Flotation characteristics and flotation kinetics of fine wolframite

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ARTICLE INFO

ABSTRACT

The flotation characteristics and kinetics of fine wolframite from Shizhuyuan Mine, Hunan, China were studied. Coarse and middle particles entered the concentrate easily. However, because of the reduction of middle particles as carriers and the poor collision and attachment between fine particles and air bubbles, it was difficult to float fine particles. A new kinetic model was proposed and compared with four common kinetic models, including a classical first-order model, a modified first-order model, a first-order kinetic model with a rectangular distribution of floatabilities and a second-order kinetic model with a rectangular distribution of floatabilities. The kinetic model evaluation showed that the author's model fitted the experimental data best. The new model was applied to industrial data in a dressing plant to verify its reliability, and a better imitative effect was obtained compared with other models investigated. The modified first-order model agreed well with experimental and industrial data. The optimum flotation kinetic equations of fine wolframite in the laboratory and dressing plant were $\varepsilon = 87.26 - 31.74e^{-3.446t} - 55.51e^{-0.879t}$ and $\varepsilon = 85.76 - 44.67e^{-2.052t} - 41.09e^{-0.434t}$, respectively.

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1. Introduction

In general, wolframite is recovered by gravity methods as long as the particle size is sufficiently large. However, because wolframite ores are brittle, they are easily over-crushed and over-ground in the crushing and grinding processes. In most cases, wolframite ore exists in a fine state. The recovery of tungsten from fine wolframite as recovered by gravity methods was below 45% [1]. Flotation is an effective and widely used separation method for fine and very fine materials [2].

Flotation as a physical-chemical process is used extensively in mineral processing to separate finely ground valuable minerals from a mixture in a pulp [2–4]. Most flotation developments of fine wolframite focus on the application of reagents and their interactions in flotation and the processing flowsheets [5,6]. Hu et al. (1997) used octyl hydroxamate as a collector to study the interactions with wolframite flotation [7]. Tian et al. (2002) synthesized a new collector with aniline and salicylaldehyde as main materials for wolframite flotation [8]. Fang et al (2007). used a mixture of 731 oxidized paraffinum sodium salts and benzyl hydroxamic acid as collectors for tungsten slime flotation [9]. Deng et al. (2015) proposed a novel surfactant, N-(6-(hydroxyamino)-6-oxohexyl) octanamide, for wolframite flotation through hydrogen bonding and electrostatic attraction [10].

Many new flotation technologies have been proposed in recent years. Lu et al. (1994) used polyacrylic acid as a flocculant to study the flocculation behaviors of fine wolframite; intermediate molecular weight polyacrylic acid showed the best flocculation effect [11]. Qiu et al. (1993) used coarse wolframite particles (>10 μm) as a carrier to recover fine wolframite particles (<5 μm) and the tungsten recovery increased from 40.5% to 70.38% [12]. The shear-flocculation flotation process and oil agglomeration flotation process have also been proposed for fine wolframite flotation.

A review of this literature indicates that virtually no data were reported on flotation characteristics and kinetics of fine wolframite. This work aims to study the kinetics of fine wolframite on the foundation of flotation characteristics of fine wolframite.

2. Experimental

2.1. Materials

Sample were from Shizhuyuan Mine, Hunan, China, and were ground to −2 mm. Their chemical analysis and mineral composition are shown in Tables 1 and 2. The main gangue minerals in the ore sample are quartz, fluorite, muscovite, anorthose and epidote.

2.2. Flotation tests

Flotation tests were conducted on a hanging trough flotation cell. Samples (1000 g) were dispersed with running water. Sodium carbonate (200 g/t), sodium fluorosilicate (20 g/t) and aluminum sulfate (250 g/t) were used as regulators. Lead nitrate (250 g/t) was used as an activator for wolframite. Benzohydroxamic acid (35 g/t) and fatty-

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Table 1
Chemical analysis of ore sample.

Component	WO$_3$	Mo	Bi	Sn	Pb	Zn	S	Fe	Mn	SiO$_2$	Al$_2$O$_3$	CaO	MgO	CaF$_2$
Content/%	0.41	0.08	0.18	0.15	0.014	0.021	1.12	7.21	0.51	36.42	8.58	22.35	0.66	21.24

Table 2
Mineral composition of ore sample.

Mineral	Wolframite	Scheelite	Quartz	Fluorite	Muscovite	Anorthose	Epidote	Chlorite	Amphibole	Potassium feldspar	Almandite
Content/%	0.19	0.34	23.06	21.48	7.54	5.88	5.48	4.33	4.22	4.20	3.66

acid collector TAB-3 (18 g/t) were used as collectors for wolframite. Terpenic oil (15 g/t) was used as a foaming agent. The froth layer was removed for a set time using a spatula. The froth product was filtered, dried and weighed, and the recovery was calculated as the weight percentage of wolframite.

3. Results and discussion

3.1. Flotation characteristics of fine wolframite

The rougher, cleaner and scavenging operations included four, seven and seven flotation cells, respectively. The concentrate grade from every flotation cell is shown in Fig. 1. The results indicate that the concentrate grade from the first to the fourth flotation cell was approximately 3%, which is attributed to tungsten particles with good flotability. The concentrate grade increased by 2.4% from the fifth to the eighth flotation cell and increased by 22.3% from the fifth to the eighth flotation cell. This phenomenon shows that the variation in wolframite flotability from bad to good required more time. The tailings grade from every flotation cell is presented in Fig. 2. The trend in grade agrees with the concentrate.

The particle size composition of wolframite is presented in Table 3. The results in Table 3 show that the coarse fraction (+0.074 mm), middle fraction (−0.074 + 0.03 mm) and fine fraction (−0.03 mm) yields were 18.81%, 32.77% and 48.42%, respectively. In general, the flotability of the middle fraction is better than that of the coarse and fine fractions. However, the total yield of the coarse and fine fractions was 67.23% and the difficulty in recovering wolframite increased significantly. The results in Table 3 show that the grade of WO$_3$ in the coarse fraction (+0.074 mm), middle fraction (−0.074 + 0.03 mm) and fine fraction (−0.03 mm) were 11.53%, 34.84% and 53.63%, respectively. More than half of the WO$_3$ was distributed in the fine fraction.
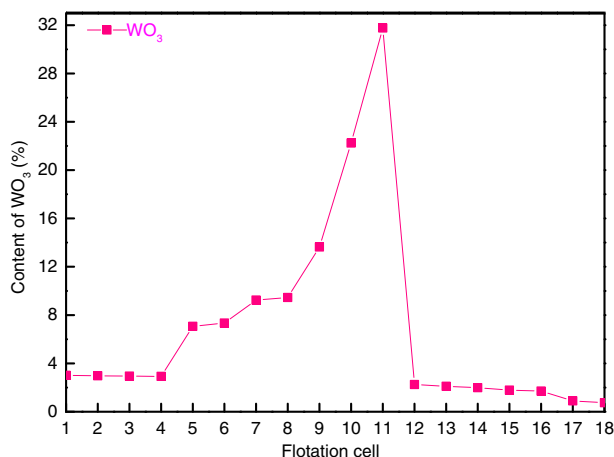
The effect of flotation time on concentrate particle size composition was investigated and the results are shown in Fig. 3. As the flotation time increased, the mass of coarse and middle particles that entered the concentrate also increased. However, because of the poor collision and attachment between the fine particles and the air bubbles and the reduction in middle particles as carriers, fine particles that entered the concentrate decreased [3]. The non-selective entrainment of fine gangue particles may have caused the decrease in fine particle concentration in the concentrate.

3.2. Flotation kinetics of fine wolframite in the laboratory

Kinetic models of flotation have been applied widely based on an analogy with the homogeneous chemical kinetics [13], in which the concentration is modeled by a first-order differential equation as follows:

$$\frac{dC}{dt} = -k \cdot C \tag{1}$$

where C is the concentration of valuable minerals, k is the flotation rate constant and t is the time.

According to the flotation characteristics of fine wolframite obtained in Section 3.1, the fine wolframite was divided into easy- and difficult-floating minerals. The flotation rate constants of minerals with different flotability are different. Therefore, Eq. (1) can convert to Eq. (2):

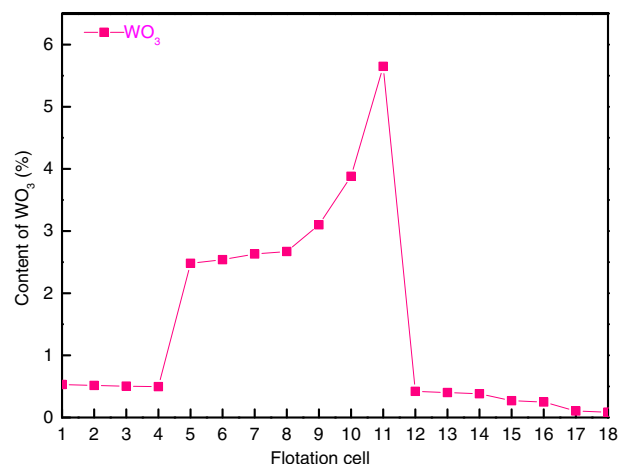$$\frac{dC}{dt} = \frac{d\sum_1^2 C_i}{dt} = -\sum_{i=1}^2 k_i C_i \tag{2}$$

Fig. 1. Grade of concentrates from every flotation cell.

Fig. 2. Grade of tailings from every flotation cell.