Investigations over the selection of reagent dose and speed of rotor in laboratory process of ore flotation for HPGR crushing products

K Oleksik, D Saramak and A Krawczykowska
Faculty of Mining and Geoengineering, Department of Mineral Processing and Environmental Engineering, AGH University of Science and Technology, A. Mickiewicza 30, 30-059, Kraków, Poland
koleksik@agh.edu.pl

Abstract. The aim of this paper was to investigate the effectiveness of flotation process depending on the changeable dose of reagents and variable speed of rotor in flotation device. HPGR crushing products were used as a feed in all flotation tests. Efficiency indices, along with Fuerstenau curves, were determined for each test. Both rotational speed and the dose of reagent have affected the flotation results in a lower degree that expected. However it could be possible to determine the optimal dose and rotational speed of rotor that increase the effectiveness of flotation process.

1. Introduction
Process of flotation is a base beneficiation method utilized in sulphide copper ore processing. It is a complex process, effectiveness of which depends on a number of factors, that can be divided into four main groups [1]:

a) factors related to the feed characteristics (mineralogical and particle size composition, fee grade, surface properties of individual minerals, size of mineralization, liberation rate of useful minerals) [2, 3],
b) factors characterizing the flotational suspension (pulp density, pH, particle size composition, particle shape, temperature) [4, 5, 6, 7],
c) factors resulting from the accepted reagent dosage regime and type of flotation (type and dose level of reagent, method and order of their dosage into the pulp, contact time of the reagent with the pulp, type of flotation process), [8, 9, 10, 11],
d) factors related to the construction and type of flotational device (rotational speed of rotor, aeration degree, type of the flotation chamber or the manner of collecting the foam product). [9, 12, 13, 14, 15].

Application of HPGR devices into ore comminution circuit may result in more favourable beneficiation results for a certain types of material. Results of various investigation confirm that HPGR comminution manner – a generation of micro-cracks through application of high-pressure force acting on the feed material – in general, positively affects the downstream flotational beneficiation of selected types of raw materials [16, 17].

In order to obtain a good quality concentrate, it is also necessary to determine the appropriate conditions of the flotation process course. Enrichment curves, based on the relationship between selected
enrichment parameters [18], are commonly used for this purpose. Over the years, many curves have been developed, the most frequently used ones are: Henry, Mayer, Halbich and Fuerstenau curves.

The Fuerstenau curve describes the relationship between the yield and the useful component grade in beneficiation products. The curve shows symmetry in the area of its maximum bend, thanks to which it is possible to determine the selectivity index F, which characterizes approximately the total separation level. Table 1 presents the conventional scale of separation selectivity based on the F index [18].

| Class of separation | Selectivity index | Separation level  |
|---------------------|-------------------|-------------------|
| I                   | 50/50 – 60/60     | Very low          |
| II                  | 50/50 – 60/60     | Low               |
| III                 | 70/70 – 80/80     | Average           |
| IV                  | 80/80 – 90/90     | Good              |
| V                   | 90/90 – 99/99     | Very good         |
| VI                  | 100/100           | Perfect           |

2. Scope of investigation
The scope of research was to test the possibilities of improving the efficiency of flotation depending on the change in the value of selected process parameters. Based on preliminary flotation tests [8], the following parameters were selected for investigation:

- the dose of a collecting reagent,
- rotational speed of the rotor.

Sulphide copper ore, with particle size below 20 mm, constituted the testing material (figure 1). The average feed grade $\alpha$ was 1.66%.

![Figure 1. Particle size distribution of the feed for the first stage of comminution.](image-url)
The preparation of feed material for flotation tests was carried out in a two-stage laboratory crushing circuit (figure 2), with the jaw crusher operating on the first stage and the ball mill working on the second one.

The particle size composition of the final product from the circuit was below 0.1 mm. The material was then divided into representative samples, 0.45 kg each. The flotation process was carried out in a Metso's Denver D12 laboratory flotation machine (figure 3.), with the working chamber volume 1.5 dm³.

Figure 2. Scheme of comminution circuit.

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Figure 3. Metso's Denver D12 laboratory flotation machine.

Figure 4 shows the sequence of fractional flotation. The froth products were collecting after 1st, 3rd, 6th, 12th and 30th minute of the process.
Figure 4. Scheme of fractional flotation tests.

Four flotation tests were carried out. The flotational pulp density and aeration were constant and equaled 1190 g/dm$^3$ and 125 dm$^3$/h, respectively. Two levels of rotational speed of rotor were accepted in investigations: 1350 and 1650 rpm. The ethyl xanthate sodium was used as a collector in two doses: 100 g/Mg and 130 g/Mg, while the froth reagent (Nasfroth) dose was 30 g/Mg.

3. Analysis of results

All products of flotation (concentrates and tails) were dried, weighted and prepared for further analyses in XRF device, in order to determine the useful mineral grade in individual products. The yields of concentrates ($\gamma$), concentrate grades ($\beta$), flotation recoveries ($\varepsilon_k$), waste recoveries ($\varepsilon$), waste recovery in concentrate ($\varepsilon_{nk}$), as well as tail grades ($\theta$) were determined on the basis of the obtained results of analyses. Complete results are presented in tables 2 to 6.

| Table 2. Values of selected technological indicators for copper ore flotation test 1: dosage of collector 100 [g/Mg], rotor speed 1350 [rpm]. |
|---------------------------------------------------------------|
| **Product** | $\gamma$ [%] | $\sum \gamma$ [%] | $\beta_{Cu}$ [%] | $\varepsilon_k$ [%] | $\sum \varepsilon_k$ [%] | $\varepsilon_{nk}$ [%] | $\sum \varepsilon_{nk}$ [%] | $\sum \varepsilon_r$ [%] |
|-------------|--------------|-----------------|-----------------|-----------------|------------------|----------------|-----------------|----------------|
| K1          | 6.41         | 6.41            | 11.95           | 11.95           | 45.75            | 45.75          | 5.74            | 5.74           |
| K2          | 10.96        | 17.37           | 3.73            | 6.76            | 24.45            | 70.19          | 10.73           | 16.47          |
| K3          | 4.67         | 22.04           | 2.11            | 5.78            | 5.89             | 76.08          | 4.65            | 21.12          |
| K4          | 7.15         | 29.19           | 1.71            | 4.78            | 7.32             | 83.40          | 7.15            | 28.27          |
| K5          | 10.20        | 39.39           | 0.79            | 3.75            | 4.79             | 88.19          | 10.29           | 38.56          |
| O           | 60.61        | 100.00          | 0.33            | 1.67            | 11.81            | 100.00         | 61.44           | 100.00         |
|-------------|--------------|-----------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|
|             | 100          | 1.67            | 100.00          | 1.67            | 100.00          | 0.00           | 100.00         |
|-------------|--------------|-----------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|

Fractioned flotation Duration: 30 minutes in total
Table 3. Values of selected technological indicators for copper ore flotation test 2: dosage of collector 130 [g/Mg], rotor speed 1350 [rpm].

| Product | $\gamma$ [%] | $\sum \gamma$ [%] | $C_u$ [%] | $\beta_{Cu}$ [%] | $\varepsilon_k$ [%] | $\sum \varepsilon_k$ [%] | $\varepsilon_{nk}$ [%] | $\sum \varepsilon_{nk}$ [%] | $\varepsilon_r$ [%] | $\sum \varepsilon_r$ [%] |
|---------|--------------|------------------|---------|-----------------|----------------|-------------------------|----------------|-------------------------|----------------|-------------------------|
| K1      | 7.93         | 7.93             | 9.42    | 9.42            | 44.82         | 44.82                   | 7.31           | 7.31                    | 92.69         | 92.69                   |
| K2      | 10.40        | 18.33            | 2.90    | 5.72            | 18.09         | 62.91                   | 10.27          | 17.58                   | 82.42         | 82.42                   |
| K3      | 5.14         | 23.48            | 1.79    | 4.86            | 5.52          | 68.43                   | 5.14           | 22.71                   | 77.29         | 77.29                   |
| K4      | 9.63         | 33.11            | 2.86    | 4.28            | 16.51         | 84.94                   | 9.51           | 32.23                   | 67.77         | 67.77                   |
| K5      | 7.64         | 40.74            | 0.60    | 3.59            | 2.76          | 87.71                   | 7.72           | 39.95                   | 60.05         | 60.05                   |
| O       | 59.26        | 100.00           | 0.35    | 1.67            | 12.29         | 100.00                  | 60.05          | 100.00                  | 0.00          | 100.00                  |
|         | 100          | 1.67             |         |                 |               |                         |                |                         |                |                         |

Table 4. Values of selected technological indicators for copper ore flotation test 3: dosage of collector 100 [g/Mg], rotor speed 1650 [rpm].

| Product | $\gamma$ [%] | $\sum \gamma$ [%] | $C_u$ [%] | $\beta_{Cu}$ [%] | $\varepsilon_k$ [%] | $\sum \varepsilon_k$ [%] | $\varepsilon_{nk}$ [%] | $\sum \varepsilon_{nk}$ [%] | $\varepsilon_r$ [%] | $\sum \varepsilon_r$ [%] |
|---------|--------------|------------------|---------|-----------------|----------------|-------------------------|----------------|-------------------------|----------------|-------------------------|
| K1      | 8.90         | 8.90             | 8.77    | 8.77            | 47.23         | 47.23                   | 8.26           | 8.26                    | 91.74         | 91.74                   |
| K2      | 6.62         | 15.52            | 3.57    | 6.55            | 14.30         | 61.52                   | 6.49           | 14.75                   | 85.25         | 85.25                   |
| K3      | 6.14         | 21.66            | 1.82    | 5.21            | 6.76          | 68.28                   | 6.13           | 20.88                   | 79.12         | 79.12                   |
| K4      | 8.90         | 30.56            | 3.14    | 4.61            | 16.90         | 85.18                   | 8.77           | 29.64                   | 70.36         | 70.36                   |
| K5      | 6.37         | 36.93            | 0.78    | 3.95            | 2.99          | 88.17                   | 6.43           | 36.07                   | 63.93         | 63.93                   |
| O       | 63.07        | 100.00           | 0.31    | 1.65            | 11.83         | 100.00                  | 63.93          | 100.00                  | 0.00          | 100.00                  |
|         | 100          | 1.67             |         |                 |               |                         |                |                         |                |                         |

Table 5. Values of selected technological indicators for copper ore flotation test 4: dosage of collector 130 [g/Mg], rotor speed 1650 [rpm].

| Product | $\gamma$ [%] | $\sum \gamma$ [%] | $C_u$ [%] | $\beta_{Cu}$ [%] | $\varepsilon_k$ [%] | $\sum \varepsilon_k$ [%] | $\varepsilon_{nk}$ [%] | $\sum \varepsilon_{nk}$ [%] | $\varepsilon_r$ [%] | $\sum \varepsilon_r$ [%] |
|---------|--------------|------------------|---------|-----------------|----------------|-------------------------|----------------|-------------------------|----------------|-------------------------|
| K1      | 8.83         | 8.83             | 7.09    | 7.09            | 38.00         | 38.00                   | 8.34           | 8.34                    | 91.66         | 91.66                   |
| K2      | 6.64         | 15.47            | 3.58    | 5.58            | 14.44         | 52.44                   | 6.51           | 14.85                   | 85.15         | 85.15                   |
| K3      | 4.74         | 20.22            | 2.11    | 4.77            | 6.08          | 58.52                   | 4.72           | 19.58                   | 80.42         | 80.42                   |
| K4      | 9.85         | 30.07            | 4.36    | 4.63            | 26.06         | 84.58                   | 9.58           | 29.15                   | 70.85         | 70.85                   |
| K5      | 8.06         | 38.13            | 0.65    | 3.79            | 3.18          | 87.75                   | 8.15           | 37.30                   | 62.70         | 62.70                   |
| O       | 61.87        | 100.00           | 0.33    | 1.65            | 12.25         | 100.00                  | 62.70          | 100.00                  | 0.00          | 100.00                  |
|         | 100          | 1.67             |         |                 |               |                         |                |                         |                |                         |
Table 6. Summary of results for four flotation tests.

| Number of flotation test | Dosage of collector [g/Mg] | Rotor speed [rpm] | \( \alpha \) [%] | \( \gamma_c \) [%] | \( \beta_{\text{mean}} \) [%] | \( \vartheta \) [%] | \( \varepsilon_k \) [%] | \( \varepsilon_0 \) [%] | \( \varepsilon_r \) [%] | \( \gamma_{c1} \) [%] | \( \beta_{c1} \) [%] | \( \varepsilon_{c1} \) [%] |
|--------------------------|--------------------------|------------------|----------------|----------------|-------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1                        | 100                      | 1350             | 1.67           | 39.39          | 3.75              | 0.33           | 88.19          | 11.81          | 61.44          | 6.41           | 11.95          | 45.75          |
| 2                        | 130                      | 1350             | 1.67           | 40.74          | 3.59              | 0.35           | 87.71          | 12.19          | 60.05          | 7.93           | 9.42           | 44.82          |
| 3                        | 100                      | 1650             | 1.65           | 36.93          | 3.95              | 0.31           | 88.17          | 11.83          | 63.93          | 8.9            | 8.77           | 47.23          |
| 4                        | 130                      | 1650             | 1.65           | 38.13          | 3.79              | 0.33           | 87.75          | 12.25          | 62.70          | 8.83           | 7.09           | 38.00          |

In order to determine optimal values of selected flotation parameters, there were determined the Fuerstenau curves (figure 5). and for each test there were determined the separation ratio F values:

\[
F_1 = \left( \frac{77.5}{77.5} \right) \tag{1}
\]
\[
F_2 = \left( \frac{74}{74} \right) \tag{2}
\]
\[
F_3 = \left( \frac{75}{75} \right) \tag{3}
\]
\[
F_4 = \left( \frac{75.5}{75.5} \right) \tag{4}
\]

Figure 5. Fuerstenau upgrading curves.

The separation ratio F for each flotation test is located within 3rd class of separation what indicates an average level of separation effectiveness. The most favorable results were obtained for the lower value...
of reagent’s dose, as well as lower speed of rotor. It may result from the fact that the type of material used in investigations was of a lower flotation potential due to ore oxidation.

4. Summary
The results of investigations show that variable speed of rotor and dose of flotational reagent affect the flotational result in a rather lower degree. However, the expected results should show a more intense variation together with an increase/decrease of reagents dose and rotational speed of rotor.

However it is worth to mention that variable speed of the rotor and dosage of the collector reagent caused the most significant impact on the obtained results for the first concentrate fractions. The most favorable results were obtained for the flotation test with the rotor speed of 1350 rpm and a 100 g/Mg of collector dosage. Increasing the collector dosage to the value 130 g/Mg resulted in an increase of a concentrate yield and decrease in the values of qualitative indicators of the process. Similar effect was observed for the variable speed of the rotor. At the same dosage of collector, the increased speed of rotor caused the higher value of concentrate yield. This trend could be observed for the first three fractions of concentrates. However, after 6 minutes the flotation test duration, the kinetics stabilizes.

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