University of Belgrade
Technical Faculty in Bor

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XV International Mineral Processing & Recycling Conference

IMPRC
INTERNATIONAL MINERAL PROCESSING & RECYCLING CONFERENCE

Proceedings

Editors:
Jovica Sokolović
Milan Trumić

17-19 May 2023
Belgrade SERBIA

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APPLICATION OF VIKOR METHOD FOR SELECTION OF COLLECTOR IN PORPHYRY COPPER ORE FLOTATION

Z. Štirbanović[1#], R. Stanojlović[1], J. Sokolović[1], D. Stanujkić[1], N. Ćirić[2], I. Miljanović[3], G. Popović[4]
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ABSTRACT – The selection of appropriate flotation collector is of the crucial importance especially for the complex ores like porphyry copper ores that are distinguished with lower copper grades and higher pyrite content. In this paper are presented the results of selection of flotation collector for porphyry copper ore from "Severni Revir" ore deposit in Copper Mine Majdanpek. The selection was performed between two collectors (Z11 and AP3404) with 3 different dosages (25; 35; 45 g/t) and their mixture with SKIK in different mass ratio. The VIKOR method was applied for the rating of 10 alternatives by 5 criteria: mass yield, copper grade in concentrate, sulfur grade in concentrate, copper recovery, and collector expenses (dosage and price). Based on the results of the analysis, alternative A8 which represents the mixture of three collectors Z11, AP3404, and SKIK with following dosage 20+8+8 g/t was selected as the best alternative.

Keywords: Porphyry Copper Ore, Flotation, Collector, Selection, VIKOR Method.

INTRODUCTION

The main characteristics of porphyry copper ore deposits are large quantities with lower copper grade, as well as high content of pyrite [1]. Pyrite as iron sulfide mineral is often associated with copper minerals and it is difficult to achieve their efficient separation especially if pyrite is activated with copper ions [2].

One of the ways to provide good selectivity of copper minerals from pyrite is to select appropriate flotation collector which will provide good floatability of copper minerals and efficient selectivity towards pyrite and other sulfide minerals.

Xanthates are mostly used collectors in copper flotation and they can be applied alone or in combination with other collectors, such as dithiophosphates or thionocarbamates, which are normally used for flotation of secondary copper minerals or in the case when flotation is performed at lower pH [3].

The selection of an appropriate collector is essential for the efficiency of the flotation process [4]. Certain minerals have similar properties in terms of floatability, so it is necessary to select a suitable collector that has a selective effect and that enables their efficient separation [5]. The selection of collectors in copper flotation is in close

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correlation with the nature and appearance of copper minerals and other sulfides that are associated with them. Recovery of useful components as well as flotation time is also recognized as important parameters when choosing a collector [6-8]. Since the collectors are organic compounds, their impact on both human health and the environment can be very large [9-11], so it is necessary to take this aspect into account as well. The price and consumption of the collector always have an influence when choosing, because economic profitability is very important.

As can be seen, there are a large number of factors that have an impact and should be taken into account when choosing the optimal collector to be used in the flotation of a porphyry copper ores. Precisely for these reasons, it is necessary to apply some of the methods that will facilitate the process of selection the flotation collector, such as multi criteria decision making (MCDM) methods.

MCDM methods present very efficient tool which can simplify selection process when large number of criteria is involved, and for that reason are being used for selection in various areas of life, science and industry. Therefore, these methods have also found applications in mineral processing in recent years, starting from selection of equipment [12,13], technologies [14,15], reagents [16, 17], etc.

In this paper are presented the results of selection of flotation collector for porphyry copper ore from "Severni Revir" ore deposit in Copper Mine Majdanpek.

METHODOLOGY

Rougher flotation tests were carried out on of porphyry copper ore samples from "Severni Revir" ore deposit in Copper Mine Majdanpek and the influence of different collectors and their dosages on flotation indicators were investigated [18].

The data obtained in the study were used for the selection of the most appropriate collector for flotation of porphyry copper ore from this ore deposit. The selection was performed between two collectors (Z_{11} and AP3404) with 3 different dosages (25; 35; 45 g/t) and their mixture with SKIK in different mass ratio (Table 1).

Table 1 Alternatives for the selection of flotation collector

Alternative	Collector	Dosage
A_1	Z_{11}	25 g/t
A_2	Z_{11}	35 g/t
A_3	Z_{11}	45 g/t
A_4	AP3404	25 g/t
A_5	AP3404	35 g/t
A_6	AP3404	45 g/t
A_7	Z_{11}+AP3404	20+16 g/t
A_8	Z_{11}+AP3404+SKIK	20+8+8 g/t
A_9	Z_{11}+AP3404+SKIK	18+10+8 g/t
A_{10}	Z_{11}+AP3404+SKIK	18+12+6 g/t

Criteria that were used for selection and their weights are given in Table 2.

Table 2 The weights of selection criteria

Criteria	**Weight**
C_1 – Mass yield (%)	0.1
C_2 – Copper grade in concentrate (%)	0.2
C_3 – Sulfur grade in concentrate (%)	0.15
C_4 – Copper recovery (%)	0.35
C_5 – Collector expenses (dosage and price)	0.2

The ratings of alternatives in relation to the selected criteria are shown in Table 3.

Table 3 The ratings of alternatives in relation to the selected criteria

	C_1	**C_2**	**C_3**	**C_4**	**C_5**
	max	max	min	max	min
A_1	16.39	1.39	19.87	83.45	3
A_2	14.63	1.55	21.58	83.06	4
A_3	15.61	1.42	22.72	81.19	5
A_4	14.08	1.54	15.99	79.43	5
A_5	14.44	1.58	17.92	83.57	6
A_6	17.31	1.32	20.32	83.70	7
A_7	14.82	1.55	22.83	84.14	6
A_8	15.26	1.52	24.81	84.96	4
A_9	14.88	1.50	21.92	81.76	5
A_{10}	14.09	1.57	23.43	81.03	6

The selection was made by using VIKOR method.

VIKOR method

The VIKOR method was proposed by Opricovic and Tzeng in 2004 [19], and it can be also mentioned as a prominent and often used MCDM method. VIKOR means Multicriteria Optimization and Compromise Solution (VIsekriterijumska optimizacija i KOmpromisno Resenje, in Serbian).

The procedure of evaluating alternatives using the VIKOR method can be explained using the following steps:

Step 1. Determine the best x_j^* and worst x_j^- value for each criterion as follows:

$$x_j^* = \begin{cases} max_j x_{ij} & j \in \Omega_{max} \\ min_j x_{ij} & j \in \Omega_{min} \end{cases}, \text{ and} \tag{1}$$

$$x_j^- = \begin{cases} min_j x_{ij} & j \in \Omega_{max} \\ max_j x_{ij} & j \in \Omega_{min} \end{cases} \tag{2}$$

where x_{ij} denotes rating of alternative *i* in relation to criterion *j*, Ω_{max} and Ω_{min} denote set of maximization and minimization criteria, respectively.

Step 2. Determine average S_i and group R_i score for each alternative as follows:

$$S_i = \sum_{j=1}^{n} w_j \left(x_j^* - x_{ij}\right)/\left(x_j^* - x_j^-\right), \text{ and} \quad (3)$$

$$R_i = max_j\left[w_j \left(x_j^* - x_{ij}\right)/\left(x_j^* - x_j^-\right)\right], \quad (4)$$

where w_j denotes the weight of criterion *j*.

Step 3. Determine the overall ranking index Q_i as follows:

$$Q_i = \nu\frac{(S_i-S^*)}{(S^- - S^*)} + (1-\nu)\frac{(R_i-R^*)}{(R^- - R^*)}, \quad (5)$$

where: S_j and R_j denotes the average and the worst group score of alternative *i*, respectively, $S^* = min_i S_i$, $S^- = max_i S_i$, $R^* = min_i R_i$, $R^- = max_i R_i$, and ν is significance of the strategy, which value is usually set to be 0.5.

Step 4. Rank the alternatives, sorting by the value Q_i in decreasing order. The alternative with the minimum value of Q_i is the most appropriate alternative.

RESULTS AND DISCUSSION

In this numerical illustration two collectors with three different dosages and their mixtures, shown in Table 1, are evaluated. Ten alternatives, shown in Table 1, were evaluated based on the five criteria shown in Table 2. Table 2 also shows the weights of the criteria.

The ratings of the alternatives in relation to the criteria are shown in Table 3. The optimization directions of the criteria are also shown in Table 3.

The best and worst value for each criterion, determined using Eq. (1) and Eq. (2) are shown in Table 4.

Table 4 The best and worst value for each criterion

	C_1	**C_2**	**C_3**	**C_4**	**C_5**
	max	max	min	max	min
x_j^*	17.31	1.58	15.99	84.96	3
x_j^-	14.08	1.32	24.81	79.43	7

Based on the data from Table 3 and Table 4, the average S_i and group R_i score for each alternative were determined, using Eq. (3) and Eq. (4). The calculated values are shown in Table 5. Table 5 also shows the overall ranking index Q_i, calculated using Eq. (5) and ν = 0.5, as well as the ranks of each considered alternatives.

From Table 5, it can be seen that the alternative denoted as A_8 was selected as the most acceptable alternative. Alternative A_8 represents the mixture of three collectors Z_{11}, AP3404, and SKIK with following dosage 20+8+8 g/t. As it can be seen from Table 3, the copper recovery rate obtained with this mixture was the highest 84.96%. Mass yield and copper grade in concentrate were 15.26% and 1.52% respectively, which were not the highest obtained values but also not the lowest. The sulfur content in the concentrate was the highest indicating lower selectivity but since the weight of this criterion was not very high it did not influence the overall ranking of alternative A_8. Considering all it can be concluded that the criterion C_4, i.e. copper recovery had the most influence during selection of flotation collector by application of VIKOR method which was expected since it was assigned the highest weight.

Table 5 The overall ranking index and rank of considered alternatives

	S_i	R_i	Q_i	Rank
A_1	0.336	0.146	0.097	3
A_2	0.371	0.120	0.096	2
A_3	0.629	0.239	0.752	8
A_4	0.581	0.350	0.920	10
A_5	0.360	0.150	0.142	4
A_6	0.553	0.200	0.551	7
A_7	0.418	0.150	0.233	5
A_8	0.310	0.150	0.065	1
A_9	0.540	0.203	0.536	6
A_{10}	0.633	0.249	0.780	9

CONCLUSION

Flotation collectors play very important role in flotation process of complex ores such as porphyry copper ores that are distinguished with lower copper grades and higher pyrite content, thus it is important to select collector which will provide good selectivity of copper minerals from pyrite. By selection of appropriate flotation collector, good floatability of copper minerals and efficient selectivity towards pyrite and other sulfide minerals can be achieved.

During the selection large number of criteria should be taken into consideration, making the selection process difficult. Therefore, the solution to the problem can be application of MCDM methods which can simplify selection process when large number of criteria is involved.

The selection of flotation collector for porphyry copper ore from "Severni Revir" ore deposit in Copper Mine Majdanpek was the aim of the study which results are presented in this paper. Two collectors (Z11 and AP3404) with 3 different dosages (25; 35; 45 g/t) and their mixture with SKIK in different mass ratio were applied for rough flotation tests and the results obtained were then used as the base for the selection. The VIKOR method was applied for the rating of 10 alternatives by 5 criteria: mass yield, copper grade in concentrate, sulfur grade in concentrate, copper recovery, and collector expenses (dosage and price). Based on the results of the analysis, alternative A_8 which represents the mixture of three collectors Z11, AP3404, and SKIK with following dosage 20+8+8 g/t was selected as the best alternative. The criterion C_4, i.e. copper recovery was recognized as the most influential during the selection of flotation collector by the VIKOR method which was not surprising since it was assigned the highest weight.

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