

D. SARAMAK\*, A. MŁYNARCZYKOWSKA\*, A. KRAWCZYKOWSKA\*

## INFLUENCE OF A HIGH-PRESSURE COMMINUTION TECHNOLOGY ON CONCENTRATE YIELDS IN COPPER ORE FLOTATION PROCESSES

### WPLYW TECHNOLOGII WYSOKOCIŚNIENIOWEGO ROZDRABNIANIA NA WYCHODY KONCENTRATÓW W PROCESACH FLOTACJI RUD MIEDZI

The article concerns the issues of flotation process effectiveness in relationship to the operating conditions of a high-pressure comminution process course. Experimental programme covering a flotation laboratory batch tests was a verification technique of a high-pressure crushing operations course. The most favorable values of flotation concentrate weight recoveries were obtained for the pressing force 6 kN and 4% of the feed moisture. It was also determined the model of the concentrate weight recovery as a function of pressing force in the press and feed moisture content. This model was the basis for the optimization of effects of copper ore flotation processes preceded in high-pressure crushing operation in roller presses.

*Keywords:* high-pressure grinding rolls, flotation, copper ore

W przedstawionym artykule przebadano efektywność procesu flotacji w zależności od warunków pracy technologii wysokociśnieniowego rozdrabniania w prasach walcowych. Zrealizowane testy flotacyjne stanowiły technikę weryfikacji przebiegu procesu rozdrabniania nadawy. Najwyższe wartości wychodów koncentratów flotacyjnych uzyskano przy sile nacisku w prasie wynoszącej 6 kN oraz wilgotności nadawy 4%. Wyznaczono model wychodu koncentratu flotacyjnego jako funkcję siły nacisku w prasie oraz wilgotności nadawy. Model ten był podstawą optymalizacji efektów procesu flotacyjnego poprzedzonego rozdrabnianiem rudy w wysokociśnieniowych prasach walcowych.

### 1. Introduction

In current investigations in the field of mineral processing technology, following main direction can be distinguished:

- energetic (economic), concerning the reduction of energy-consumption of enrichment circuits,
- technological, heading towards the improvement of recovery of the useful component in concentrate,
- ecological, leading to the effective management of resources as well as decreasing the burdensome impact of mining and processing activities on the natural environment.

In realization of the above issues the emphasis is on investigations connected with modern processing technologies, especially in the field of preparation of feed into main beneficiation operations. In a multi-stage ore processing circuit operations of reduction of the material particle size are crucial, because their results pre-determine the effectiveness of main enrichment processes (i.e. operations of flotation). A selection of suitable technology of ore comminution and configuration of crushing and grinding circuit allow to obtain high values of indices of assessment of technological process at reduced expenditures.

One of the methods of work improvement for technological crushing and grinding circuits is modernization of comminution operations through the application of the high-pressure grinding rolls units on the fine crushing stage. Numerous investigation results prove that products of high-pressure comminution contain more finer particles, while an unfavorable phenomenon of over-grinding is limited. HPGR units also guarantee a satisfactory degree of feed disintegration at relatively lower energy-consumption, comparing to conventional tumble mills (rod or ball mills) as well as to semi-autogenous (SAG) ones. Additional benefit of HPGR application is generation of micro-cracks in individual particles of crushing product. This leads to the improvement of kinetics of grinding resulting from decreasing the value of the Bond's grindability index (up to 30%). As a result of the above the grinding process runs faster and measurable savings of grinding processes energy-consumption (about over a dozen per cent), can be observed (Saramak 2012).

Application of HPGR units in technological circuits also influences the downstream beneficiation processes. Investigations in this field indicate the improvement of flotation kinetics and better concentrate recovery. It also applies to leaching operations. In example, Freeport Indonesia (commissioned November 2006) use two units to pretreat ball mill feed, to gen-

\* AGH UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF MINING AND GEOENGINEERING, DEPARTMENT OF ENVIRONMENTAL ENGINEERING AND MINERAL PROCESSING, AL. A. MICKIEWICZA 30, 30-059 KRAKÓW, POLAND

erate a finer mill product and consequently enhance flotation performance.

## 2. Influence of the feed particle size on the flotation operations

Feed particle size is one of the variables of a key-influence on the flotation process (Kowalczyk et al 2011, Bakalarz 2011). For a high recovery of flotation concentrate, the valuable mineral particle requires a certain degree of liberation to attach to a bubble and, as a result, to be transported into the froth product. Complete liberation of all valuable minerals in the feed requires fine grinding, usually in a ball or pebble mill. However, this can also lead to the unfavorable phenomenon of over-grinding of the valuable minerals, which are too fine to pass into the froth product. As a result, the increased generation of gangue slimes is observed what adversely affect the high recovery and selectivity desired in subsequent flotation stages. One of the effect of the HPGR performance is a high liberation of the useful mineral (mentioned above) in the crushing product. As the valuable mineral is sufficiently liberated it is possible to apply an “flash flotation” – an early recovery of coarser mineral particles in the grinding circuit. This can results in savings, provided the flotation feed particle size is within a certain range, enabling to obtain sufficient level of flotation process recovery. Various investigations (Brożek and Młynarczykowska 2010, Potulska 2008) show that relationship between the floatable particle size and the process recovery can be presented as in Figure 1. For the Polish copper ores, the most favourable particle size of feed for flotation operations is below  $70 \mu\text{m}$  (Fig. 1). In a multi-stage ore comminution process, the material from  $20 \mu\text{m}$  to  $70 \mu\text{m}$  may appear in the circuit even at the fine crushing stage. It can be then taken out from the crushing circuit and sent directly to flotation, bypassing the grinding operations, thus lowering their energy-consumption. The test results showed that even up to 15% more of the material below  $70 \mu\text{m}$  can be generated in roller presses, as compared to rod mills (Saramak 2012).

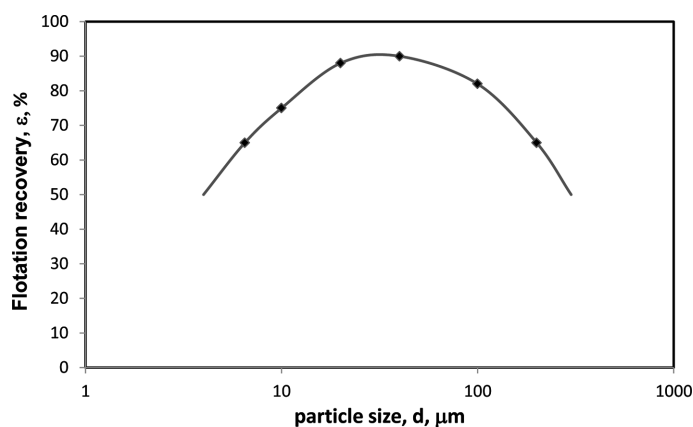


Fig. 1. Relationship between the metal recovery in flotation operations and particle size distribution for sulphide copper ores

Participation of very fine particles in grinding products, which are mainly an effect of the over-grinding phenomenon, significantly decreases the flotation effectiveness, in turn. It

is therefore aiming at the limitation of their forming during grinding and regrinding stages of the comminution circuit. Taking into account the above issues, the enrichment process of sulphide copper ores should be designed in such a way in order to maximize the weight recovery of the particle size fraction between  $20 \mu\text{m}$  to  $70 \mu\text{m}$ , at minimizing the content of particle fractions finer than  $20 \mu\text{m}$  (Trahar, 1981).

## 3. Experimental programme

Polish copper ore was used into investigations and the material was not separated into individual lithologic fractions. However it is well known that copper ore in a slate form (shale with chalcopyrite) has the most favourable floatability (Bakalarz 2011a, Bakalarz 2011b). A lack of ore separation in the pre-preparation process has resulted, from the point of view of the assumed aim, and for its realization the flotation tests were applied only as a verification technique. Their aim was to demonstrate whether the ore comminution ratio in HPGR (the level of useful mineral liberation) influences the beneficiation results. A series of HPGR laboratory comminution tests preceded by jaw crusher crushing operation were run. The HPGR product was then ground in a closed circuit ball mill (Fig. 2). Material finer than  $100 \mu\text{m}$  was feed for flotation operation and weight recoveries of flotation concentrates were analyzed.

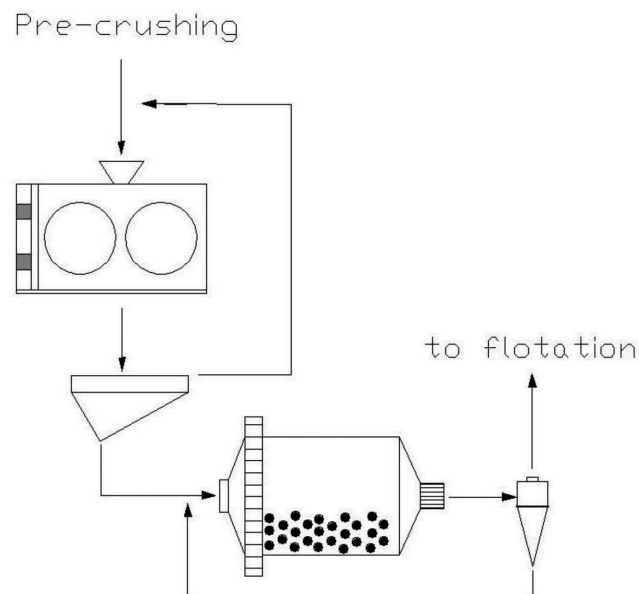


Fig. 2. HPGR-based grinding circuit

In further experiments, the influence of the HPGR operating parameters (pressing force) as well as chosen properties of HPGR feed (moisture content) on the effectiveness of flotation process, was under examination. The flotation kinetics was investigated as well as the process efficiency, measured through the obtained weight recoveries of flotation concentrates. The presented analysis is a semi-qualitative one, for the reason that only the weight recoveries of flotation concentrate from individual batch flotation tests were under examination. It was assumed that minimization of useful components (copper) in tails is the target. In next investigations the analysis of effectiveness of flotation operations depending on the comminution

processes run, measure through copper contents in concentrate and tails, will be presented (Saramak and Młynarczykowska, 2014).

The batch flotation tests were run in a laboratory unit with 1dm<sup>3</sup> volume. A mix of sodium xanthate as collector and NASFROTH 245B as foaming reagent was used. The ore was initially mixing with water for about 30 minutes in order to provide thorough wetting of material. Next, the reagents were dosed and the main flotation process occurred. Froth products were collected after 2, 5, 10 and 15 minutes.

## 4. Results of investigations

### 4.1. Analysis of concentrate weight recoveries

In the first stage of experiments the analysis of concentrate weight recoveries were under examination.

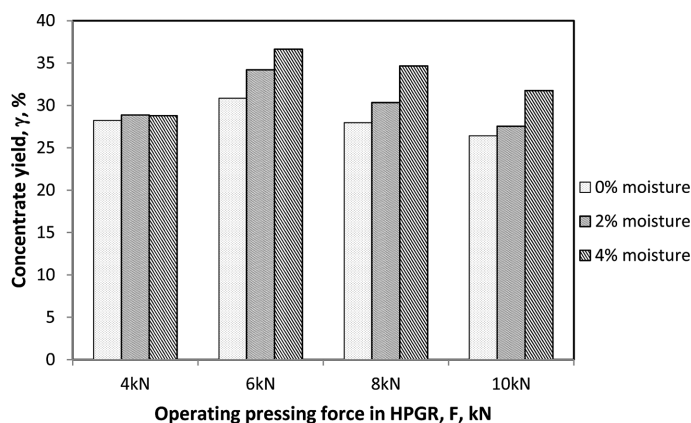


Fig. 3. Total yield of flotation concentrates collected after five minutes in relationship with various pressure values and HPGR feed moisture contents

The yields of total concentrate collected after five minutes were presented in Fig. 3. Due to the short time after which the results were under evaluation, this analysis corresponds to the flash flotation run in the pilot scale. Results of investigations show that the press operating condition as well as feed moisture content influences the flash flotation results measured through yield of 5-minute flotation concentrate. In general, for higher moisture content, higher weight recoveries of concentrates were obtained.

The combined effect of both factors, i.e. HPGR pressing force and feed material moisture content, on the level of concentrate recovery was also analyzed. First, linear correlation coefficients between all variables, were determined (Table 1). Coefficients statistically significant ( $\alpha = 0,05$ ) were marked in bold red.

Results show that the feed moisture content has stronger correlation with the obtained flotation recoveries than the HPGR pressing force. In plant condition, however, HPGR operating pressure has a significant influence on comminution results. Inspecting Fig. 3 it can be seen that relationship between the two variables can be quite well characterized with using of parabolic curve. It can be observed an initial increase in concentrate weight recovery together with increasing the value of pressing force from 4 to 6 kN. With further increase

of this force a systematic decrease in flotation recovery can be observed. It was also confirmed through a high value of correlation coefficient between the square of the pressing force and concentrate recovery ( $r = 0,97$ ) and the model presented in Fig. 4 and with using of formula (1):

$$Z = 11,045 + 0,393X + 7,170Y + 0,106X^2 + 0,190XY - 0,479Y^2 \quad (1)$$

where: X – HPGR pressing force, kN; Y – HPGR feed moisture, %; Z – concentrate weight recovery, %.

TABLE 1  
Coefficients of correlation between all variables

	HPGR feed moisture content [%]	Flotation concentrate weight recovery [%]	HPGR operating pressing force volume [kN]
HPGR feed moisture content [%]	1,000	<b>0,612</b>	0,000
Flotation concentrate weight recovery [%]	<b>0,612</b>	1,000	-0,113
HPGR operating pressing force volume [kN]	-0,113	0,000	1,000

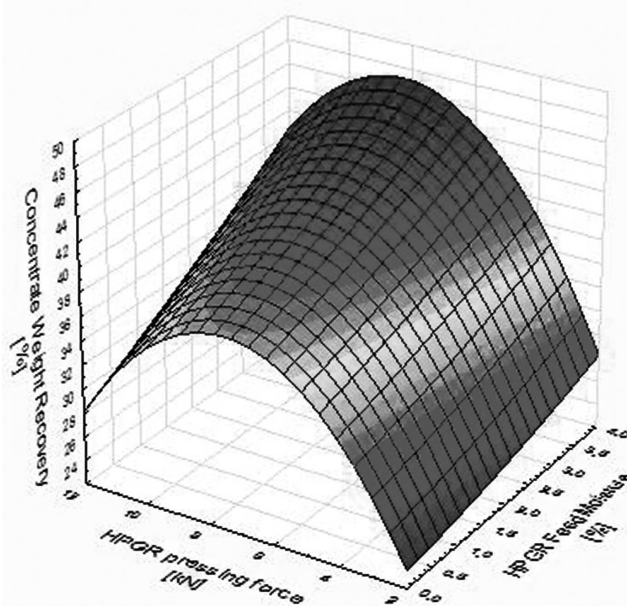


Fig. 4. Total flotation concentrate weight recovery as a function of HPGR pressing force and HPGR feed moisture content

It follows a practical application that it is not necessary to select a high value of the pressing force for the material under examination. Maximum weight recoveries were obtained at the force value between 6 and 8 kN, depending on the moisture content.

In the plant conditions it is just demanded such adjustment of the operating pressure in the press, in order to achieve the required degree of feed material disintegration (the force shall be not less than 4 kN). The lower force, in turn, results in reduced power consumption of the device and, as a result, lower energy-consumption of the process. This is advantageous in terms of efficiency of the high-pressure comminution

processes. An additional benefit is that the lower the pressure, the greater the gap in the press. The change in the gap value is rather low, but this results in a slight increase in capacity of the unit, which is an additional benefit.

Increase of the HPGR feed moisture content (above 2%), in turn, causes a slight increase of energy-consumption of comminution process and greater wear of linings, which is an unfavorable phenomenon high-pressure comminution operations. The above relationships are presented in Fig. 5. In order to maximize the economic effect a specific values of pressing force and feed moisture content should be selected.

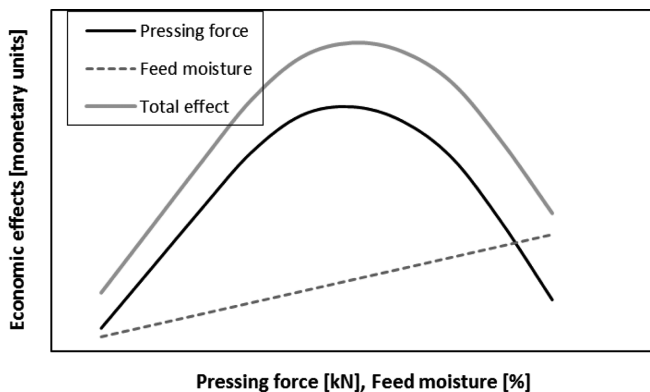


Fig. 5. Economic effects in relationship to the HPGR pressing force and HPGR feed moisture content

#### 4.2. Flotation kinetics analysis

In the next stage, the influence of the flotation kinetics in relationship to the HPGR crushing process conditions and HPGR feed moisture content, was analyzed. Results are presented in Figures 6 to 8:

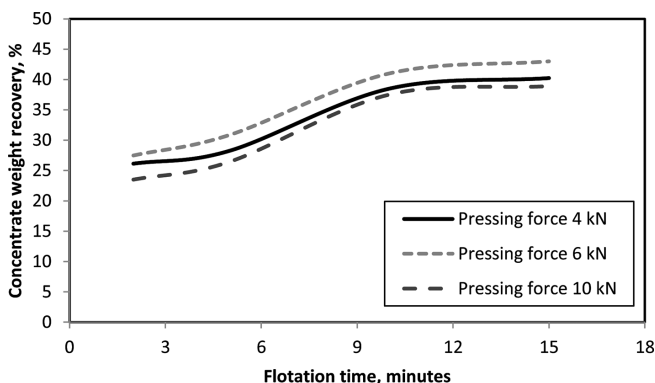


Fig. 6. Kinetics of the flotation process for HPGR feed moisture 0%

It is noticeable that the flotation process course is similar for all values of pressing forces, but it is clear that the maximum value of the total concentrate recovery were obtained for the pressing force of 6 kN. For the higher moisture contents (2% and 4%) higher concentrate recoveries were achieved. The presented analysis reveals that both the HPGR operating pressure and the feed moisture content do not substantially affect the course of the flotation process, however, they significantly determine its effectiveness measured through the obtained concentrate recoveries. The most favorable results were obtained for the pressing force around 6 kN and 4% of feed moisture content.

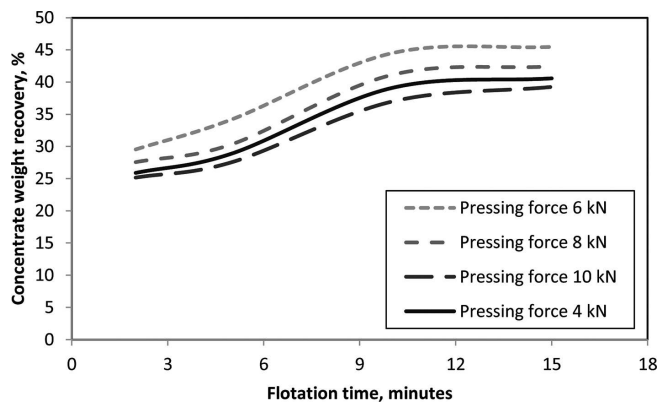


Fig. 7. Kinetics of the flotation process for HPGR feed moisture 2%

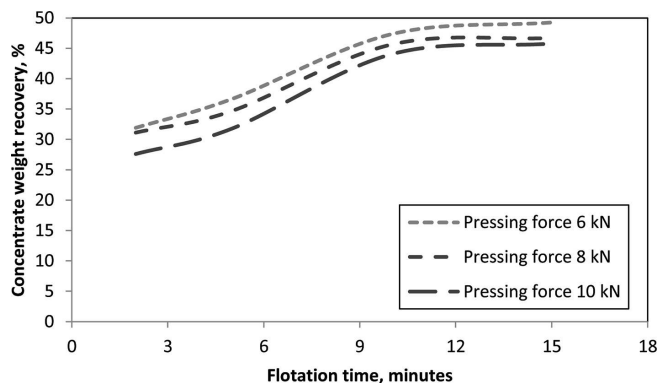


Fig. 8. Kinetics of the flotation process for HPGR feed moisture 4%

#### 5. Summary and conclusions

The results of conducted laboratory tests confirm that the high-pressure grinding process for copper ore has a significant impact on the course and effectiveness of flotation process. The nature of the course of the flotation kinetics curves confirms the correct progress in the concentration of useful component in the froth product. Maximum yields achieved for particular batch flotation tests are between 38% and 50%.

The most favourable concentration results were obtained for 15-minutes flotation process, with the average yield of concentrate 46%, and for HPGR pressing force 6 kN. The lowest values of the cumulative yield, in turn, were obtained for the flotation of HPGR products crushed under 4 and 10 kN pressing force, which average values of 40% and 41%, respectively.

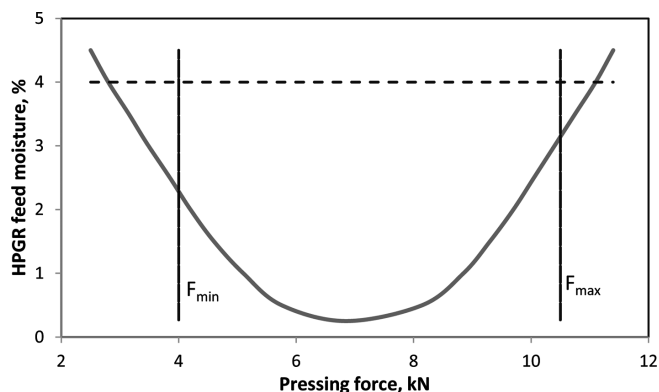


Fig. 9. Feasible solutions area for model (1)

The above results can be a starting point towards the optimization of the flotation concentrate yield in relationship to the high-pressure crushing process run and chosen properties of feed. Projecting the model (1) into X-Y plane (X – HPGR pressing force, Y – feed moisture content) it can be obtained a graph presented in Fig. 9.

It can be accepted the minimum value of the concentrate weight recovery, which should be achieved during technological process. It is presented as a parabolic function in Fig. 9. A vertical boundary line on the left represents the minimum value of the pressing force in the press ( $F_{min}$ ), which will achieve a certain level of particle disintegration. The pressing force values smaller than  $F_{min}$  (on the left of the vertical line) leads to insufficient comminution of the product and running the crushing process at such low pressing forces is meaningless. The vertical line on the right side, in turn, reflects the maximum force ( $F_{max}$ ), which can be achieved in the device. The horizontal line is the limitation on the maximum accepted level of moisture content of feed in the high-pressure comminution operations. On the border of the area bounded by the parabola, two vertical and one horizontal line, it is placed the sought solution - the configuration of the feed moisture and pressing force of press, which ensures obtaining the assumed value of flotation concentrate recovery.

Based on the obtained results it can be concluded that:

- both the operating parameters of the copper ore preparatory process course and feed characteristics significantly affect the efficiency of the flotation process measured through weight recoveries of froth products;
- determined model of flotation process efficiency can be used in a practical purpose to optimize the achieved effects of beneficiation, taking into account the respective technological limitations;
- after determination of the useful mineral content in flotation concentrate it is possible to carry out a full qualitative analysis and assessment of the copper ore flota-

tion process, depending on the conditions of comminution processes course. This will be the subject of a following investigations.

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