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Progress in The Application of Centrifugal Resorice Technology in The Field of Minerals

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Abstract: How to effectively carry out mineral sorting while reducing environmental pollution and waste of resources is a problem that is constantly explored by researchers engaged in mineral sorting. Centrifugal reselection is one of the main and important technologies of mineral sorting. This paper focuses on the research status and development trend of centrifugal reselection technology in the field of minerals at home and abroad, points out the research direction of centrifugal reselection technology, and provides a reference for the further research and application of centrifugal reselection technology in the field of minerals.

Keywords: Centrifugal reselection, Operational parameters, Structural improvements, Process optimization.

1. Introduction

China is rich in mineral resources, and a variety of substances necessary for people's daily life and production, such as iron, copper, lead, zinc, etc.,are sorted from minerals. According to the physical and chemical properties of different minerals, mineral sorting can be flotation, reseparation and magnetic separation[1]. However, due to the capacity limitations of existing mining technology and equipment, in the process of mineral sorting, there have been different degrees of waste of land resources and environmental pollution[2-3].With the development and progress of society, the world pays more and more attention to environmental protection and comprehensive development and utilization of mineral resources, and efficient and environmentally friendly mineral sorting technology has also become a research hotspot for scholars[4-5].Among many sorting technologies, heavy separation plays an important role in modern beneficiation due to its advantages of high efficiency, low cost and no pollution.In this paper, the research progress of centrifugal reseparation in the field of minerals is analyzed, and the development prospect of centrifugal reseparation is proposed, which provides help for subsequent research and application.

2. Introduction to Centrifugal Reseparation Techniques

2.1. Sorting principle

Centrifugal re-separation applies the principle of gravity strengthening, and the strengthening gravity field is generated by the rotation of rotating parts, and the gravitational acceleration of ore particles in the field reaches tens or even hundreds of times of the natural force field, and its separation is easier to achieve[6].Figure 1a is a schematic diagram of the force of the ore grain when the equipment is stationary, and Figure 1b is the force diagram of the ore grain during re-separation.It is obvious that the ore grains obtain super-gravitational acceleration in the enhanced gravity field generated by rotation, which increases the sedimentation speed difference between light and heavy particles, and the particles move away from the axis, due to the existence of speed difference, the greater the displacement difference in the same time, the more obvious the distance difference between light and heavy particles, and the easier it is to separate ore particles.

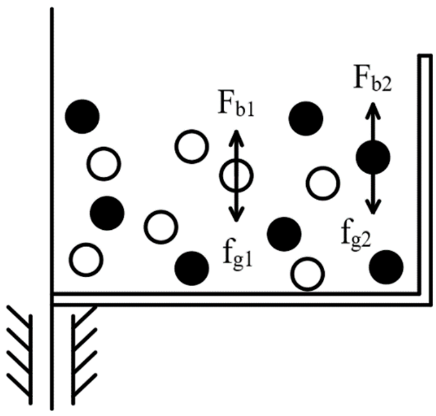

Figure 1a. The force on the ore particles when the equipment is stationary

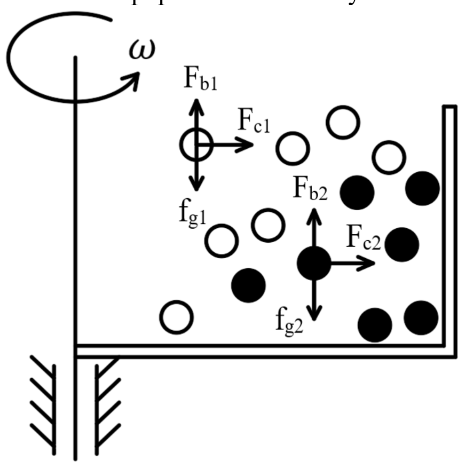

Figure 1b. Schematic diagram of the stress on the ore during reselection

The most widely accepted method of centrifugal reselection is the sedimentation theory, which analyzes the forces exerted by particles in all directions during the sedimentation process to obtain the motion state of the ore particles. Classic Stokes formula, Allian formula and Newton's formula, etc., through the settlement formula, the theoretical settlement final velocity of ore grains in the slurry can be calculated, so as to obtain the settlement state of all ore particles. The difference in the final sedimentation rate is mainly due to the difference in particle size and density. According to Newton's second law, the formula for the final velocity of the free sedimentation of the resulting particles is[7]：

$$u_t = \sqrt{\frac{4(\rho_p - \rho) g d_p}{3\rho\xi}}$$

In the formula; ρ_p is spherical particle density, g/cm^3; ρ is the density of the fluid, g/cm^3; g is the acceleration of gravity, m/s^2; d_p is the diameter of the spherical particles, mm; ξ is the drag coefficient.

2.2. Sorting equipment

In the 19th century Hunty invented the world's first centrifugal re-separator. In 1978, Canada's LeeMar Industries developed the most famous Nielsen centrifugal rebalancing machine as shown in Figure 2, which was quickly applied to gold mines around the world [8]. In 1986, Southern Illinois University of the United States and Canada's Falcon Company jointly developed the Falcon centrifugal recentrifugal separator as shown in Figure 3, and in 1993, the Falcon centrifugal concentrator was put into industrial application. These two centrifugal redressers are similar in design principle, compared with the traditional centrifugal beneficiation equipment, a backflush water device is added, which effectively solves the problem of rapid crushing of the heavy mineral bed existing in the traditional centrifugal concentrator in the process of beneficiation.

In the 80s of the 20th century, Yunxi Company developed a counter-current continuous centrifugal concentrator, which solved the problems of the control mechanism of the traditional intermittent centrifuge being ineffective and the action was not coordinated [9]. At the end of the 80s of the 20th century, the SL jet centrifugal concentrator developed by Beijing Mining and Metallurgical Research Institute successfully solved the problem of discontinuous work of the original centrifuge, and the processing capacity and sorting effect were significantly improved. At the end of the 80s of the 20th century, Riehard Mozley Co., Ltd. of the United Kingdom developed the MGS multi-force concentrator, which combines the beneficiation principle of centrifugal concentrator and shaker, which is a typical shaker centrifugal concentrator.

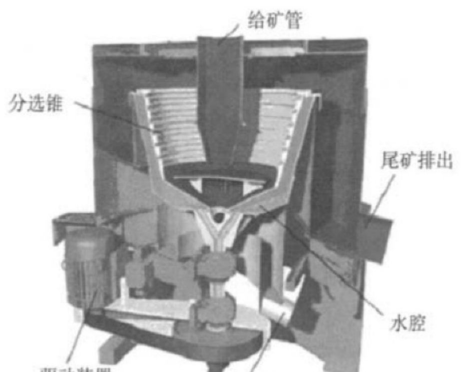

Figure 2. Knelson beneficiation equipment

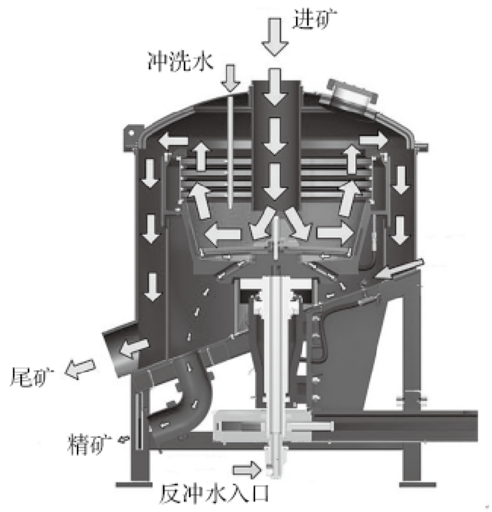

Figure 3. Falcon beneficiation equipment

3. Research Status

3.1. Research status abroad

Minor changes in the structure of centrifugal gravity separation equipment will significantly affect the experimental results. A. R. Laplante [10] studied the Angle of cone in Falcon concentrator. When the cone Angle is 8° and 10°, it is suitable for recovering heavy minerals (5-7 g/cm3), while when the Angle is 14°, it is suitable for recovering gold and other heavy minerals from light minerals (2.6-5 g/cm3).

The operation parameters of centrifugal gravity separation equipment have a great influence on the separation of different minerals, especially the speed of rotating parts and recoil pressure. Namik Atakan Aydogan [11] on the Falken concentrator different particle size, centrifugal force and recoil water pressure ratio of experimental research, concluded that in the use of Falken concentrator, different mineral particle size using specific operating conditions, can get a better recovery ratio. C. Marion[12] used Nelson separator to separate minerals with magnetite and quartz as raw materials, and the grade of magnetite was 5%, 10% and 15% respectively. To simulate low-density ores, I adopted central composite design for experimental design, and adopted response surface method for optimization. It is found that for 5% and 10% magnetite materials, inner cone speed has a negative effect on concentrate grade, a positive effect on recovery of heavy minerals, and a negative effect on separation by recoil water pressure. When the magnetite grade is 15%, the highest concentrate grade and recovery of magnetite can be achieved under certain operating conditions. In addition, Lahiru Basnayaka[13] conducted sorting tests on clay ores through the Nelson equipment and found that although the addition of clay increased the apparent viscosity, the hydrodynamics in the inner cone of sorting were not affected. It is worth noting that the feed size distribution and recoil water pressure significantly affect the performance of Nelson centrifugal separator.

In addition, the theoretical model and prediction model of centrifugal gravity separation have also been studied. Jean-Sébastien Kroll-Rabotin[14]use the UF Falcon concentrator as an example.The theoretical model of separation of ultrafine particles (below 80 μm) by UF Falken concentrator was verified by experiments. The physical process of separation of ultrafine particles in UF Falken concentrator was obtained. RickHonaker、Avimanyu Das[15] take Nelson beneficiator as an example, through the test found that the particle size in the range of 150~25 μm coal particles, by adding bubbles into the feed pipe to form bubbles - coal particle agglomeration to reduce the density of coal particles, so that the cleaned coal yield increased by 10%~20%, and ash reduced by 2 percentage points. Q. Dehaine[16] take Falcon UF as an example to analyze its dynamics and separation mechanism, and find that it contradicts the stationarity and non-resuscitation assumptions based on the existing physical models. I discuss the issue of adding a lift component to the existing models, and propose a resuspension criterion as a physical guide involved in this secondary separation mechanism.

In addition, Filiz Oruç[17] used several groups of test data and Minitab 15 mathematical software package to deduce the mathematical model equations of clean coal ash content and recovery rate. It is concluded that under the optimized condition, the Falcon separator can produce clean coal with ash content of 36% from raw coal with ash content of 66%.Ozcan Oney[18] studied the beneficiation process of fine coal powder by Nelson concentrator.The effects of these variables on recovery of concentrate ash content and recovery of fuel were studied by central combination design.Quadratic regression models with estimated coefficients are developed to assess responses, and 3D plots are proposed to assess the interaction between independent variables and responses. The upgrading curve is used to evaluate the optimization results.Through the comparison of upgrade curves, it is proved that the purification effect of Nelson separator on fine coal is better, and the appropriate operation parameters will obtain a certain expected recovery rate.On the basis of the physical analysis of the separation principle of Falken centrifuge separator, Jean-Sébastien Kroll-Rabotin[19] established the prediction model of Falken centrifuge separator, using polynomial continuous function to represent the particle size and density distribution.Making the model directly usable without the need to know the numerical methods behind it, and allowing the reconstruction of missing information. The new model can reproduce the results of the discrete version without the discretization step and is more suitable for industrial applications.

3.2. Domestic Research Status

The research scope of centrifugal gravity separation in China involves operation parameters of centrifugal gravity separation equipment, separation mechanism, process optimization and transformation, and computer software. Although domestic independent research and development of horizontal centrifugal separator, but in recent years the domestic research focus is still focused on the improvement and optimization of foreign developed Falcon concentrator and Nelson concentrator, etc.

Consistent with foreign research results, the operating parameters of equipment have a great impact on mineral recovery. Domestic researchers study the operating parameters from the perspective of equipment and process. Xuefeng Wen[20] take the Falcon SB centrifugal sorter as an example to establish the dynamics equations of spherical particles in the stratified and separated zones of the centrifugal sorter.It is concluded that the high intensity centrifugal acceleration is the key factor to achieve the rapid sedimentation of fine particles in the Falcone SB stratified zone.Chun Wang[21] through to the pulp particle dynamics analysis, illustrates the recoil pressure's influence on recovery, and through experiment further proved the importance of recoil pressure control and got ideal recoil water pressure value at the same time, nelson concentrator recovery enhancement and recoil water technology research provides the theoretical guidance.A gold mine was recovered and utilized through total gravity separation process. The effects of feeding concentration, flushing water flow rate and centrifugal force on gold concentrate grade, recovery rate and beneficiation efficiency of Nelson gravity coarse separation were studied by orthogonal test method, and the optimum process parameters of Nelson gravity separation were determined[22].

The structure of the equipment also has a great influence on the mineral separation effect.By analyzing the static and dynamic characteristics of the centrifugal cone structure of the Nelson concentrator, Zuoshi Liu[23] provide a reference for the design and improvement of the equipment.

The domestic applications are mainly concentrated in the combination of centrifugal gravity separation and other processes to carry out beneficiation. Through the process optimization and transformation of Nelson concentrator, the closed-circuit cyclone overflow of the first stage and the discharge of the second stage ball mill were combined in Fengxian Sifang Gold Mine Co., LTD., Shaanxi Province. The recovery rate of the gravity separation of gold was increased from about 30% to 51.93%, and the treatment capacity increased by 3.24%. The grade of leaching gold is reduced by 47.0%, the grade of leaching residue gold is reduced by 11.2%, and the annual comprehensive benefit is about 4.44 million yuan[24]. In a gold ore concentrator, the process technology of mercury-full slime cyanide carbon slurry was transformed into Nelson concentrator and shaker combined gravity separation system, which reduced the production cost, increased the processing capacity to 700 t/d, and the recovery rate of gold was 49.72%. It also reduced the production cost, avoided the environmental pollution problem of the original process, and the comprehensive benefit was significant[25]. The gold concentrate with grade of Au 60.95 g/t, Pt 218 g/t, recovery of Au 29.92% and Pt 61.96% was obtained by adding Nelson concentrator in semi-self-grinding nickel-copper beneficiation in Jinchuan Company[26].A quartz vein type gold ore from Hainan was used as raw material to conduct Nelson gravity separation-flotation test. According to GRG test, the mass fraction of gold recovered by gravity separation is 80.88%. The optimum conditions of Nelson gravity separation and flotation were determined by condition tests[27]. Xiaoyi Zhao[28] in a moderate granularity, sexual brittle is crystalline uranium deposit, especially after grinding crystalline uranium part of clay, by comparing different gravity separation process, using spiral dressing - table - nelson joint re-election process, sorting - 0.074 mm content is 33% of uranium, eventually uranium grade of 2.52% and recovery rate 91.88% uranium ore concentrate.

Fine - grained minerals have always been a difficult problem in sorting.According to the characteristics of difficult separation and low enrichment ratio of fine cassiterite slime with high sulfur and high slime in fine slime system of Bari Concentrator of Guangxi Gaofeng Mining Co., LTD., the beneficiation process of fine cassiterite slime was studied. Using the principle process of flotation desulphurization and desmuding, tin flotation and centrifugal gravity separation, the tin concentrate with tin grade of 26.72% and recovery of 70.77% was obtained, and the high efficiency recovery of fine cassiterite with high sulfur and mud was realized[29]. Ting Zhang[30] used flotation desulfurization and centrifugal concentrator to recover tungsten tin and associated copper and zinc in a tungsten-tin fine mud in Guangxi.Tungsten and tin concentrate with WO3 and Sn grade of 16.65% and 9.28%, recovery of WO3 and Sn are 69.09% and 59.58%, respectively, sulfide ore containing Cu1.65% and Zn 5.91%, recovery of 85.49% and 73.13%, respectively, were obtained. Xiaowen Zhou[31] a dressing plant in jiangxi belongs to complex mineral composition and mineral fine granularity of tungsten fine mud, and by changing the centrifugal drum cone Angle, the set concentration enrichment tank, equipped with electromagnetic directional valve and pneumatic clamp tube valve and other specific design of vertical continuous centrifugal separator can not only improve the centrifuge production efficiency, also achieve the efficient recovery of fine grain tungsten content.

In addition, Kai Liu[32] aimed at the horizontal centrifugal separator ore discharge difficulties, in the analysis of the horizontal centrifugal separator automatic control system structure on the basis of the design to meet the mineral processing technology, control requirements, in line with the mineral processing process automatic control system. Moreover, the mineral processing accuracy and efficiency are improved. Based on PLC control technology, the automatic control system of horizontal centrifugal separator is realized.

4. Conclusion and Prospect

The changes of equipment structure, particle size, centrifugal force, recoil pressure and other operating parameters, as well as the material grade, will obviously affect the mineral recovery, while the viscosity of the material has no obvious effect on the mineral separation in centrifugal re-selection. When the micro-fine minerals are recovered by centrifugal gravity separation, the recovery rate can be improved from the aspects of suspension and depolymerization. A large number of experimental references have been provided for the recovery of micro-fine minerals by centrifugal gravity separation combined process in China.The prediction model makes centrifugation more intuitive and intelligent.The combined process is superior to the single centrifugal gravity separation process in the recovery of minerals in the mine, and the appropriate recovery process should be selected according to the conditions of hardness and particle size of minerals. The combination of centrifugal gravity separation technology and automation technology is helpful to improve the precision and efficiency of mineral processing.

As an effective and environmentally friendly beneficiation equipment for mineral recovery, centrifugal gravity separation equipment has been widely used in mines at home and abroad.The structure and process optimization of equipment is still the hot research direction in China, and the standardization, automation and intelligence of centrifugal gravity separation equipment are the research hotspots. A large number of studies on centrifugal gravity separation combined process show that the centrifugal gravity separation technology has been developed from a single process to a combined process. In the later stage, the relationship between centrifugal gravity separation and other processes can be studied on the basis of the existing equipment and process, and the integrated equipment suitable for the combined process can be designed.

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