Influence of grinding on flotation of industrial semi-product from sedimentary copper ore upgrading process

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Abstract. The effect of the grinding and liberation changes of sulphide minerals on their floatability in the flotation process of concentrate from rougher flotation from the Rudna Concentration Plant (KGHM Polska Miedz SA) was analyzed. It has been found that the upgrading selectivity decreases with the decreasing size of sulphide particles regardless of liberation degree. The best selectivity of flotation was observed for the fully liberated sulphides. Totally locked sulphides and minerals marginally liberated are characterized by very poor upgrading selectivity or even no upgrading. Moreover, for the smallest particles of sulphides (below 20 μm), despite of good liberation, very low selectivity of enrichment is observed. It was found that the application of one-stage grinding of concentrate from rougher flotation in separation circuit can result in higher upgrading selectivity of cleaning stages and higher content of useful minerals in final concentrate.

1. Introduction

Flotation is the most versatile technique used in mineral processing [1]. The selectivity and efficiency of flotation relies on various factors e.g. particle size, mineralogy, reagent type and dosage, air flow rate or solid content [1-4].

According to Pease et al [5], the finer particles tend to be more liberated, different than coarse particles. To achieve the liberation of valuable minerals, reducing of grain size should be conducted [6,7]. The possibility of achieving liberation by comminution is strongly related to textural relationship between minerals [7,8]. Three textural features appear as the most significant for mineral liberation characterization: grain size, grain boundary irregularity and the pattern of intergrowth type [8-10]. Quality and quantity of composites determine location of the mineralogical limit to flotation or theoretical grade recovery [7].

Inadequate liberation is often the main reason of the poor upgrading performance. This is the reason that process mineralogy study is highly required to control the plant performance [11]. It helps understand and predict flotation concentrate grade and recovery, and understand and predict causes of dilution to concentrate or losses to tailings [12].

Based on flowsheet of technological circuit at Rudna Concentration Plant (KGHM Polska Miedz SA), the concentrate from I and II cascade of rougher flotation is directed into first cleaning flotation operation. It is assumed that the grains in concentrate are too coarse and valuable minerals not liberated enough. The aim of this paper is the analysis of influence of one-stage grinding on the
flotation selectivity and changes of sulphide liberation. The effect of comminution on upgrading of sulphide minerals liberated in various degree and upgrading of sulphide of different size was studied.

2. Experimental

2.1. Materials and methods

A representative sample of concentrate from I and II cascade of rougher flotation stage was collected from Rudna Concentration Plant (KGHM Polska Miedz SA). It was collected for 3 days, at each three work shifts. The content of copper in examined sample was 7.5%. The mass of flotation feed was 300 g. Two flotation experiments were performed. The first test was performed for the raw sample of concentrate, while in the second test the feed, before the upgrading process, was grounded in a laboratory ball mill in 30 minutes. All flotation tests were conducted in a Denver D12 laboratory flotation machine equipped with 1.5 dm³ flotation cell, in the presence of process water salinity. The air flow rate was regulated during each flotation test using a rotameter. Industrial mixture of sodium ethyl and isobutyl xanthate and sodium O,O-diethyl dithiophosphate in proportion of 7:3 and the dose of 20 g/Mg was used as a collector. An aqueous solution of mixture of alkyl polyglycol ethers was utilized as a frother at a dosage of 5 g/Mg in each flotation tests. Both reagents were prepared directly before flotation test. Four concentrates and one tailing were collected in each flotation test. After the experimental part, all the products were dried and weighted. Mineral analyses were performed using the QEMSCAN® automated mineral analysis system. The content of copper was determined by using an iodic titration.

The analysis of the influence of sulphide minerals liberation on their flotation was carried out for five particle size fractions: 0–20 μm, 20–40 μm, 40–71 μm, 71–100 μm and above 100 μm. Liberation analysis was performed for liberation ranges as follows: 0–10% (totally locked particles), 11–20%, 21–30%, 31–40%, 41–50%, 51–60%, 61–70%, 71–80%, 81–90%, 91–99% (impregnations) and 100% (free particles). These data were calculated for main sulphides of copper (chalocite/digenite/djurleite, chalcopyrite, bornite, covellite and tennantite), zinc (sphalerite), lead (galena) and iron (pyrite with marcasite).

2.2. Results and discussion

The results of particle size analysis are presented in Table 1. The results of flotation were evaluated by the mass balance of components and products of separation as well as by plotting recovery-recovery (the Fuerstenau upgrading curve) and grade-recovery separation curves (the Halbich upgrading curve).

As it can be shown in Table 1, the particle size decreased markedly after wet milling, especially it is noticeable for fines content.

The upgrading results for copper are presented in Figures 1 and 2. As it has been shown, significantly better upgrading results were observed in test with using grinding operation before the flotation. In this test the higher selectivity of process as well as the quality of flotation concentrate was observed. It is desired result because the concentrate from I and II cascade of rougher flotation is directed into cleaning stages. Improving the quality of concentrate and selectivity of cleaning flotation results in higher content of useful minerals in final concentrate.

### Table 1. Particle size distribution of flotation feeds.

| Particle size (mm) | Yield, γ (%) | Raw sample | Sample after milling |
|--------------------|--------------|------------|----------------------|
| <0.020             |              |            |                      |
| 0.020–0.040        |              |            |                      |
| 0.040–0.071        |              |            |                      |
| 0.071–0.100        |              |            |                      |
| >0.100             |              |            |                      |

2
As it is presented in Figures 3-7, the applying the grinding has an impact on the enrichment of sulphide minerals in each size fraction and liberation degree. The greater degree of sulphides liberation the higher selectivity of flotation process is observed in each size fraction. Moreover, the differences in the position of each upgrading curves of the analysed liberation ranges are larger in test with applying of one-step grinding. It is the most visible for the particles size of 0–40 and 71–100 μm.
Figure 3. Recovery of sulphides in concentrate vs. recovery of remaining components in tailing in size fraction 0–20 μm for flotation test of raw sample (a) and with grinding stage (b).

Figure 4. Recovery of sulphides in concentrate vs. recovery of remaining components in tailing in size fraction 20–40 μm for flotation test of raw sample (a) and with grinding stage (b).
Figure 5. Recovery of sulphides in concentrate vs. recovery of remaining components in tailing in size fraction 40–71 μm for flotation test of raw sample (a) and with grinding stage (b).

Figure 6. Recovery of sulphides in concentrate vs. recovery of remaining components in tailing in size fraction 71–100 μm for flotation test of raw sample (a) and with grinding stage (b).
A very poor upgrading selectivity or no upgrading is observed for totally locked sulphides and minerals marginally liberated. It is noticeable mainly for smaller sulphides particles. The highest selectivity of upgrading of fully liberated grains (100%) can be seen for the coarsest sulphides while poorer selectivity is observed with the decreasing of particle size. For the smallest particles (below 20 μm), despite of good liberation of sulphides, quite low selectivity of enrichment is observed (Figures 3a,b). These results confirm data from literature on the problems of flotation of fines. It is quite interesting, that e.g. for the sulphides liberated in 100% the applying of grinding improves their selectivity in all size fractions. Unfortunately, for the size fractions +100 μm, problems with the interpretation of the obtained results are observed (Figures 7a,b).

Additionally, the data points forming the Fuerstenau upgrading curve were approximated using the following equation [13]:

$$\varepsilon_r = a \frac{100 - \varepsilon_i}{a - \varepsilon}$$

where $\varepsilon$ stands for the recovery of useful minerals in concentrate while $\varepsilon_r$ stands for the recovery of the remaining components in the tailing. This equation is a result of second-order flotation kinetics of useful and nonuseful components in the ore [14]. The upgrading results, fitted with this equation and plotted as the Fuerstenau separation upgrading curve, form a symmetrical plot with reference to diagonal. Ideal upgrading is observed for $a$ equal to 100, and $a$ values greater than 100 indicate lower selectivity. Therefore, the higher values of $a$ the lower selectivity. Relationships between all possible to calculate selectivity indicators and particle size for all analyzed liberation ranges for flotation tests are presented in Figures 8a,b.

It can be seen in Figure 8a that the values of selectivity indicators increase with the decreasing size of sulphide particles regardless of liberation degree. Moreover, Figures 8a,b clearly show that applying one-stage grinding of concentrate from rougher flotation results in higher upgrading selectivity of sulphide minerals without regard to particle size. The lower values of selectivity indicator (greater efficiency of flotation) are observed in particular strongly for fine sulphides (below 40 μm) in test with additional grinding operation.
2.3. Summary and conclusions

In the paper two laboratory flotation tests of raw sample of concentrate from I and II cascade of rougher flotation (Rudna Concentration Plant, KGHM Polska Miedz SA) and with applying one-stage grinding operation were conducted. The effect of the grinding on the flotation selectivity and the changes of sulphide liberation was analysed in details. The analysis was performed for the main sulphides which occur in the sedimentary copper ore. It was found that the applying of one-stage grinding results in higher liberation of useful minerals from the gangue and improve the selectivity of the upgrading process. The upgrading selectivity decrease with the decreasing size of sulphide particles regardless of liberation degree. In both flotation tests, the best selectivity of flotation was observed for the fully liberated sulphides. Totally locked sulphides and minerals marginally liberated are characterized by very poor upgrading selectivity or even no upgrading. Moreover, among all analysed size fractions, for the smallest particles of sulphides (below 20 μm), despite of good liberation, very low selectivity of enrichment is observed.

In conclusion, an application of one-stage grinding of concentrate from rougher flotation in the technological circuit increases upgrading selectivity of sulphide minerals through the improvement of liberation degree in each particle size fraction. It can result in higher upgrading selectivity of cleaning stages and higher content of useful minerals in final concentrate.

3. References

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