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Investigating the first-order flotation kinetics models for Sarcheshmeh copper sulfide ore

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ABSTRACT

This study was performed in two phases of work. In the first stage, four conventional first-order flotation kinetics models were fitted to the measured recoveries data and the best model were selected. In the second stage, influence of pH, solid concentration, water chemistry and the amount of collector dosage were investigated on kinetics parameters including flotation rate constant and ultimate recovery. The results indicated that that perfectly mixed reactor model and Kelsall model gave the best and the weakest fit to the experimental data, respectively. It was observed that flotation rate constant and ultimate recovery were strongly affected by chemical factors investigated especially water quality. The flotation rate constant decreased with increasing the solids content, while ultimate recovery increased to certain value and thereafter reduced. It was also found that the most values of flotation rate constant and ultimate recovery obtained in dosage of collector are 30 and 40 g/t, respectively.

1. Introduction

The fine particle mineral processing technology has become one of the most important development directions in current field of mineral processing [1–3]. Froth flotation is a physicochemical method which is widely used in mineral processing technologies, for the separation of finely ground valuable minerals from a mixture with gangue minerals initially present in a pulp [4,5]. Flotation is the most widely used and effective method of separation of fine and very fine materials. The principle of flotation is based on different surface properties of mineral matter [6–8]. Very important aspect of flotation is its kinetics. In fact, kinetics is one of the most important aspects of separation process [9]. The flotation rate is measured as the recovery change of the floating material in the flotation product per unit time and it is characterized by a rate constant and kinetics order [10,11].

The quantification of kinetic parameters is of increasing importance in industrial flotation to shed light on the speed of the process. Numerous researchers have studied the kinetic aspects of froth flotation paid special attention to particle size, bubbles and their complex interactions both in mechanical and in column cells [12–17]. Arbiter and Harris found that the flotation kinetics is the study of the variation in amount of froth overflow product with flotation time, and the quantitative identification of all rate-controlling variables [18]. With such variables maintained constant, the algebraic relationship between the proportion of mineral floated and flotation time is a flotation rate equation. This contains the constant values of all the rate determining variables implicit in one or more rate constants, which must be evaluated from experimental data. Also, most researchers believe that flotation is a first order process and a function of only the particle concentration and a rate constant under reasonable operating condition [18–28].

Kinetic models are often used to analyze batch flotation data and to evaluate various parameters such as flotation chemical and equipment operating conditions for flotation process [29]. The important aspect of the kinetics models is that the model parameters should in some way be characteristic of a flotation process. They can be effectively used to evaluate variables affecting flotation process [30]. Under-standing and interpreting changes in the values of ultimate recovery (R_∞) at long times and rate constant (k) are very important and can often be misleading [31]. In many laboratory studies, changing one condition leads to a change in both R_∞ and k values. This can make it difficult to compare flotation rate data between tests or to establish a trend for R_∞ and k values under different conditions. For instance, changing one condition may lead to an increase in k but a decrease in R_∞, while selectivity between the valuable and gangue minerals might be unchanged, increased or decreased depending only on the combined measure of k and R_∞ [27].

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Although the fundamentals of the first order kinetics models have been developed, detailed information about the factors which affect flotation kinetics has still not been exact obtained. In addition, influence of chemical factors such as pH, solid content, water chemistry and dosage collector has been little investigated on flotation kinetics. Therefore, remaining problems not only include the effect of factors, such as chemical factors (pH, solid content, water chemistry and reagent type), air flow rate and impeller speed, on the parameters of flotation models, but also the flotation model itself, since most of the models are not well constructed in representing true flotation behavior.

As mentioned in literature, kinetics is a tool to evaluate the flotation process. In addition, the common kinetic models applied to the flotation process are first order and they are validated on the basis of experimental analysis. Therefore, this paper was aimed to evaluate the first-order kinetics models and to investigate the influence of some controlling operational factors on flotation kinetics. This study was carried out on Sarcheshmeh porphyry copper sulfide ore which was obtained from Kerman province in the southeastern part of Iran. The Sarcheshmeh copper mine is the largest copper producer in Iran, and one of the major copper producers in the world [32].

2. Experimental procedure

In order to conduct the experiments of flotation kinetics, the obtained samples from the ball mills input of the Sarcheshmeh copper mine were prepared after two stages of laboratory comminution including crushing in a jaw crusher and milling in a Bond ball mill. Representative samples were chemically analyzed, and it contained 0.74% Cu, 4.34% Fe, 0.032% Mo, 3.05% S, 55.07% SiO_2 and 14.35% Al_2O_3. Batch flotation experiments on the samples were conducted, using a Denver D12 flotation machine with the impeller speed of 1400 r/min in a 4.3 L flotation cell. The pulp density was adjusted to 28% solids by volume at the beginning of each test. The slurry pH was set to be 12, and CaO was used for adjusting pH. Then 40 g/t collectors of Z11 (15 g/t) and mercaptobenzothiazole (25 g/t) were added to the cell; after 1 min, 30 g/t frothers of MIBC (15 g/t) and F742 (Polypropylene glycol) (15 g/t) were added to the cell; and finally after 2 min, air was opened and flowed inside the cell and the collecting of the froth was started. The concentrate froth samples were collected at the intervals of 0.5, 2, 4, and 8 min. The flotation froth was scraped every 10 s. Finally, the concentrate and tailing samples were filtered, dried and assayed. It is mentioned that water type and the values of pH, solid percentage and collector dosage for different experiments changed, but other parameters were constant. The different conditions of experiments performed were presented in Table 1.

In each experiment, the recoveries of copper the concentrate were calculated according to Wills and Napier-Munn using the following formula [9].

Table 1
Different condition of flotation experiments.

Run	pH	Solid (%)	Water type	Collector dosage (g/t)
1	11.5	28	Tap	30
2	11.5	28	Distilled	40
3	11.5	15	Tap	40
4	11.5	40	Tap	40
5	11.5	20	Tap	40
6	7.0	28	Tap	40
7	11.5	28	Tap	50
8	9.0	28	Tap	40
9	8.0	28	Tap	40
10	11.5	28	Tap	20
11	11.5	28	Tap	40

$$R = \frac{Cc}{(C+T)\times f}\times 100 \quad (1)$$

where R is recovery of Cu, %; C the dry weight of concentrate; c the grade of concentrate, %; T the dry weight of tailing; and f the grade feed, %.

3. Results and discussion

Studying particles flotation rate in flotation operation is called kinetic operation analysis. The main purpose of the flotation kinetics is to study the rule of flotation rate constant, and analyze the effects of various parameters such as the properties of ores, the system of flotation reagent and the characteristics of flotation machines. Under-standing and interpreting changes in the values of R_∞ and k are very important and can often be misleading [31]. The rate constant, k, is determined as a function of the dynamics of flotation cells as well as the properties of minerals. This parameter shows a quantitative measurement of the likelihood of a mineral recovery in concentrate and reflects the flotation performance. Hence, these kinetics parameters, i.e., ultimate recovery in a long time and flotation rate constant were investigated. This study was carried out in two phases. In the first phase of the work, four more applicable first-order flotation kinetics models were fitted to the experimental data and evaluated. These models are summarized in Table 2. In Table 2, R is the recovery of components at the times t; R_∞ represents ultimate recovery; k is referred to flotation rate constant; z denotes fraction of flotation components with the slow rate constant; k_s is rate constant for slow floating component; and k_f is rate constant for fast floating component.

Since the cumulative recovery of a component in the concentrate is proportional to flotation time, the flotation process can be considered as a time–rate recovery process [4,5]. Hence, in this stage, cumulative recovery–time curves were employed to evaluate the first-order kinetics models, as they provide an excellent tool to evaluate the flotation tests. The results of fitting the kinetics models were presented in Table 3 and Figs. 1–4.

It is mentioned that in fitting the kinetics models, firstly kinetics parameters (R_∞ and k) were determined by the model fit to experimental data using Mathematica software [33].

Table 3 indicates the measured recoveries versus the estimated recoveries by kinetic models.

Also, recovery–time curves for four selected experiments are displayed in Figs. 1–4. As observed, the perfectly mixed reactor model and model with fast and slow-floating components (Kelsall model) have the best and the weakest fit to the measured recoveries, respectively. In addition, model with rectangular distribution of floatabilities and classical model have similar results and relatively good fit to the experimental data.

Since the perfectly mixed reactor model fitted the experimental data very good, this model was applied to investigate the effects of some of operating parameters on flotation kinetics. Therefore, in the second phase of the work, kinetics parameters for the best first-order kinetics model, i.e., fully mixed reactor model were

Table 2
First order kinetic models of flotation.

Model	Equation
Model 1: classical model	$R = R_\infty(1-\exp(-kt))$
Model 2: model with rectangular distribution of floatabilities	$R = R_\infty \times (1-(\frac{1}{kt})\times(1-\exp(-kt)))$
Model 3: model with fast and slow – floating components (Kelsall model)	$R = (1-z)(1-e^{-k_f t}) + z(1-e^{-k_s t})$
Model 4: fully mixed reactor model	$R = R_\infty\left(1-\frac{1}{1+t/k}\right)$