CONTROLLING OVERGRINDING OF VALUABLE MATERIALS USING MODIFIED AIR-SPARGED HYDROCYCLONE①

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ABSTRACT Enlightened by the separation characteristics in the air-sparged hydrocyclone (ASH) that both classification and flotation exist simultaneously, a modified air-sparged hydrocyclone (MASH) was introduced to control the overgrinding of valuable materials with higher density in the fine grinding circuit. Investigations were made on the optimization of the geometric and operation parameters of the MASH, and on the effects of the physicochemical characters of feed slurry on the MASH separation performance. A new classification system, which could be effectively used to control the overgrinding of valuable materials with higher density in the fine grinding circuit was developed, including a MASH and a conventional hydrocyclone.

Key words modified air-sparged hydrocyclone grinding-classification overgrinding flotation

1 INTRODUCTION

In the conventional classification equipment of grinding-classification circuit, the classification process is dependent on the densities and sizes of the feed particles. This results in a low classification efficiency for the classifier to deal with particles with two or more kinds of densities. The main problem is that there are some coarse particles with lower density in the overflow and some fine particles with higher density in the underflow. For metal ores, almost all the fine particles with higher density in the underflow are metal materials and most of them have been completely liberated with their sizes already being fine enough for flotation. However, because these fine particles are in the underflow, they will be sent to mill again. As a result, these particles will be overground and their sizes will be reduced even lower than the critical flotation limit. Two main disadvantages will result from the overgrinding. One is the increase of circulating load for mills, leading to the total grinding circuit capacity decreases and more energy be consumed, the other is the decrease of recovery of metals. So, not only are the energy and the mineral resources wasted but also the economic benefit of mineral processing plant be decreased because of the existence of overgrinding. Therefore, it is essential and important to control the overgrinding of valuable materials in grinding circuits.

To avoid the overgrinding of valuable minerals or prevent the valuable fine particles with higher density from repositing to underflow, it is essential to accomplish classification not only just by the difference in density and size of the particles but also by some external forces, i. e., it is essential to accomplish classification in a kind of classifiers in which there exists a compound force field. E. g., the magnetic hydrocyclone[1, 2] could prevent the fine magnetite particles from repositing to underflow because of the magnetic force existing in the hydrocyclone, therefore it

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could be used to control the overgrinding of magnetite. However, the magnetic hydrocyclone could be only used to deal with magnetic ores. Up to now, there has not been any effective techniques or methods to effectively control the overgrinding of other kind of valuable minerals such as some nonferrous metallic ores and nonmetallic ores and so on.

Because there exist both classification and flotation in the air-sparged hydrocyclones (ASH) simultaneously, if the ASH were used as a kind of classifiers, it is possible to prevent the fine hydrophobic particles from entering into the underflow by the enlargement of buoyancy for the hydrophobic materials due to the hydrophobic minerals being transformed from solid particles into mineralized bubbles. As a result, the overgrinding of hydrophobic materials could be controlled effectively. In this paper, a modified ASH (MASH) was introduced, for the first time, to try to control the overgrinding of valuable minerals with higher density in the fine grinding circuit of nonferrous metallic ores. The goal of this research project is to get an effective new classification technique.

2 EXPERIMENTAL

2.1 Apparatus

The geometry of the experimental MASH is shown in Fig. 1 and Table 1. Compared with the ASH that was used as a kind of flotation apparatus previously, the modification of the experimental MASH includes four aspects, i. e., (1) the length/diameter ratio is reduced by about one half; (2) a thick-wall vortex finder is introduced; (3) the bottom is designed with a cone; and (4) the area ratio of vortex finder to apex opening is larger. The MASH is arranged vertically with the tangential inlet upward.

2.2 Characteristics of feed slurry

The experiments were carried out in the mineral processing plant of Hongtoushan Copper Mine in China. The feed slurry of MASH was sampled just before the inlet to the hydrocyclones which are the classifiers in the fine grinding circuit. Table 2 gives the distribution of particle size, ratio (in mass fraction), grade and total content (in mass fraction) of copper in feed slurry. The concentration of the slurry was about 45% in solids by weight fraction. The pH value of the feed slurry was 8~ 8.5.

2.3 Programme

The feed slurry was mixed with flotation reagents in a conditioning tank before pumped into the MASH. In the experiments, not only could the geometric parameters (including diameter of apex opening, diameter of vortex finder and length of vortex finder) be adjusted, but also the inlet pressure, air flowrate, flotation reagent dosage and feed concentration all could be adjusted as variables. Samples of both the overflow and underflow were taken simultaneously and weighed, and the flowrates of both

Fig. 1 Schematic diagram of the MASH
1—inlet; 2—vortex finder; 3—porous cylinder; 4—compressed air; 5—baffle; 6—underflow pipe

Table 1 Geometry of the MASH

Parameters	Symbols	Dimensions
Inlet area	$a \times b$	$24 \times 8\ mm^2$
Porous cylinder		
Diameter	D	74 mm
Length	L	300 mm
Thickness	δ_w	10 mm
Average pore size	d_c	5~ 10 μm
Height of inlet chamber	L_o	50 mm
Vortex finder		
Inner diameter	d_o	20, 24, 28 mm
Outer diameter	D_o	58 mm
Length	h	53, 83, 133 mm
Height of underflow chamber	L_u	70 mm
Baffle diameter	D_u	64 mm
Cone angle	θ	60°
Diameter of underflow pipe	d_u	8. 12. 16 mm

Table 2 Distribution of particle size and copper in feed

Size / μm	Yield / %	Copper grade/ %	Total copper/ %
+ 75	38. 78	1. 727	33. 39
− 75~ + 38	26. 01	2. 020	26. 20
− 38	35. 21	2. 302	40. 41
Σ	100. 00	2. 006	100. 00

overflow and underflow were measured. The samples then were dried and screened into three size fractions, i. e., − 400 mesh (− 38 μm), 400 mesh to 200 mesh (+ 38~ − 75 μm) and + 200 mesh (+ 75 μm). The solids in every size fraction were weighed and assayed for copper.

3 RESULTS AND DISCUSSION

3. 1 Optimization of geometric and operating parmeters of MASH

To control the overgrinding of the valuable materials with higher density, the valuable fine particles should be prevented from repositing to underflow. Therefore, in the investigation of optimization of geometric and operating parameters of MASH, the copper recovery of − 400 mesh particles in overflow, ε_{400}, was chosen as the main target separation performance index. When the length of vortex finder was taken as 83 mm, the dosage of butyl xanthate was fixed at 30 g/ t, the dosage of pine camphor was fixed at 75 mg/ L and the feed concentration was fixed at 45% solids, the orthogonal analyses of the effects of diameter of vortex finder d_o, diameter of underflow pipe d_u, inlet pressure p_s and air flowrate Q_g on ε_{400} are shown in Fig. 2, from which the optimum dimensions were determined as: $(d_o)_{opt} = 28$ mm, $(d_u)_{opt} = 12$ mm, $(p_s)_{opt} = 0.10$ MPa and $(Q_g)_{opt} = 100$ L/ min, and the influence degrees of these four parameters on

Fig. 2 Orthogonal analyses of the results of the parameter optimization experiments with ε_{400} as the target index

ε_{400} could be listed from strong to weak as: $d_u \rightarrow p_s \rightarrow d_o \rightarrow Q_g$.

The results of the optimization experiments on the length of vortex finder are given in Fig. 3. In these experiments, the other parameters were taken as: $d_o = 24$ mm, $d_u = 12$ mm, $p_s = 0.08$ MPa, $Q_g = 83$ L/min, the dosage of butyl xanthate 30 g/t, the dosage of pine camphor 75 mg/L and the feed concentration 45% solids weight fraction. From Fig. 3 it can be found that both a too large length of vortex finder and a too short length of vortex finder are not proper to improve the ε_{400} value, and the results show that the optimum length of vortex finder was 83 mm in this study.

Fig. 3 The effect of the length of vortex finder on ε_{400}

Based on the results of the above optimization experiments, the MASH geometric and operating parameters were chosen as $d_o = 28$ mm, $d_u = 12$ mm, $h = 83$ mm, $p_s = 0.10$ MPa and $Q_g = 100$ L/min.

3.2 Effect of dosages of flotation reagents on MASH performance

Table 3 gives the results of experiments on dosages of collector and frother, where γ_{-400} stands for the mass percentage of −400 mesh particles entering into overflow, ε_{400} is the same as mentioned above, and E_{-400} and E_{-200} for the classification efficiencies for −400 mesh and −200 mesh size fraction respectively which were calculated by the followed formula[3]:

$$E = \frac{(\alpha - \theta)(\beta - \alpha)}{\alpha(1 - \alpha)(\beta - \theta)} = \frac{\gamma(\beta - \alpha)}{\alpha(1 - \alpha)} \quad (1)$$

where α, β and θ are individually the mass percentages of the particles with the calculated size in feed, overflow and underflow decimally, and γ is the total mass percentage of solids entering overflow from feed.

From Table 3 the following aspects could be indicated: (1) the effects of the dosages of flotation reagents on the MASH performance are much less than those of the MASH geometric and operating parameters; (2) it is just like the case in a common flotation apparatus that the effect of the collector dosage on the MASH performance is much larger than that of the frother dosage; and (3) with the dosages of flotation reagents increasing, E_{-400} is increased while E_{-200} varies little, i.e., more particles in +400 ~ −200 mesh size fraction are separated and entered into overflow.

3.3 Effect of feed concentration on MASH performance

Table 3 Experimental results on the effects of dosages of flotation reagents on separation performance

Dosages of flotation reagents		Separation performance indexes			
Butyl xanthate/ $g \cdot t^{-1}$	Pine camphor oil/ $mg \cdot L^{-1}$	γ_{-400} /%	ε_{400} /%	E_{-400} /%	E_{-200} /%
30	12.5	53.4	78.1	42.8	27.1
30	37.5	52.1	77.8	37.6	28.6
30	75.0	52.7	79.2	41.6	30.1
60	75.0	58.6	81.2	42.2	34.1
90	75.0	58.5	82.5	41.4	35.5

The results of the experiments on feed concentration are given in Table 4, where C_e stands for feed concentration, i is the copper enrichment ratio in overflow, and the other symbols are the same as mentioned above.

Table 4 Effect of feed concentration on separation performance

C_e /%	γ_{-400} /%	ε_{-400} /%	ε_{+200} /%	E_{-400} /%	i
14.0	44.4	87.6	16.0	33.9	2.541
18.4	43.6	82.7	17.8	33.7	2.433
24.3	43.3	84.7	9.9	35.0	2.492
40.6	52.7	79.2	8.8	41.6	1.738
44.1	53.0	75.8	6.1	42.9	1.578

With the feed concentration increasing, the enrichment ratio of copper in overflow, i, and the copper recoveries of − 400 mesh and + 200 mesh particles in overflow, ε_{-400} and ε_{+200}, all decreased, while both the mass percentage of − 400 mesh particles entering into the overflow, γ_{-400}, and the classification efficiency for − 400 mesh size fraction, E_{-400}, also increased, this indicates that the flotation performance in MASH is better with lower feed concentration. The selectivity of copper flotation of − 400 mesh particles will get worse with the feed concentration increasing, this shows that when the feed concentration increasing, even though E_{-400} is increased, ε_{-400} will drop down yet, i. e., more fine particles of copper materials will reposit to underflow and this will result in more copper materials being overground. Therefore, it is more proper for the MASH to deal with slurry with lower concentration.

3.4 Effect of flotation on MASH performance

Table 5 gives the effect of flotation on MASH performance, where γ and γ_{+200} individually stand for the mass percentages that total solids and particles in + 200 mesh entering into the overflow from feed, the other symbols are the same as mentioned above.

From the results in Table 5 it could be found that: (1) certain classification exists in the MASH without flotation; (2) after sparging air into MASH and adding flotation reagents into feed slurry, the classification efficiency of the MASH is slightly improved by the flotation in MASH, and the copper in overflow is enriched in the MASH with flotation. Although the total mass percentage of solids entering overflow, γ, decreases by 8.6% in the MASH with flotation; the mass percentage of − 400 mesh particles entering overflow, γ_{-400}, decreases by 5.2%; and the mass percentage of + 200 mesh particles repositing to overflow, γ_{+200}, decreases by 9.3%; while the copper recoveries of − 400 mesh and + 200 mesh particles in overflow, ε_{-400} and ε_{+200}, increase by 16.3% and 4.6% individually. The results in Table 5 obviously show that the MASH could effectively prevent the fine hydrophobic particles from entering into underflow and separate some of the coarser hydrophobic partlcles, i. e., the MASH could be effectively used to control the overgrinding of valuable minerals in the fine grinding circuit.

Table 5 Effect of flotation on the separation performance

Parameters/ Performance indexes	Without flotation	With flotation
Butyl xanthate/ $g \cdot t^{-1}$	0	60
Pine camphor oil/ $mg \cdot L^{-1}$	0	75
Air flowrate/ $L \cdot min^{-1}$	0	100
γ/ %	41.2	32.6
γ_{-400}/ %	63.8	58.6
ε_{-400}/ %	64.9	81.2
γ_{+200}/ %	17.3	8.0
ε_{+200}/ %	10.0	14.6
i		
total solids	1.031	1.535
− 400 mesh size fraction	1.017	1.385
+ 400− 200 mesh size fraction	0.930	1.685
+ 200 mesh size fraction	0.577	1.827
E_{-400}/ %	42.1	42.2
E_{-200}/ %	32.4	34.2

3.5 A new classification system developed to control the overgrinding of valuable ma-

terials in the fine grinding circuit

From the above experimental results, it could be found that although the experimental MASH could effectively prevent the − 400 mesh valuable minerals from repositing to underflow, some − 400 mesh gangue minerals enter into underflow yet. It is essential to separate those fine particles from the underflow product before the underflow product being sent to mill again. Because almost all the fine particles in the underflow product of the MASH are gangue minerals, i. e., the densities of fine particles are smaller than those of the coarse particles in the underflow product of the MASH, it is easy to separate fine particles in the underflow product of the MASH from coarse particles just depending on the differences in their sizes. A new classification system for the fine grinding circuit was advanced including a MASH and a conventional hydrocyclone, as shown in Fig. 4. With the new classification system, the overgrinding of hydrophobic materials in a grinding circuit could be avoided effectively, and the content of those particles in the overflow product which are too coarse or too fine to be separated in the follow-up flotation could be reduced as far as possible in the new classification system. As a result, the recovery of valuable materials in the follow-up flotation would be increased consequently.

4 CONCLUSIONS

(1) According to the influence degrees on the copper recovery of − 400 mesh particles in overflow, the MASH geometric and operating parameters could be put in an order from strong to weak as following: diameter of underflow pipe → inlet pressure → diameter of vortex finder → air flowrate. Both a too large length of vortex finder and a too short length of vortex finder are not proper to be used to separate fine particles of valuable materials. An increased dosage of flotation reagents could be helpful to separate some more relatively coarse particles of hydrophobic minerals, but result in a decreased selectivity of separation. It is more proper for the MASH to deal with slurry with lower concentration.

Fig. 4 A new classification system developed to control the overgrinding of valuable materials in the fine grinding circuit

(2) The MASH has the ability to effectively prevent fine particles of valuable materials from repositing into underflow. The new classification system, developed with a MASH and a conventional hydrocyclone, could be used to effectively control the overgrinding of valuable materials in grinding circuits and to decrease as far as possible the content of those particles in the overflow product which are too coarse or too fine to be separated in the follow-up flotation separation, and then result in an increased recovery of valuable materials.

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