm fine-grained heavy minerals; the spiral chute with a diameter of 1200mm and a pitch to diameter ratio of 0.45 can obtain more obvious enrichment effect for the 50μm fine-grained heavy minerals; the spiral chute with a diameter of 1200mm and a pitch to diameter ratio of 0.6 has a better sorting performance for the 100μm fine-grained heavy minerals. This thesis research provides guidance for the selection of industrial spiral chutes and the development of new spiral chutes.

Keywords: spiral chute, gravity separation, CFD, mineral specific gravity, particle trajectory.

1 Introduction

A spiral chute is a kind of fluid film-type gravity separation equipment that mainly relies on gravity, friction, and other external forces to realize the separation of minerals according to specific gravity. China began to study the spiral separator in 1955, and in 1974, Fan Xiangbo and others from the Beijing General Research Institute of Mining and Metallurgy (BGRIMM) designed a spiral chute for concentrating fine-grained hematite from Anshan Steel[1][2].In 1974, Fan Xiangbo et al. of Beijing General Re

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search Institute of Mining and Metallurgy (BGRIMM) designed a more gentle cubic parabola as the cross-section shape curve of the spiral chute for the beneficiation of fine-grained hematite in Anshan Steel. Due to the adoption of a more gentle cubic parabola as the cross-section shape curve, in order to distinguish it from the elliptical cross-section of the spiral concentrator, this spiral concentrator is called a spiral chute. In 1989, in order to improve the single processing capacity of the spiral chute, Li Kaigong developed the DL-2000 spiral chute with a diameter of Ø2000mm[3].In 1999, in order to solve the problem of the recovery of fine-grained minerals in large spiral chutes, the author of this paper developed the BL1500 series spiral chute with a diameter of Ø1500mm[4][5].In 1999, in order to solve the problem of recovering fine-grained minerals by large spiral chutes, the author developed the BL1500 series spiral chute with a diameter of Ø1500mm.

Spiral chute diameter and pitch-to-diameter ratio are the two parameters that have the most significant influence on the mineral sorting behavior of spiral chutes. In order to study the influence of these two parameters on the spiral chute sorting behavior, in the past, it was necessary to design and manufacture different parameters of the spiral chute prototype and conduct a large number of comparative mineral sorting tests in order to obtain certain results. The traditional method of this research is not only a large amount of work, but it is also difficult to obtain satisfactory results[6][7].

In recent years, with the development of computer technology, computational fluid dynamics (CFD) technology has been more and more widely used in the study of the sorting process of spiral chutes by virtue of its advantages, such as its low cost and short development cycle.. Gao Shuling et al[8] used the RNG k-ε turbulence model and the VOF multiphase flow model to study the water flow field in a Ø600 spiral chute with three section curves and found that the Reynolds number showed a linear growth trend from inside to outside, which was favorable for the separation of fine particles in the movement of the water layer. Li Hualiang[9] is the first time that CFD simulation technology and the orthogonal test method are combined to optimize the groove structure of the spiral chute, and it is found that the reasonable configuration of grooves with certain angles, widths, and depths on the groove surface of the spiral chute is conducive to the improvement of the efficiency of the spiral chute sorting.

In order to further investigate the influence of spiral chute diameter and pitch-to-diameter ratio on the mineral sorting behavior of spiral chute, the relationship between spiral chute diameter, pitch-to-diameter ratio and mineral sorting behavior was investigated in this paper with the help of CFD technology.

2 CFD modeling of spiral chute

In order to better compare and study the influence of diameter and pitch-to-diameter ratio on the mineral sorting behavior, this paper chooses industrial BL1200-A (pitch-to-diameter ratio of 0.45, abbreviated as BL1200-0.45), BL1200-B (pitch-to-diameter ratio of 0.6, abbreviated as BL1200-0.6), and BL600 (pitch-to-diameter ratio of 0.6, abbreviated as BL600-0.6), three types of screw chutes with diameter of Ø1200mm, as the research object. (pitch-to-diameter ratio of 0.6, abbreviated as BL600-0.6) three types of spiral chutes as the object of study.

The BL spiral chute cross-section shape uses a cubic parabolic curve, as shown in figure 1.

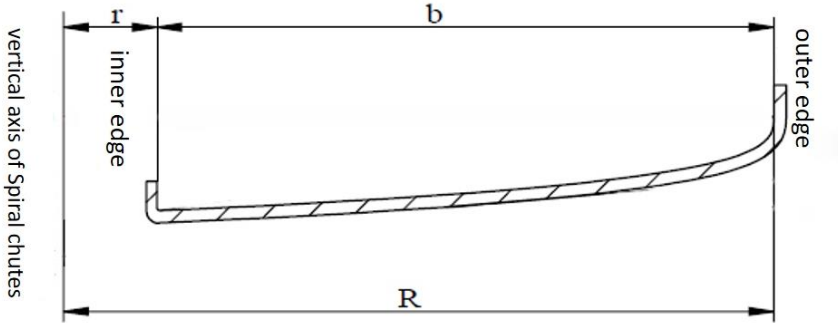


Fig. 1. Spiral chute cross-section shape

2.1 Selection of models

Since the spiral chute has a certain slope along the helix direction, the slurry containing mineral particles is given to the upper end of the spiral chute, and the velocity will increase with time under the action of gravity, so this paper adopts the non-constant simulation. Since the liquid phase and gas phase on the spiral chute can not be mixed with each other, and the thinness and thickness of the liquid phase have an important impact on the sorting flow pattern, the accurate capture of the liquid phase and gas phase interface is crucial for the accuracy of numerical simulation, so this paper selects the VOF model and uses implicit solving.

In terms of turbulence modeling, the RNG k-ε model is used in this paper to accurately capture the secondary circulation in the spiral chute[10]; a discrete phase model (DPM model) is used to simulate the trajectory of mineral particles.

2.2 Grid division

In this paper, the simulation of the spiral chute is all divided by hexahedral structured mesh, and the minimum mesh size is set to 2 mm. Due to the large size of the spiral chute, in order to improve the calculation speed and reduce the number of meshes, only the bottom of the spiral chute is added to the boundary layer when the mesh is divided. In this paper, most of the mesh quality is distributed between 0.95 and 1, and less than 1% below 0.6, which meets the mesh quality requirements, and the meshing results are shows in Figure 2.

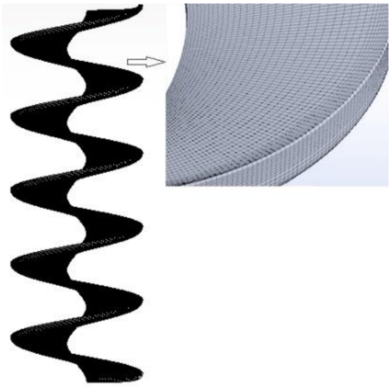


Fig. 2. Grid division results

2.3 Setting boundary conditions

The slurry enters from the upper inlet, flows down the surface of the spiral chute under the effect of gravity, and flows out from the lower outlet, setting the upper inlet as the velocity inlet. By consulting the literature[11], it is known that the incidence velocity V of the spiral chute can be calculated by the following formula:

$$V = \frac{Q}{A} \tag{1}$$

Where Q is the volumetric flow rate of the slurry at the inlet of the spiral chute, and A is the cross-sectional area of the inlet of the spiral chute.

The groove and sides of the spiral chute are set as no-slip solid walls, and the upper surface of the spiral in the computational domain is set as symmetry. The flow rate and pressure at the lower outlet are unknown and are set as free outflow (outflow) boundary conditions.

2.4 Operational environment

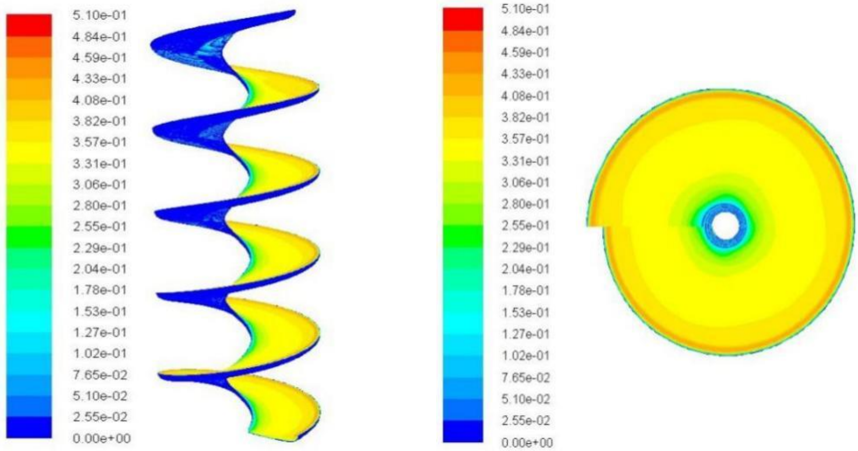
The computer configurations and software versions used in this paper are shown in Table 1.

Table 1. Software platform parameters

Configuration Name	parameters
CPU	Xeon E5-26400@2.50GHz
Computer mainboard	X79 G7-2011
memory stick	16GB DDR3L 1600 MHz
hard disk	SL300 160 GB
display card (computer)	NVIDIA GeForce GTX 1060 6 GB
hardware	FLUENT 19.2
operating system	Windows 10 64 bit

2.5 Fluid Flow Field Simulation

The flow velocity field of the BL1200 series and the BL600 spiral chute with different pitch-to-diameter ratios is simulated with the help of simulation software FLUENT, as shown in figure 3.



(a) Main view (b) Top view

Fig. 3. Velocity distribution of flow field in spiral chute

3 Study of the influence of the main structural parameters of the spiral chute on the sorting behavior of mineral particles

In order to investigate the effect of the spiral chute structural parameters on the sorting behavior of mineral particles, three specific gravity mineral particles were chosen as the discrete phase in this paper, namely, quartz sand (2650 kg/m^3), sulfurous iron ore (4500 kg/m^3), and galena (7600 kg/m^3), and different particle sizes were set up for each type of mineral ore (5 µm, 50 µm, 100 µm, and 500 µm). In order to investigate the aggregation effect of the spiral chute on the mineral particles, the focus was on analyzing the trajectory and aggregation tendency of 1-2 mineral particles on the outside of the spiral chute moving towards the center of the spiral chute.

3.1 Effect of diameter on mineral particle sorting in spiral chute

Firstly, the influence of diameter on the mineral particle sorting in spiral chutes is analyzed, and the three different types of spiral chute models constructed are used to simulate the simulation, and the trajectories of quartz sand, sulfurous iron ore, and galena particles with different particle sizes on the surface of the BL1200-0.6 and BL600-0.6 spiral chutes are shown in figure 4-figure 9. When simulating the particle motion of the BL1200-0.6 spiral chute, particles with 5µm, 50µm, 100µm, and 500µm particle sizes were selected. When simulating the particle motion of the BL600-0.6 spiral chute, according to the research results of our team, Li Hualiang[9] When simulating the particle movement of the BL600-0.6 spiral chute, according to the research results of our team, Li Hualiang, the sorting effect of the BL600-0.6 spiral chute with large specific gravity and large particles (500μm) is poor, so only the movement trajectories of particles with sizes of 5μm, 50μm, and 100μm are investigated.

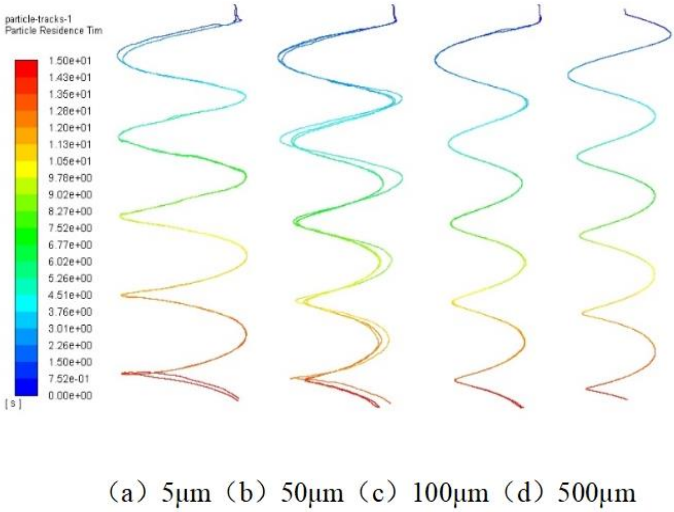


Fig. 4. Trajectory of quartz ore particles in BL1200-0.6 spiral chute

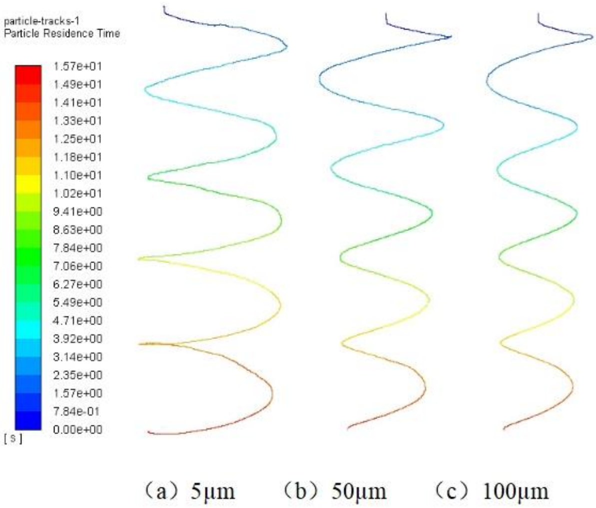


Fig. 5. Trajectory of quartz ore particles in BL600-0.6 spiral chute

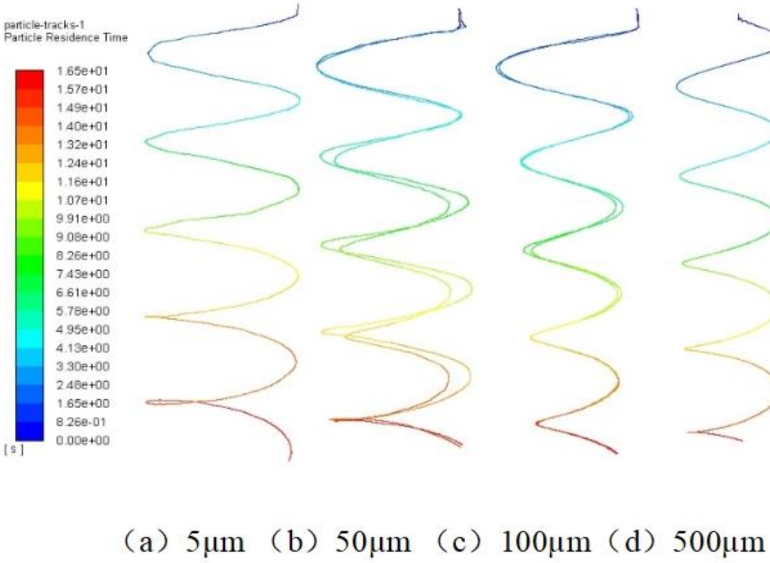


Fig. 6. Trajectory of sulfide iron ore particles in BL1200-0.6 spiral chute

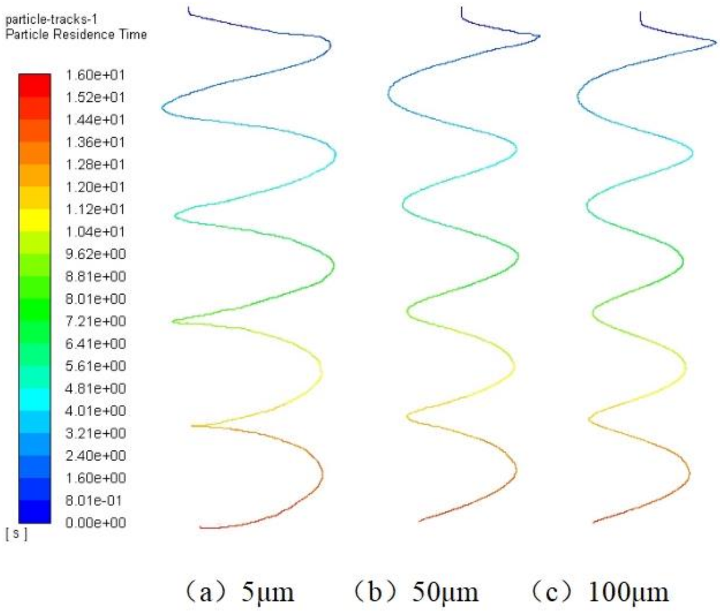


Fig. 7. Trajectory of sulfide iron ore particles in BL600-0.6 spiral chute

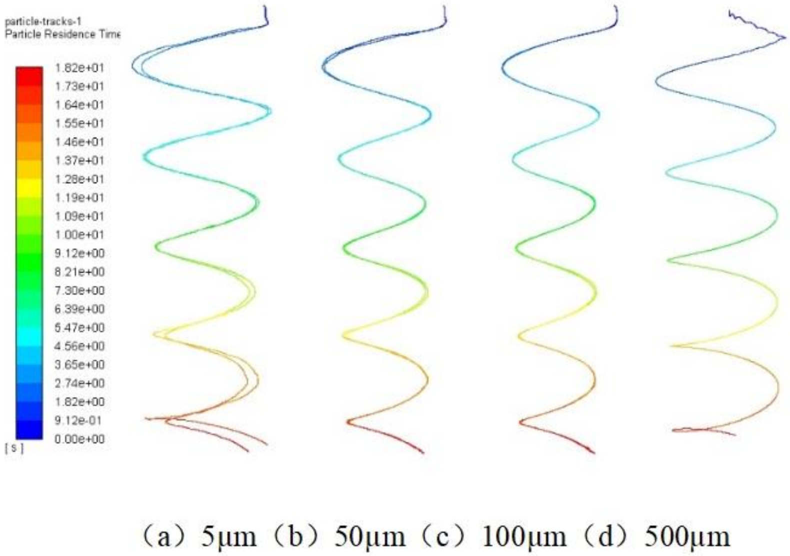


Fig. 8. Trajectory of galena particles in BL1200-0.6 spiral chute

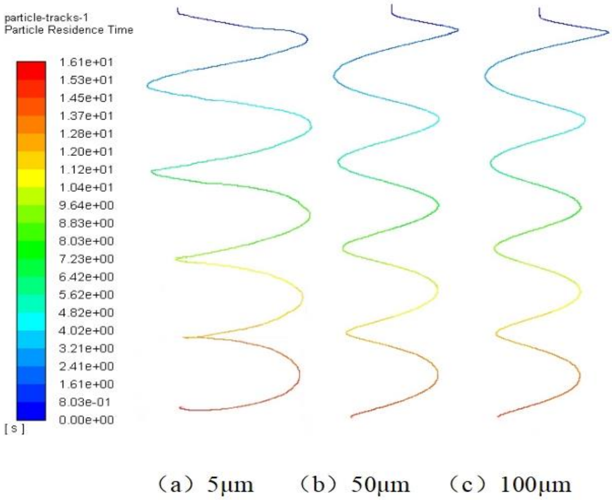


Fig. 9. Trajectory of galena particles in BL600-0.6 spiral chute

A comparison of the particle motion trajectory curves shown in Figures 4-Figure 9 shows that:

For the sorting process of 5μm mineral particles, it can be seen through Figs. 4(a), 6(a) and 8(a) that the particles basically do not converge to the inner side (i.e., they cannot be enriched) when sorting 5μm particles by the BL1200-0.6 spiral chute, and it can be seen through Figs. 5(a), 7(a) and 9(a) that when sorting 5μm particles by the BL600-0.6 spiral chute, it can be It is obvious to see the contraction in the third circle, so when sorting micro-fine particles, it is better to use the spiral chute with a small diameter to sort the particles.

For the sorting process of 50μm mineral particles, it can be seen through Figs. 5(b), 7(b), and 9(b) that the aggregation behaviors of the three kinds of mineral particles are obvious during the sorting process of the BL600-0.6 spiral chute; all of them completed the contraction before the end of the third lap, and it can be seen through Figs. 4(b), 6(b), and 8(b) that during the sorting process of the BL1200-0.6 spiral chute, 50μm mineral particles only basically complete the contraction in the fourth circle, and the enrichment effect is not as good as that of BL600-0.6 type spiral chute.

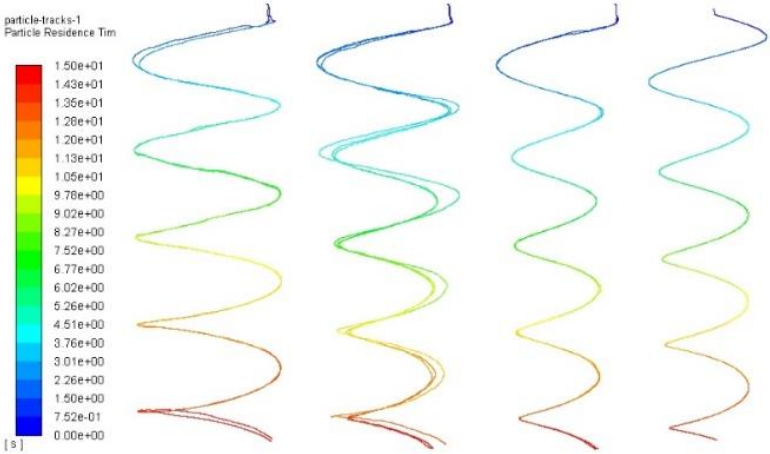
For the sorting process of 100μm mineral particles, it can be seen through Figs. 7(c) and 9(c) that the enrichment of 100μm sulfurous iron ore and galena on the BL600-0.6 spiral chute is more obvious, and both of them finish the contraction before the third lap, but it can be seen through figure 5(c) that the quartz sand aggregates inward prematurely during the sorting process of the BL600-0.6 spiral chute, and it will cause interference to the heavy minerals' It is unfavorable to the sorting; Figures 4(c), 6(c), and 8(c) show that in the sorting process of BL1200-0.6 spiral chute, the three kinds of mineral particles are all contracted at the end of the second lap, and after the contraction, the radius of rotation of the particles will decrease with the increase of the specific gravity of the particles, and it is a state of contraction all the time, which shows that BL1200-0.6 spiral chute has a good performance on the mineral particles with a size of 100μm, and it is also good for the mineral particles of 100μm, and it is good for the mineral particles of 100μm. This shows that the BL1200-0.6 spiral chute has a good enrichment effect on 100μm mineral particles. Therefore, the BL1200-0.6 spiral chute is more suitable for sorting 100μm mineral particles.

For the sorting process of 500μm mineral particles, it can be seen through Figs. 4(d), 6(d), and 8(d) that when BL1200-0.6 spiral chute sorts 500μm three kinds of mineral particles, the three kinds of mineral particles hardly shrink, which indicates that BL1200-0.6 spiral chute does not have a significant effect on the enriched effect of the large-size particles, and it is not suitable for the sorting of large-size particles.

Therefore, for the above simulation results, it can be seen that it is suitable to use a small-diameter spiral chute for sorting fine-grained minerals and a large-diameter spiral chute for sorting medium-coarse-grained mineral particles. The results of the study are consistent with the experience of industrial applications of spiral chutes.

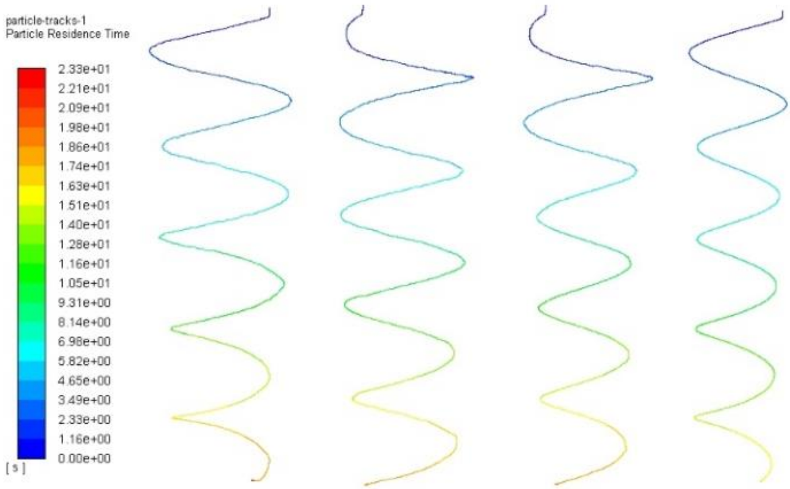
3.2 Effect of pitch ratio on mineral particle sorting in spiral chute

The following study is to investigate the effect of the pitch-to-diameter ratio on the sorting of mineral particles in the spiral chute. The movement trajectories of quartz sand, sulfurous iron ore, and galena particles of different grain sizes on the groove surface of the spiral chute of the BL1200-0.45 and BL1200-0.6 types are shown in figure 10-figure 15.



(a) 5μm (b) 50μm (c) 100μm (d) 500μm

Fig. 10. Trajectory of quartz ore particles in BL1200-0.6 spiral chute



(a) 5μm (b) 50μm (c) 100μm (d) 500μm

Fig. 11. Trajectory of quartz ore particles in BL1200-0.45 spiral chute

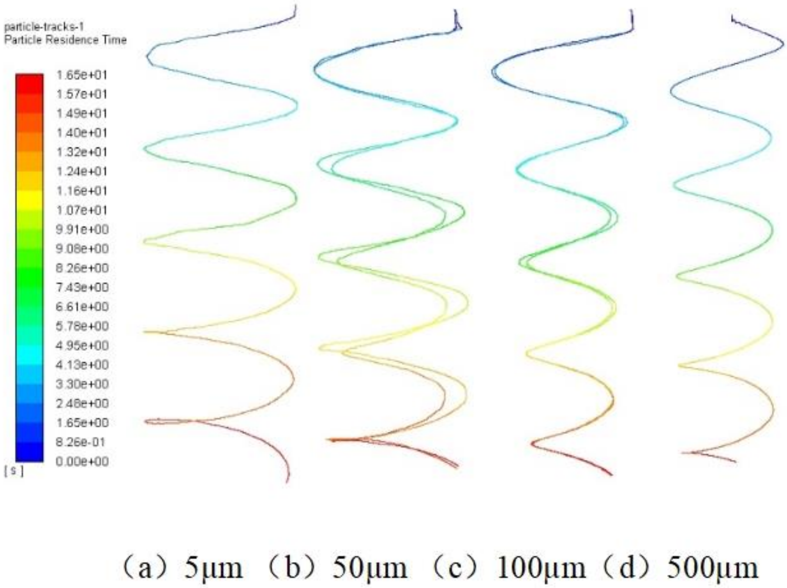


Fig. 12. Trajectory of sulfurous iron ore particles in BL1200-0.6 spiral chute

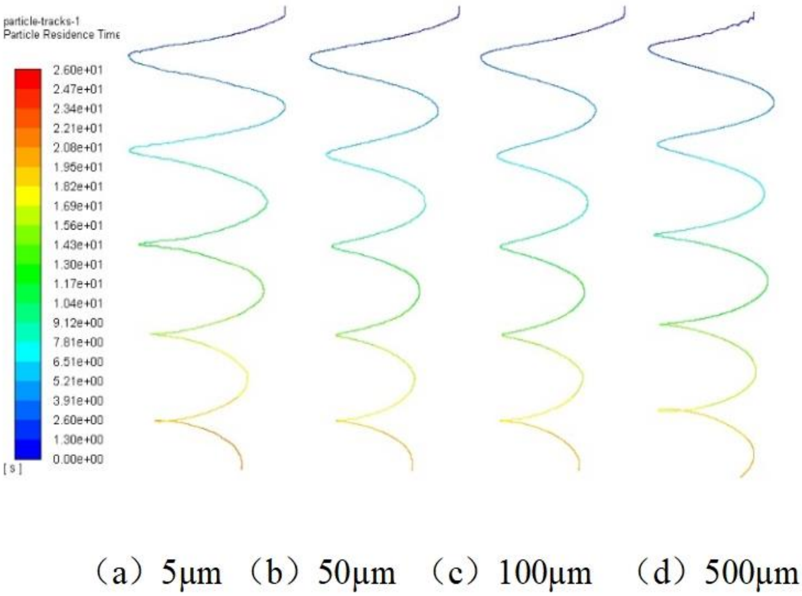


Fig. 13. Trajectory of sulfide iron ore particles in BL1200-0.45 spiral chute

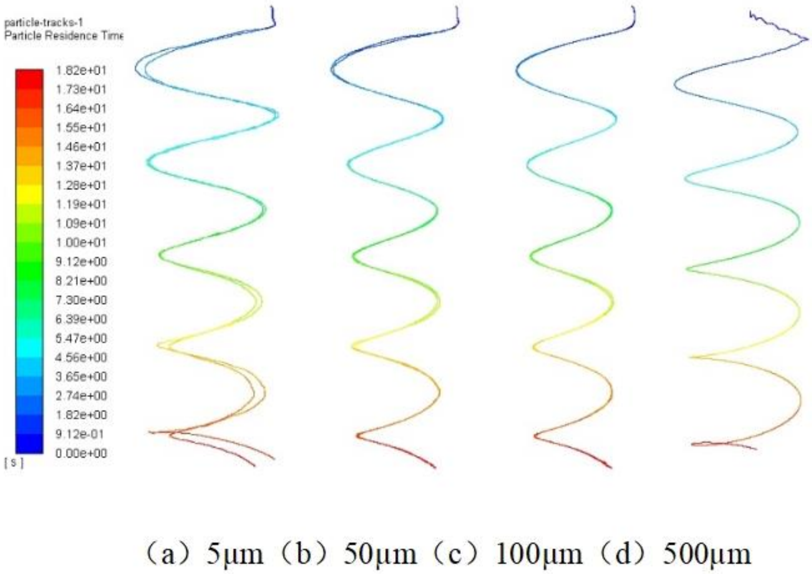


Fig. 14. Trajectory of galena particles in BL1200-0.6 spiral chute

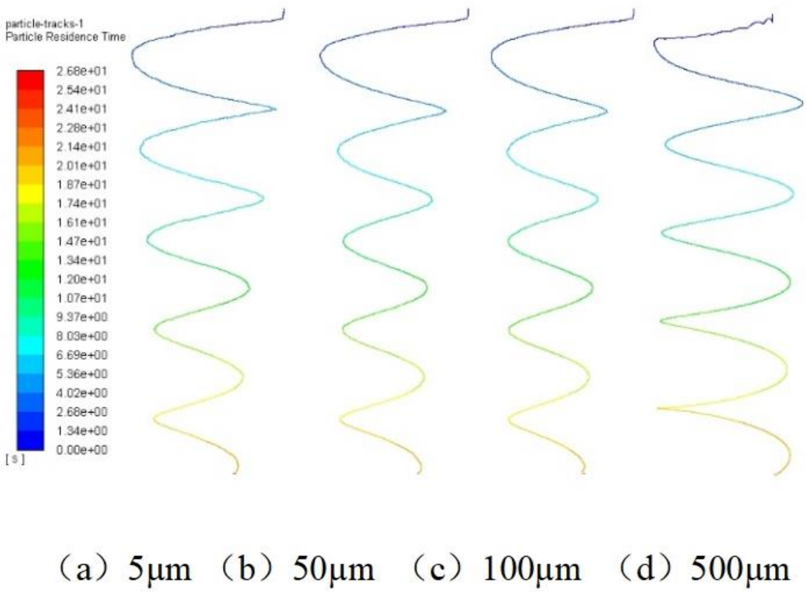


Fig. 15. Trajectory of galena particles in BL1200-0.45 spiral chute

A comparison of the particle trajectory curves shows that the BL1200-0.45 spiral chute tends to be the same as the BL1200-0.6 spiral chute in sorting mineral particles.

For the sorting process of 5μm mineral particles, it can be seen through Figs. 10(a), 12(a), and 14(a) that the particles basically cannot be enriched in the BL1200-0.6 spiral chute when sorting 5μm mineral particles, and it can be seen through Figs. 11(a), and 13(a) that the quartz sand and sulfide iron ore particles can be enriched, indicating that the spiral chute with a small pitch-to-diameter ratio is more favorable for sorting microfine-grained mineral particles.

For the sorting process of 50μm mineral particles, it can be seen through Figs. 10(b), 12(b), 14(b) that in the sorting process of BL1200-0.6 spiral chute, the 50μm mineral particles basically complete the contraction in the fourth circle, and the radius of gyration is at about 0.4m, and through Figs. 11(b), 13(b), 15(b) that in the sorting process of BL1200-0.45 spiral chute, 50μm mineral particles similarly complete the contraction movement in the fourth circle, and the radius of gyration is at about 0.3m, with better sorting effect. In the 0.45-type spiral chute sorting process, 50μm mineral particles also complete the contraction movement in the fourth circle; the radius of gyration is about 0.3 m, so the sorting effect is better.

For the sorting process of 100μm mineral particles, it can be seen through Figs. 10(c), 12(c), and 14(c) that in the sorting process of BL1200-0.6 spiral chute, 100μm mineral particles finish contraction at the end of the second circle, and the radius of gyration is about 0.2m, and through Figs. 11(c), 13(c), and 15(c) that in the sorting process of BL1200-0.45 spiral chute, 100μm mineral particles finish contraction only at the end of the third circle, with the radius of gyration at about 0.3m, and the sorting effect is not as good as BL1200-0.6 type spiral chute. 0.45 spiral chute sorting process, 100μm mineral particles in the third circle before the completion of the contraction, the radius of gyration is about 0.3m, the sorting effect is not as good as the BL1200-0.6 spiral chute, so the BL1200-0.6 spiral chute is more suitable for sorting 100μm mineral particles.

For the sorting process of 500μm mineral particles, it can be seen through Figs. 10(d), 12(d), and 14(d) that the 500μm mineral particles basically do not shrink during the sorting process of BL1200-0.6 spiral chute, and it can be seen through figure 11(d) that there is a tendency for quartz sand particles to shrink during the sorting process of BL1200-0.45 spiral chute, but this is On the contrary, it is unfavorable to the enrichment of heavy minerals because both light and heavy minerals gather inwardly, which will interfere with the sorting, and it can be seen from Figs. 13(d) and 15(d) that sulfurous iron ore and galena particles can not be enriched during the sorting process of the BL1200-0.45 spiral chute, so BL1200-0.6 and BL1200-0.45 spiral chutes are unsuitable for the sorting of 500μm mineral particles.

Therefore, for the above simulation results, it can be seen that for a certain diameter, the spiral chute with a small pitch-to-diameter ratio (0.45) is more effective in sorting finer 50μm particles, and the spiral chute with a large pitch-to-diameter ratio is more effective in sorting coarser 100μm particles.

4 Conclusion

(1) For 5μm fine-grained heavy minerals, it is suitable to use Ø600mm small-diameter spiral chute for recovery and enrichment; for 50μm fine-grained heavy minerals, it is suitable to use Ø1200mm large-diameter 0.45 small-pitch-ratio spiral chute for sorting; for 100μm medium-grained minerals, it is suitable to use Ø1200mm large-diameter 0.6 large-pitch-ratio spiral chute for sorting;

(2) The simulation study found that the larger the particles, the easier they are to gather. The 500μm coarse particles of minerals in the flow field of BL1200-0.6 and BL1200-0.45 two types of spiral chute trajectory found that regardless of the specific gravity of the particles, basically there is no tendency to gather to the inner edge, which also shows that at a certain diameter of the spiral chute there is an upper limit of the size of the sorting.

(3) Comparative analysis found that it is appropriate to use a small-diameter, small-pitch spiral chute for sorting fine-grained minerals, and a larger-diameter spiral chute with a larger pitch-to-diameter ratio is appropriate for sorting medium-coarse-grained mineral particles. The results of the study are consistent with the experience of industrial applications of spiral chutes.

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