Influence of flotation cell volume and solids mass on kinetics of sulfide ore flotation

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Abstract. The paper presents studies on the influence of flotation cell capacity and mass of solids in the suspension on the flotation kinetics of sulfide copper ore. A sample of copper ore that was collected from the Polkowice Mine of KGHM Polska Miedz S.A. in Poland was used in the experiments. It was determined that neither the volume of flotation cell nor the mass of solids had influence on the type of kinetics equation of flotation. Copper-bearing minerals floated according to the second-order equation, while the remaining components according to the first-order equation. The kinetic rate constants and maximum recovery of the studied components decreased with increasing solids mass in the flotation cell, regardless of the capacity of the cell. The best results were obtained for tests using a 1.0 dm^3 cell, while the less favorable kinetics results were observed in the test with the smallest cell of 0.75 dm^3 volume. The obtained results can be helpful in choosing the most appropriate methodology of upgrading the sulfide copper ore from Poland in order to obtain the best kinetics results.

1 Introduction

Flotation is a process of selective separation of hydrophobic materials from hydrophilic ones. Three major groups of factors have influence on the flotation effectiveness, namely: chemistry, operation and equipment components. The most important factors of the aforementioned groups are: feed rate, particle size, mineralogy, flotation agents, pulp density, electrochemical properties of feed (pH, redox), temperature, air flow and cell design [1]. Therefore, it is important to take all of these factors into account in flotation operations. A change of one factor will automatically cause changes in the whole process [1-2].

Numerous papers have considered the effect of pulp density on flotation effectiveness and selectivity [3-6]. Mehrotra and Kapur [3] analyzed the influence of pulp density on quartz flotation. It was shown that for low pulp densities there was no influence on the flotation kinetics. For higher pulp densities, the rate constant of separation *k* decreased along with increasing the pulp density. According Mehrotra and Kapur [3], these observations could be different for various materials. The influence of pulp density (7.5% and 20% by weight) on flotation selectivity of a mixture of sphalerite and pyrite was investigated by Uçurum and Bayat [4]. Higher pulp density of flotation suspension caused more effective separation of these sulfides. Uçurum [5] studied the flotation kinetics of carbon for five different pulp densities, that is 5, 7.5, 10, 15, and 20% by weight. The author stated that the best results of flotation kinetics of carbon were observed under the conditions of medium values of pulp

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density, i.e. 10%. According to Konieczny et al. [6], the yield of concentrate of Polish copper ore increased with the pulp density. Additionally, it was shown that the pulp density does not have significant effect on the recovery of copper in the concentrate.

Kinetics is one of the most important aspects of separation process, which determines the time needed for removal of valuable components of ores. The kinetics of separation is also a basic element of separation models relating to components recovery, products grade and properties of the feed [7-9]. Numerous kinetic models are available and applied in separation science and technology [10-11]. In this paper, only first-order and second-order kinetic equations are analyzed. The models are described in details elsewhere [11-12].

2. Experimental

2.1. Materials

For the purpose of conducting the experiments a sample of copper ore was collected from the Polkowice Mine of KGHM Polska Miedz S.A. in Poland. Before each flotation test, a sample of 900 g was wet-ground in a laboratory ball mill for 80 minutes, in the presence of stainless grinding media and tap water (0.5 dm^3). An industrial mixture of sodium ethyl and izobuthyl xanthates (MX) in the dose of 100 g/Mg was used as a collector. An aqueous solution of Corflot was utilized as a frother in the dose of 0.9 g per 1 dm^3 of water. Both reagents were prepared directly before flotation tests.

2.2. Procedures

Nine flotation tests were performed. Description of all experiments is presented in Tables 1-2. All experiments were conducted in the laboratory mechanical flotation machine with removable flotation cells and rotors. Three different flotation cells with various capacity were applied: 1.5, 1.0 and 0.75 dm^3. The conditioning time with collector and frother was 3 and 1 minute, respectively. During each flotation test the water solution of frother (0.9 g per 1 dm^3 of water) was added to retain the froth on the constant level. The air flow rate was regulated during each flotation test by using a rotameter. The speed of stirrer was 1900 rpm and the flow of air was 60 dm^3/h. During each flotation test seven concentrates were collected 45 sec. and 1.5, 4, 8, 15, 25, 40 minutes.

Table 1. Symbols of performed tests.

Mass of the solids/ capacity of flotation cell	**400 g**	**300 g**	**200 g**
1.5 dm^3	F1	F2	F3
1.0 dm^3	F4	F5	F6
0.75 dm^3	F7	F8	F9

Table 2. Pulp densities (*d*) in each flotation test.

Symbol of test	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
d, kg/m^3	1 112	1 058	1 026	1 238	1 156	1 066	1 258	1 208	1 140

The flotation products were dried in a laboratory drier at 105 °C for 24 hours, and then weighted. The content of copper in each flotation product was determined by using an XRF analysis. The results of flotation were evaluated by analyzing and plotting kinetics. Two kinetics equations were taken into account in the description of the flotation kinetics of copper and useless components into the concentrate, namely: first-order and second-order equations. The first-order equation is:

$$\varepsilon = \varepsilon_{\max}(1 - e^{-kt}), \tag{1}$$

while the second-order equation is:

$$\varepsilon = \frac{\varepsilon_{\max}^2 kt}{1 + \varepsilon_{\max} kt} \quad . \tag{2}$$

In Equations (1-2) ε stands for recovery of a component in separation product, $\varepsilon_{\max}$ for maximum recovery of the same component in separation product, k for rate constant of separation, and t denotes separation time. All calculations were performed using the MATLAB software.

3. Results and discussion

Table 3 shows the results obtained by checking the adjustment of first and second order kinetic equations. The equation which the best describes the flotation kinetics of Cu and the rest of the components was chosen based on the values of determination coefficient (R^2) and standard estimation error (*SEE*). The equation which the best describes the kinetics flotation is bolded in Table 3.

Table 3. Analysis of the kinetics of copper and useless components for all conducted flotation tests.

Flotation test	Equation order	Copper			Useless components		
		k, min^{-1}	R^2	*SEE*	k, min^{-1}	R^2	*SEE*
F1	1	0.2843	0.9839	5.9404	**0.0612**	**0.9924**	**1.2672**
	2	**0.0059**	**0.9981**	**2.1403**	0.0031	0.9599	3.1504
F2	1	0.3559	0.9839	6.0128	**0.0641**	**0.9928**	**1.0550**
	2	**0.0073**	**0.9987**	**1.6651**	0.0035	0.9667	2.6895
F3	1	0.4374	0.9758	7.1567	**0.0672**	**0.9946**	**1.0651**
	2	**0.0087**	**0.9986**	**1.3414**	0.0032	0.9651	3.1159
F4	1	0.4416	0.9682	7.9609	**0.0782**	**0.9878**	**1.4839**
	2	**0.0088**	**0.9968**	**1.8208**	0.0042	0.9704	2.3449
F5	1	0.6333	0.9663	7.8581	**0.0905**	**0.9940**	**1.1401**
	2	**0.0126**	**0.9962**	**2.0188**	0.0049	0.9809	2.0238
F6	1	0.6724	0.9753	7.1557	**0.0885**	**0.9921**	**1.3285**
	2	**0.0130**	**0.9983**	**1.3687**	0.0040	0.9833	2.5842
F7	1	0.3055	0.9757	7.0836	**0.0843**	**0.9928**	**1.4312**
	2	**0.0064**	**0.9957**	**2.4593**	0.0040	0.9708	2.7109
F8	1	0.3813	0.9635	8.5353	**0.0743**	**0.9961**	**1.0987**
	2	**0.0077**	**0.9924**	**2.9903**	0.0030	0.9697	3.6516
F9	1	0.5257	0.9767	7.2930	**0.0692**	**0.9926**	**1.2836**
	2	**0.0100**	**0.9986**	**1.2582**	0.0030	0.9703	3.1829

Table 4 presents the maximum values of copper and useless components recoveries in the concentrate with their rate constants. As seen from Tables 3 and 4, flotation of copper-bearing minerals is the best described by the second-order kinetic equation, while the remaining (useless) components by the first-order kinetic equation. It is observed regardless of the capacity of flotation cell and content of solids.

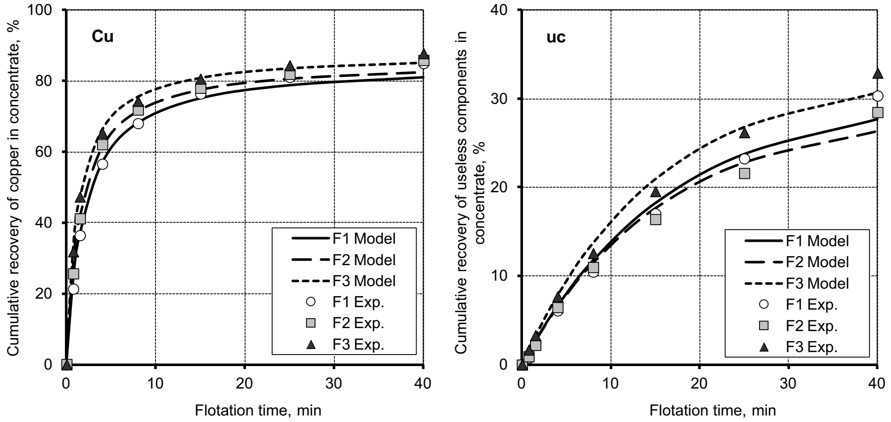
The flotation results are also presented in Figs. 1-3 in the form of the recovery of either Cu or useless (remaining) components vs. flotation time. The fastest flotation of copper in all experiments is observed in the first 5–10 minutes. After 30 minutes of the flotation process the maximum recoveries of copper achieve a plateau level. The maximum recoveries of copper in the concentrate are in the range of 80–90% for each test. However, different results can be observed for useless (remaining) components. The maximum recoveries do not reach the plateau level even after 40 min of flotation. The maximum recoveries of useless (remaining) components in the concentrate range from 30 to 35%.

Table 4. Maximum values of recovery of copper and useless (remaining) components in all flotation tests.

Symbol of test	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**
Copper									
k, min^{-1}	0.0059	0.0073	0.0087	0.0088	0.0126	0.0130	0.0064	0.0077	0.0100
$\varepsilon_{\max}$, %	81.02	82.50	85.04	84.08	84.98	87.33	83.71	87.23	87.41
Useless (remaining) components									
k, min^{-1}	0.0612	0.0641	0.0672	0.0782	0.0905	0.0885	0.0843	0.0743	0.0692
$\varepsilon_{\max}$, %	27.73	26.32	30.69	29.90	30.01	35.22	34.42	36.98	34.86

Figures 4-6 show the relationships between the parameters of kinetics (maximum recovery and rate constant) estimated for copper and useless (remaining) components as well as mass of solids in the flotation cell. It can be seen that the rate constant for copper increases when the mass of solids in the flotation cell decreases (Fig. 4a). The highest values of constant k are observed in the tests with the 1.0 dm^3 cell. The lowest values of k are obtained in tests with the 1.5 dm^3 flotation cell. Similar results are observed for the maximum recovery of copper in the concentrate (Fig. 4b). The highest values of $\varepsilon_{\max}$ of copper are obtained in the tests with the smallest flotation cell used (0.75 dm^3), while the lowest maximum recoveries of Cu in the concentrate are observed for the biggest cell used (1.5 dm^3). The values of k and $\varepsilon_{\max}$ (Fig. 4c) show that the best results of copper kinetics are observed for the 1.0 dm^3 flotation cell in the presence of solids mass in the amount of 200 g. The worst results are obtained for the flotation cell with the biggest volume and capacity. Similar observation is obtained for the flotation kinetics of useless (remaining) components. However, different flotation results using the cell with the capacity of 0.75 dm^3 are obtained. The flotation rate constant (Fig. 5a) and maximum recovery (Fig. 5c) increase with the mass of solids in the feed.

As it can be seen in Fig. 6, the most beneficial results of kinetics (the highest values of k for copper and useless components) are received in the tests using the flotation cell in the capacity of 1.0 dm^3, regardless of the mass of solids in the feed. The less favorable results of kinetics are observed in tests with the smallest cell (0.75 dm^3).



a b

Figure 1. Flotation kinetics of copper (a) and useless (remaining) components (b) in 1.5 dm^3 flotation cell.

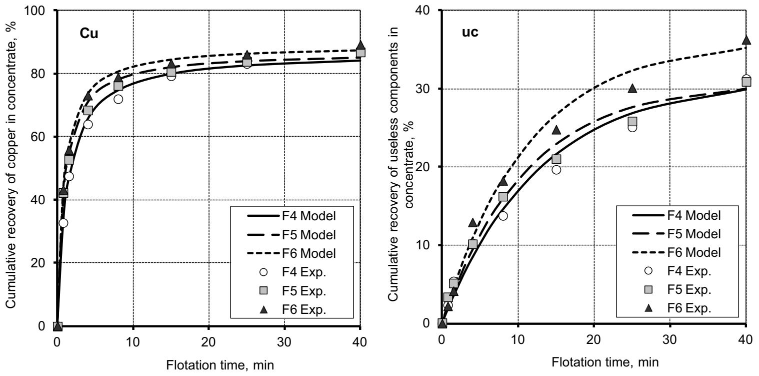


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Figure 2. Flotation kinetics of copper (a) and useless (remaining) components (b) in 1.0 dm^3 flotation cell.

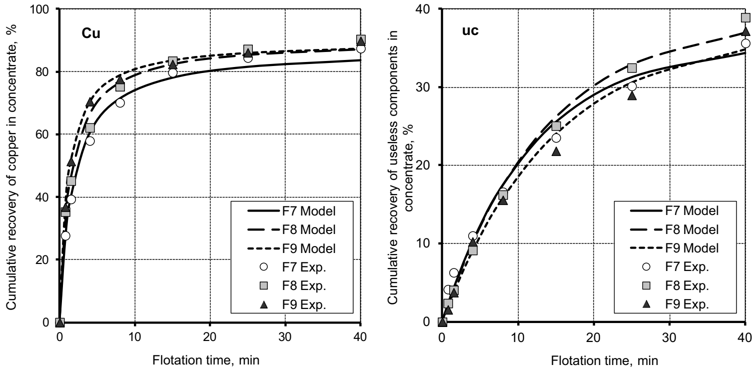

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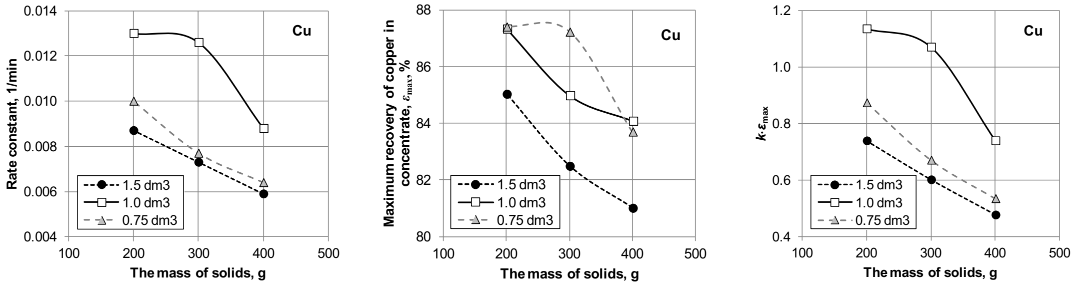
Figure 3. Flotation kinetics of copper (a) and useless (remaining) components (b) in the 0.75 dm^3 flotation cell.



a b c

Figure 4. Relationship between kinetic parameters estimated for copper and mass of solids for all conducted flotation tests.

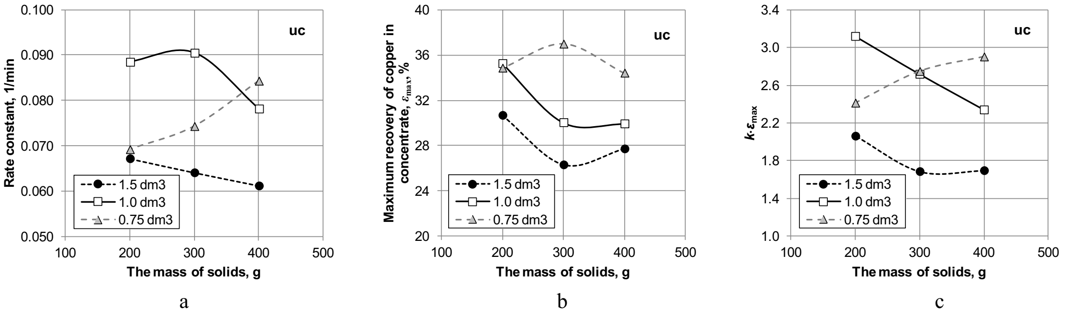


Figure 5. Relationship between kinetic parameters estimated for useless components and the mass of solids for all conducted flotation tests.

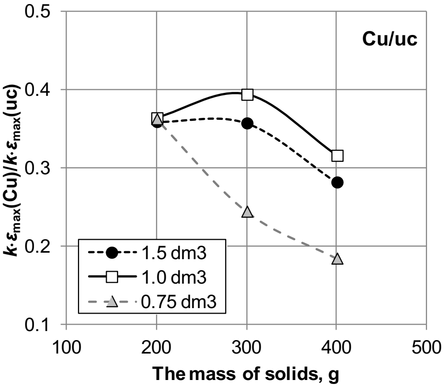


Figure 6. Relationship between kinetic parameters estimated for copper and useless components and mass of solids for all conducted flotation tests.

4. Conclusions

The study presents the influence of the flotation cell volume and mass of solids used on the flotation kinetics of the copper sulfide ore (Polkowice, KGHM Polska Miedz S.A.). Nine flotation tests were conducted. Three flotation cells with different cell volumes (0.75, 1.0. and 1.5 dm^3) and three various portions of solids (200, 300 and 400 grams) were used in the experiments. First-order and second-order kinetic equations were used to describe the process. It was shown that neither the capacity (volume) of the flotation cell nor the mass of solids had the influence on the type of kinetics equation for flotation of Cu and useless (remaining) components. The obtained results confirmed data presented in a previous paper [13]. In both papers, the flotation kinetics of copper components can be described by the second-order equation, while the useless (remaining) components by the first-order equation. The rate constants as well as maximum recoveries of both studied components decreased with increasing solids mass in the flotation cell, regardless of the capacity (volume) of the cell. The best kinetics results were obtained in the tests with the medium cell (1.0 dm^3), while the less favorable kinetics results were observed in tests performed in the smallest flotation cell (0.75 dm^3). The obtained results can be helpful in choosing the most appropriate methodology of upgrading of the sulfide copper ore from Poland in order to obtain the best kinetics results.

Acknowledgements

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