Influence of reagent dose on the flotation selectivity of copper ore from LGOM area (SW Poland)

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Abstract. The influence of amount of flotation reagents on the efficiency of copper ore flotation in standard laboratory experiments was investigated. The aim of the study was to evaluate the effect of collector and frother amount on the selectivity of copper upgrading during flotation process of dolomite-shale ore from Fore-Sudetic Monocline area (Legnica-Glogow Copper Basin). The amount of collectors added in industrial conditions was the starting point for the process assessment. Since the dose of flotation reagents influences on the quality and quantity parameters of obtained concentrates, a decrease or increase of reagent dosage can have a major impact on the overall metal production costs at the mining-metallurgical complex.

1. Introduction

One of the main factors which determine the efficiency and upgrading selectivity is amount, type and dosage of flotation reagents. Usually flotation reagents are divided into: collectors, frothers and modifying reagents (regulators). The role of collectors is to form a hydrophobic layer on a given mineral surface in the flotation suspension while the frother creates conditions for froth formation. The role of regulators is controlling the interaction of collectors between individual minerals [1].

For flotation of sulphide minerals, xanthates as well as dithiophosphates and dithiocarbamates from the anionic collectors group are most commonly used. The basic collecting reagents in industrial systems of non-ferrous ores enrichment are xanthates, characterized by great selectivity of sulphide minerals and native metals flotation, good solubility in water and stability in alkaline environment.

In recent years, interest has increased for the use of mixtures of different type of collectors for enhancing the selectivity and recovery. First research on application of mixed collector can be found during the 1950’s [2]. The interactions between differently structured collectors, for example strong and weak collectors like xanthate and non-ionic, and the synergism of them are described in many papers [3,4,5,6,7,8]. The main advantages of using such mixtures include: reducing the costs of the whole process by reducing the dose of the main and usually more expensive collector, improving the flotation kinetics, increasing the useful minerals recovery, improving the selectivity of the process and increasing the size range of the floatable particles (e.g. increased the recovery of coarse particles). The combination of xanthates and dithiophosphates has a positive influence on the sulphide minerals flotation efficiency [9].

The technological properties of Polish copper ore from Fore–Sudetic Monocline are specific and unique in the global copper resource base [10]. The presence of three various lithological with different properties types of rocks: sandstone, dolomitic and shale, make some difficulties in processing of mined copper ore. The lithological and mineralogical composition of the ore requires
creation and use of complex technological flowsheets. Moreover, the complexity of copper ore is the main reason of difficulties in keeping of high upgrading efficiency, despite the relatively high contents of precious metals in the feed.

In the case of the processing of Polish copper ores an important factor is the properties of technological waters used in flotation. At processing plants, circulating technological (flotation) waters are strongly saline, and all dissolved salts act as additional portion of the frother reagent in the flotation process [11].

In the case of copper ore flotation, the effectiveness of the process is measured by the loss of copper in waste, which in the technological system is a non-linear function of froth depth and, above all, the amount of flotation reagents dosed into the system [12]. An insufficient amount of the flotation reagent may reduce the yield of the final concentrate, while too high dose of reagents may reduce the selectivity of the separation of useful and useless components. It is extremely important that the dose of the collecting reagent should be appropriate to the parameters of ore being processed and technological system.

At present, a mixture of sodium ethyl and isobutyl xanthates alone or their mixture with the addition of dithiophosphates as collectors are used in flotation process of Polish copper ore. The amount of collector and frother at concentrator plants is between 70–100 and 10–20 grams per ton, respectively. The doses of flotation reagents at each concentrator plant depend on feed density, technological system, content of useless components in the feed and floatability of ore being processed [13]. Wherefore, the aim of this paper is to evaluate the effect of collector and frother amount on the selectivity of copper upgrading during flotation process of sulphide ore from Fore-Sudetic Monocline area (SW Poland).

2. Experimental
The examined material was the sample of dolomite-shale ore with chalocite mineralization predominance which was collected from Legnica-Glogow Copper Basin (LGOM) area. The mineral composition of studied copper ore is presented in Table 1. The sample was dry-crushed in a jaw crushe below 1 mm. Directly before the flotation test, the ore sample was wet-ground in a laboratory ball mill to obtain about 80% of the mass passing 0.040 mm. Particle size distribution of the feed is presented in Table 2.

| Mineral/minerals                  | Content (%) | Mineral/minerals                  | Content (%) |
|----------------------------------|-------------|-----------------------------------|-------------|
| Chalcocite/digenite/djurleite     | 1.52        | Bornite                           | 0.27        |
| Chalcopyrite                     | 0.12        | Covellite                         | 0.10        |
| Pyrite/marcasite                 | 0.14        | Galena                            | 0.05        |
| Sphalerite                       | 0.02        | Quartz                            | 23.94       |
| Ca, Mg carbonates                | 56.97       | Clay minerals + micas             | 13.26       |
| Others                           | 3.61        |                                   |             |

Table 1. Mineral composition of flotation feed.
Table 2. Particle size distribution of flotation feed.

| Particle size (mm) | Yield, $\gamma$ (%) before wet milling | Yield, $\gamma$ (%) after wet milling |
|-------------------|----------------------------------------|--------------------------------------|
| >0.10             | 66.1                                   | 0.4                                  |
| 0.07–0.10         | 3.5                                    | 1.7                                  |
| 0.04–0.07         | 4.8                                    | 8.9                                  |
| <0.04             | 25.6                                   | 89.0                                 |

2.1. Materials and methods

All flotation experiments were conducted in a laboratory mechanical flotation machine of Denver D12 type equipped with 2.5 and 1.5 L flotation cells. Each experiment was carried out according to the standard method of multi-stage operation which consist of rougher and cleaning flotation. The last cleaning stage was kinetic flotation test in which the feed was the concentrate obtained from the first stage of cleaning flotation.

In Figure 1 the scheme of flotation methodology is presented. The density of the flotation suspension was 300 g/L. The industrial water and reagents were used in flotation experiments. As a frother an aqueous solution of polyethylene glycols was used. The mixture of sodium ethyl and isobutyl xanthate (in ratio 7:3) was applied as a collector. Both reagents were prepared directly before flotation test. After the experimental part, all the products were dried in a laboratory dryer at 70 °C, and next weighed. The chemical analysis of copper content was conducted.

![Figure 1. The scheme of flotation methodology.](image)

Tests were conducted in two series. In the first series an influence of collector dose on the upgrading selectivity of copper in concentrates was analysed. The collector was added in three various doses: 60, 80 and 120 g/Mg while the frother amount was constant 20 g/Mg. In second series the impact of amount of frother on the process selectivity was studied. The frother was dosed in range of 10 to 40 g/Mg while the amount of collector was constant and equal 80 g/Mg.

2.2. Results and discussion

The results of flotation were evaluated by the mass balance of components and products of separation (Table 3) as well as by plotting recovery-recovery (the Fuerstenau upgrading curve) and grade-recovery separation curves (Figures 2-3).

As it can be seen in Figure 2 quite similar flotation selectivities of copper upgrading were obtained in the first series. It should be noted that for the test with the usage of medium collector dose
(80 g/Mg) the recovery-recovery curve in the range of the maximum curvature of the curve (the point characterizing the industrial system) was characterized by the highest selectivity of upgrading (Figure 2a). In this experiment, the lowest content and the loss of copper in tailings were observed. It has been seen in Figure 2a, the curve for this test is close to the ideal upgrading curve (the higher process selectivity) for higher recoveries values.

**Table 3.** The mass balance of components and products of separation.

| Product        | γ, % | β, % | ε, % | γ, % | β, % | ε, % | γ, % | β, % | ε, % |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| concentrate 1 | 1.2 | 34.3| 24.5| 2.8 | 28.5| 45.4| 1.8 | 32.1| 32.6|
| concentrate 2 | 0.7 | 29.3| 8.8 | 2.8 | 21.3| 22.8| 2.0 | 26.2| 24.1|
| concentrate 3 | 5.1 | 18.1| 40.0| 5.6 | 13.0| 14.2| 4.2 | 16.8| 20.2|
| concentrate 4 | 3.4 | 13.5| 7.6 | 4.8 | 9.5 | 3.8 | 3.0 | 13.0| 4.9 |
| product 2     | 11.2| 7.0 | 5.7 | 14.0| 5.3 | 4.0 | 7.9 | 7.9 | 3.6 |
| product 1     | 23.0| 3.6 | 5.8 | 38.6| 2.5 | 6.8 | 25.9| 3.6 | 6.6 |
| tailing       | 55.3| 1.7 | 7.5 | 31.4| 1.8 | 3.0 | 55.3| 1.8 | 7.9 |
| feed          | 1.7 |     |     | 1.7 |     |     |     |     |     |

| Product        | γ, % | β, % | ε, % | γ, % | β, % | ε, % | γ, % | β, % | ε, % |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| concentrate 1 | 3.4 | 24.5| 49.5| 2.8 | 28.5| 45.4| 1.4 | 30.9| 25.7|
| concentrate 2 | 3.3 | 17.2| 18.3| 2.8 | 21.3| 22.8| 2.7 | 22.8| 29.4|
| concentrate 3 | 4.9 | 11.6| 11.5| 5.6 | 13.0| 14.2| 4.8 | 14.4| 20.4|
| concentrate 4 | 6.1 | 8.2 | 5.7 | 4.8 | 9.5 | 3.8 | 5.7 | 9.8 | 7.8 |
| product 2     | 15.2| 4.7 | 4.9 | 14.0| 5.3 | 4.0 | 13.3| 5.4 | 5.2 |
| product 1     | 27.8| 2.7 | 5.5 | 38.6| 2.5 | 6.8 | 27.8| 2.9 | 6.0 |
| tailing       | 39.3| 1.7 | 4.6 | 31.4| 1.8 | 3.0 | 44.2| 1.7 | 5.4 |
| feed          | 1.7 |     |     | 1.7 |     |     | 1.7 |     |     |
Figure 2. The recovery-recovery and grade recovery separation curves for the flotation of dolomite-shale copper ore in the presence of various doses of collecting agent.

The analysis of separation curves in Figure 2b has been shown that in flotation test in the presence of lower dose of collector, the concentrates are characterized by lower contents of copper at the similar recovery of this metal in concentrate. It was noted that the increase of collector dose more than 80 g/Mg causes the poorer upgrading parameters at rougher flotation stage. It results in higher losses of metal in final tail despite the higher selectivity of copper upgrading at cleaning stages.

At the next step of experiments the impact of frother dosage on the copper upgrading selectivity in concentrate was examined. It has been shown in Figure 3a that the increase of frother dose above 20 g/Mg has negative effect on process efficiency, particularly at cleaning stages. The concentrates collected in cleaning flotations are characterized by lower contents of copper compared to experiment with the medium dose of frother. Too high dose of frother can result in increased mechanical entrainment of useless components particles into concentrate. It can reduce the quality of concentrates from cleaning stages. Moreover, the poorer yield of tailings and the lower content of copper in tailings from rougher flotation in the test in the presence of lower dose of frother were observed (Figure 3b).

In the tests with the lowest and higher amounts of frother, the concentrates have a lower yield and contain less copper compared to dose of 20 g/Mg. Final tailings are characterized by higher losses of copper and higher contents of this metal in these products (Figure 3). Reducing the dose of frother below 20 g/Mg has a negative influence on upgrading selectivity of copper at cleaning stages which is related to the small amount of arising froth – too small dose of reagent.
A statistical analysis of the obtained results was carried out by determining the selectivity indicator \( c \) which allows for one-parameter evaluation of the upgrading process (Table 4). The indicator was determined on the basis of approximation of enrichment results on the Fuerstenau plots using the equation for asymmetric curve in regard to the diagonal curve. This curve is characterized by noticeable convexity for lower recovery values and flattened course for higher recoveries [14]. The higher \( c \) selectivity indicator the greater upgrading efficiency and close to the ideal upgrading process.

Table 4. Statistical analysis of obtained upgrading results

| Influence of collector dose on flotation | collector (g/Mg) | 60 | 80 | 120 |
|-----------------------------------------|-----------------|----|----|-----|
| | frother (g/Mg) | 20 |    |    |
| | selectivity indicator, \( c^a \) | 10.82 | 12.29 | 10.64 |
| | standard error of estimation, \( SEE \) | 1.23 | 1.72 | 1.66 |

| Influence of frother dose on flotation | collector (g/Mg) | frother (g/Mg) | 80 |
|---------------------------------------|-----------------|----------------|----|
| | 10 | 20 | 30 | 40 |
| | selectivity indicator, \( c^a \) | 10.59 | 12.29 | 10.68 | 10.55 |
| | standard error of estimation, \( SEE \) | 2.01 | 1.72 | 1.67 | 2.34 |

\[ c^a = (100\% - \varepsilon^c)/100^{(\varepsilon^c)} \]

The highest upgrading selectivity was obtained for flotation test with the collector and frother dose of 80 g/Mg and 20 g/Mg, respectively. It was observed that the influence of collector amount on upgrading results is not such significant as the impact of frother dosage. The increase of frother amount noticeably reduces the efficiency of upgrading (lower selectivity indicator \( c \)) which is probably result of mechanical entrainment of useless components. Decreasing of frother dosage below 20 g/Mg causes higher losses of copper in tailings and poorer quality of final concentrates.
3. Conclusions
The analysis and evaluation of separation curves for flotation tests using various doses of collector have been shown that regardless of reagent dosage the process selectivity is quite similar. The highest upgrading selectivity of concentrates in copper in test in the presence of collector and frother in doses of 80 and 20 g/Mg respectively was observed. The increase of frother dosage above 20 g/Mg clearly reduces the upgrading selectivity of concentrates in copper. It is related to the mechanical entrainment of gangue particles. The reducing the dose of frother below 20 g/Mg causes an increase of content and loss of copper in tailings with poorer quality of final concentrates.

It has been noted that a change of collector dose has only a slight impact on upgrading selectivity of concentrates in copper. As it can be seen that the flotation process of examined material is much more responsive on the dosage changes of frother than the collector. In the presence of too low frother dose the copper concentrates are characterized by poor content of copper while higher amount of copper accumulates in tailings. In the process when the amount of frother is too high, the concentrates are diluted by useless components that results in decreasing of upgrading selectivity.

It is advisable both for the collecting and frothing reagents to perform technological tests to determine the optimum dosages of flotation reagents which are used in current flotation process. As it has been shown in the paper, the collector amount should be reduced to 80 g/Mg while the dose of frother should be about 20 g/Mg. These changes of flotation reagents dosages affect the quality and quantity parameters of final products. Moreover, it has a major impact on the total costs of purchase of these chemicals and the overall metal production costs at the mining-metallurgical complex.

4. References
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