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Effect of different process water sources on rougher flotation efficiency of a copper ore: A case study at Sarcheshmeh Copper Complex (Iran)

Amir Mousa Soufiabadi [1], Milad Nejadaria [2], Reza Dehghan [3], Mehdi Safari [4,5], Ahmad Hassanzadeh [6,7], Hamid Khoshdast [8,9]

[1] Khan Khatoon Plant Manager, IBKO Group of Companies, Bam, Iran

[2] Metallurgy and Process Control Manager at Khan Khatoon Plant, IBKO Group of Companies, Bam, Iran

[3] Mining and Metallurgical Engineering Department, Yazd University, 89195-741 Yazd, Iran

[4] Mineral Processing Division, Mintek, Private Bag X3015, Randburg 2125, South Africa

[5] Faculty of Engineering and the Built Environment, University of the Witwatersrand, 1 Jan Smuts Ave., Johannesburg 2000, South Africa

[6] Department of Geoscience and Petroleum, Faculty of Engineering, Norwegian University of Science and Technology, Trondheim 7031, Norway

[7] Mineral Services Ltd, Ty Maelgwyn, 1 A Gower Road, Cathays, Cardiff CF244PA, United Kingdom

[8] Department of Mining Engineering, Higher Education Complex of Zarand, Shahid Bahonar University of Kerman, Kerman 7761156391, Iran

[9] Mineral Industries Research Center, Shahid Bahonar University of Kerman, 76169133 Kerman, Iran

Corresponding authors: khoshdast@zarand.ac.ir (H. Khoshdast), ahmad.hassanzadeh@ntnu.no (A. Hassanzadeh)

Abstract: In this research, the effect of different sources of process water on the flotation efficiency of copper sulfide ore prepared from the Sarcheshmeh copper mine was investigated. For this purpose, samples of fresh water to the plant, overflows of copper-molybdenum concentrate thickener, copper concentrate thickener, and recycled water pool as well as a mixture of fresh water and recycled water were prepared and characterized. Flotation tests were performed under the same conditions as the plant's rougher circuit and were kept constant during all experiments. Grade and recovery of copper, iron, molybdenum, and silica were selected as the metallurgical response of flotation tests. The results were subjected to statistical analysis to assess the relative significance of which water source affects the flotation performance as evaluated from the experimental results. The results showed that the copper concentrate thickener overflow had the greatest effect on the flotation efficiency, so the grade and recovery decreased by about 10% and 75% for copper, and 10% and 6% for iron in the concentrate, respectively, while the grade and recovery increased up to 0.1% and 12% for silica, and 3% and 25% for molybdenum, respectively. The reason for this effect was attributed to the high content of suspended solid particles, and Cu^{2+}, Mo^{2+}, and Fe^{2+} cations in this water source that increased the coating effect over gangue minerals and entrainment rate. The improvement of molybdenum flotation was also ascribed to the possible presence of residual diesel oil from the flotation process in the plant. Due to the relatively equal amount in all sources of process water, the effect of anions and ions of dissolved salts was difficult.

Keywords: process water, copper flotation, recycled water, metallurgical efficiency, fine suspended solids

1. Introduction

The froth flotation process is an important method for the treatment of sulphide minerals, and since this process is carried out in an aqueous environment and also a significant amount of water is used in this process, it is essential to provide sufficient water of suitable quality (Mirshrkari et al., 2022; Hoseinian

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et al., 2021 and 2023). Considering the geographical location of Iran and the limited capacity of freshwater resources in many regions of the country, the use of recycled water in mineral processing plants is inevitable (Bahmani-Ghaedi et al., 2022). However, in addition to the lack of fresh water, other reasons require the need to recycle process water and reuse it in the process. The most important of these factors are the following (Corin et al., 2011; Bıçak et al., 2012):

- Tailings from mineral processing operations can be hazardous for the environment due to the presence of some substances such as suspended fine particles, different types of anions and cations, residual of non-degradable chemical reagents used in the process,
- Water consumption in areas where mineral processing plants are located represents a large share of local water consumption, this can lead to lack of access to water for other uses. Also, the dissatisfaction of the locals, especially the farmers, can lead to serious challenges,
- Even in some cases, recycled water can be used to reduce chemical consumption,
- The production and transportation of fresh water are usually expensive and may affect the operating costs of mining industries to some extent.

However, despite the inevitable necessity of using recycled water in the process, these waters contain several ions and compounds that can have adverse effects on the efficiency of the sulphide flotation process. SO_4^{2-}, Cl^-, F^-, Ca^{2+}, Mg^{2+}, Fe^{2+}, and K^+ ions, as well as chemicals used in the process, including collectors, frothers, depressants, activators, and flocculants, along with base metal cations and colloidal materials such as clays, can be considered as important pollutants with recycled water in most flotation plants (DeBoer and Linstedt, 1985; Muzenda, 2010). Also, properties including pH, electrical conductivity, total dissolved solids (TDS), and specific gravity of recycled water are usually different from fresh water. It is obvious that the presence of any of these pollutions or changes in any of these properties can have major effects on the flotation of sulphide minerals. For instance, molybdenite depression by residual anionic polyacrylamides and non-ionic polyethylene oxide added into bulk Cu–Mo concentrate thickener was reported by Castro and Laskowski (2015). Table 1 summarizes some of the pollutants present in recycled water and their effects on the sulphide flotation process.

Table 1. Effect of constituents in recycled water on sulphide flotation efficiency

Constituent	How to impact	References
Residual collectors and their oxidized products such as dixanthogen	Diminish the flotation selectivity (Dixanthogens have a high collecting property)	Hao et al. (2008); Chen et al. (2009); Boujounoui et al. (2015); Muzinda and Schreithofer (2018); Manenzhe et al. (2023)
Residual frothers	It may reduce frother consumption and on the other hand, cause excessive froth stability.	Hao et al. (2008); Wei et al. (2016)
Soluble salts	They affect the critical pH and cause its decrease or increase.	Corin et al. (2011); Moreno et al. (2011); Ramos et al. (2013); Feo et al. (2021)
SO_3^-, SO_4^-, and S_2^-	Due to their high reductive properties, they have the affinity to prevent the oxidation of xanthates.	Levay et al. (2001); Boujounoui et al. (2015)
Ca^{2+}	It may react with non-sulphide tailings such as quartz and enter the concentrate.	Rao et al. (1988); Rao and Finch (1989); Lutandula and Mwana (2014)
Cu^{2+}, Zn^{2+}, and Pb^{2+}	The presence of these ions can make flotation non-selective; e.g., the presence of Cu^{2+} in the flotation of copper and zinc increases the amount of zinc in the copper concentrate.	Liu et al. (1993), (2013); Boujounoui et al. (2015); Wang et al. (2016)
Residual flocculants	They may react with other flotation reagents and decrease the recovery.	Rao et al. (1988); Rao and Finch (1989), Castro and Laskowski (2015)

Sarcheshmeh copper complex is the largest copper processing plant in Iran, which consists of several large processing units, all of which work under wet conditions. Due to its location in the center of Kerman province, this complex has a dry climate, and for this reason, the management of water resources in this complex is of critical importance. Therefore, it is necessary to use the recycled water of the complex to the maximum because of the lack of water in the region and the need to reduce the consumption of freshwater from underground natural resources. In this regard, this research is conducted to investigate the effect of different sources of process water on the efficiency of the flotation circuit of the first phase of this complex. For this purpose, samples were collected from different water flows and after characterizing their qualitative and quantitative properties, the effect of each type of water source on the flotation efficiency was investigated. Two key purposes followed in this work were first to assess the significance of effects using statistical tests and next, to provide a reliable comparison on how various components in water sources may influence the copper ore flotation performance. These are the real challenges of almost all valuable works reported by other researchers. Moreover, a variety of water sources have been considered in this study making the research study more practical to practitioners active in the mineral processing sector.

2. Materials and methods

2.1. Sampling procedure of process water sources

Sarcheshmeh copper mine is a large porphyry copper deposit, which is located 180 km southwest of Kerman province (Iran). The average grade of copper and molybdenum of its ore is around 0.5% and 0.025%, and 90% of the water used in the concentration plant of this complex is supplied from recycled water. Therefore, considering the difference in the quality of freshwater (FW) and recycled water (RW), it is necessary to investigate the effect of its use on the performance of the plant flotation circuit. The recycled water circuit used in the concentration plant is shown in Fig. 1. Considering that the recycled water is a combination of two overflow streams of the thickeners of the copper/molybdenum processing unit (CM) and the molybdenum processing plant (CT), it is necessary to investigate the individual impact of these two water sources. Moreover, in case of emergency and lack of water, up to 50% of freshwater may be added to the mixture of thickener overflows. Therefore, in addition to

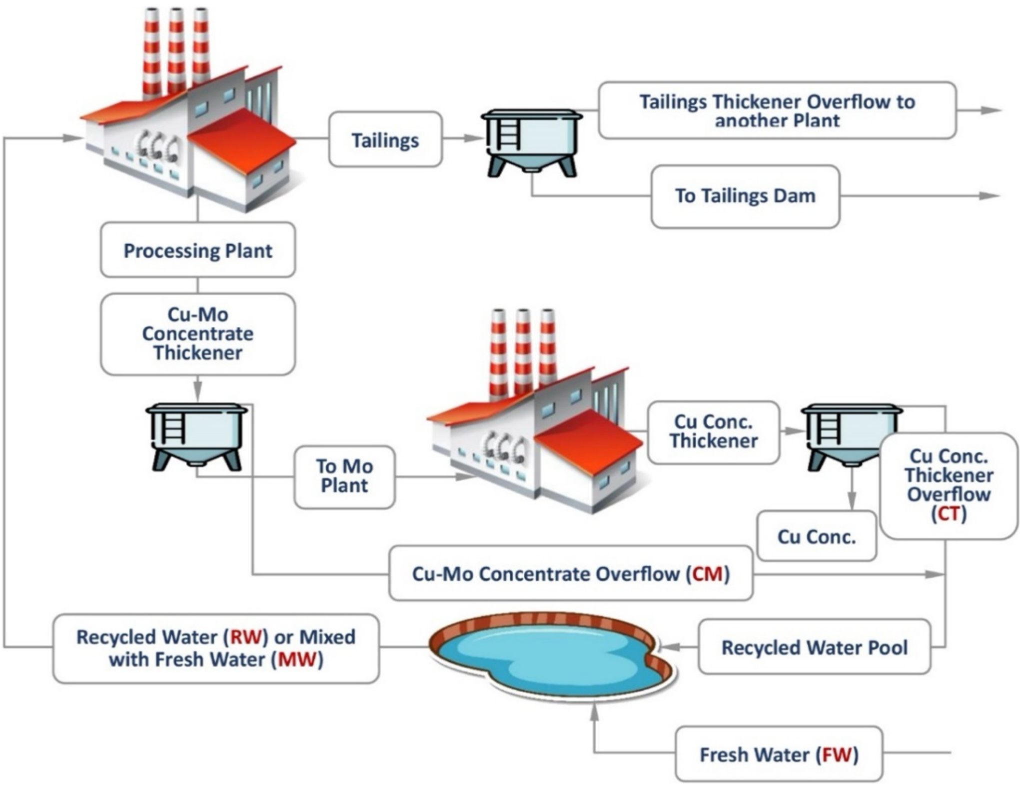

Fig. 1. Simplified illustration of water cycle circuit at Sarcheshmeh Copper Complex

to overflows of thickeners, recycled water, and freshwater, the mixture of fresh water and recycled water (MW) with the maximum ratio (50:50) was also investigated. To prepare water samples required for flotation studies, using an automatic pneumatic sampler, during a period of three days, 200 dm^3 of samples were collected from each of the streams shown in Fig. 1, and then, the representative samples were sent to the plant's water laboratory for qualitative and quantitative analyses. To compare the quality of process waters and fresh water, at the same time, a representative sample of freshwater entering the plant was also collected and analyzed using Inductively Coupled Plasma (ICP) Spectroscopy (Shami et al., 2021).

2.2. Flotation experiments

To perform flotation tests, using an automatic rotary sampler, 100 kg of representative samples were collected from the fine storage of the plant (d_{80} < 25 mm). Then, a sub-sample was also sent to the plant's central laboratory for chemical analysis using X-ray Fluorescence (XRF) (Fozooni et al., 2017). The result of the chemical analysis of the ore sample used is presented in Table 2. To prepare the sample required for flotation tests, the bulk sample was ground by a laboratory ball mill for 9 minutes to obtain a product with characteristic size (d_{80}) finer than 80 µm.

Table 2. The main chemical composition of the copper ore used in flotation experiments

Component	Cu	Fe	Mo	SiO_2
Amount (wt%)	0.54	4.30	0.024	54.26

To perform flotation tests, a standard self-aspiration Denver® flotation device equipped with a 4 L (equals 4 dm^3) cell was used. In all experiments, the stirring speed was set at 1400 rpm and the solid percentage of the pulp was set to 28% (w/w) according to the standard test procedure optimized based on previous test works (Azizi et al., 2015; Hassanzadeh and Hasanzadeh, 2017). To adjust the solid percentage, a given mass of ore was mixed with different samples of the process, recycled and fresh waters and also a combination of the same weight ratio of fresh water and recycled water. After the pH of the pulp was adjusted to 12 (for fresh and mixed waters) by lime, reagents including collectors and frothers were added to the pulp. The flotation reagents include collectors of sodium isopropyl xanthate (Z11) and sodium alkyl dithiophosphate (C7240), and frothers of methyl isobutyl carbinol (MIBC) and A65 (a polyglycol ether with a molecular weight of 250 g/mol). All of the reagents were of commercial purity. The dosage of all reagents was considered constant similar to the plant's conditions according to Table 3. The conditioning time for collectors and frothers was considered to be 2 and 1 min, respectively. Then, each flotation test was started by opening the aeration valve and froth was continuously collected for 12 minutes (Gholami et al., 2022). Each experiment was replicated thrice to ensure its reproducibility. Finally, samples were filtered, dried, and sent for chemical analysis using X-ray Fluorescence (XRF).

Table 3. Type and dosage of reagents used in flotation experiments

Reagent	Z11	C7240	MIBC	A65
Role	Collector	Collector	Frother	Frother
Dosage (g/t)	15	25	15	15

2.3. Statistical analysis of metallurgical results

Considering that the main goal of this research is to compare the effect of the type of process water on the metallurgical behavior of copper ore flotation, it is necessary to ensure that the differences between the results are significant. For this reason, the metallurgical responses including grade and recovery were analyzed two by two for copper, iron, molybdenum, and silica using the 2-sample t method at the 95% confidence level (Montgomery, 2020; Gholami et al., 2021).

2.4. Statistical analysis of water quality measures

To investigate the main effect of each of the water quality criteria (Table 4) on the metallurgical parameters, a one-way analysis of variance (ANOVA) was performed at a 95% confidence level. It should be noted that because the statistical analysis was performed based on irregular data, it is not possible to pursue the real interaction effect of the criteria due to the presence of aliases among the data (Shojaei and Khoshdast, 2018).

3. Results and discussions

3.1. Water characterization

The results of qualitative and quantitative analysis of process, recycled, and freshwater samples are presented in Table 4. As can be seen, the very high values of pH and conductivity of process and recycled waters are very impressive compared to the freshwater. These high values of pH and conductivity can be attributed to the addition of lime as a pH regulator to the ore to improve the efficiency of the plant's flotation operation. Also, the increase of metals such as lead and molybdenum can be seen in all process waters, which can be related to their preferential dissolution under the influence of flotation collectors, especially xanthate. As can be seen, the overflow of copper concentrate thickener has far more suspended solid particles than recycled water. However, although recycled water is a mixture of all process waters, it has lower TSS than CT. The reason for this decrease in TSS is because of the settling of suspended particles in the water pool. By time passing, some of the suspended particles are settled, and considering that the recycled water is provided by pumping from the surface points of the pool, it contains less suspended particles.

Table 4. Quality of process, recycled and freshwater samples used in flotation tests

Water sample	pH	EC[1]	TSS[2]	TH[3]	Cu^{2+}	Ca^{2+}	Fe^{2+}	Na^{+}	Mo^{2+}	Pb^{2+}	SO_4^{2-}	Cl^{-}
		μS/cm	mg/L	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Freshwater (FW)	8.10	620	2	74	0.01	25	0.03	93	0.07	0.05	75	58.8
Recycled water (RW)	11.80	6050	17	1268	0.04	499	0.05	725	0.5	0.25	842	453
50% FW + 50 RW (MW)	11	4225	12	1123	0.05	294	0.08	654	0.2	0.21	458	211
Cu-Mo thickener overflow (CM)	12	5930	50	520	0.11	27	0.23	1650	2.76	0.26	637	499
Cu thickener overflow (CT)	12	4400	126	521	0.03	234	0.03	750	1.34	0.14	721	318

[1] Electrical conductivity

[2] Total suspended solids

[3] Total hardness

3.2. Reliability analysis of results

The results of the reliability analysis are shown in Fig. 2. Probability values (p-values) that are shown in bold italic form indicate the significance of the difference between the changes; that means that the water source used has a significant effect on the target process parameter (p-value < 0.05). As can be seen in Fig. 2a, the use of fresh, recycled, and mixed waters as well as the overflow of copper and molybdenum thickener has not caused significant changes in grades. However, the use of overflow of copper concentrate thickener has significantly changed the grade of other components, except molybdenum grade. On the contrary, according to Fig. 2b, the use of all water sources has changed the recovery of copper, molybdenum, and silica. Also, although the overflow of copper concentrate thickener did not affect molybdenum grade, it has significantly influenced molybdenum recovery compared to fresh and recycled waters.

3.3. Interpretation of metallurgical responses

The influence of the process water source on the metallurgical behavior of copper ore is shown in Fig. 3. Based on the results of the reliability analysis in Fig. 2, the use of copper concentrate thickener

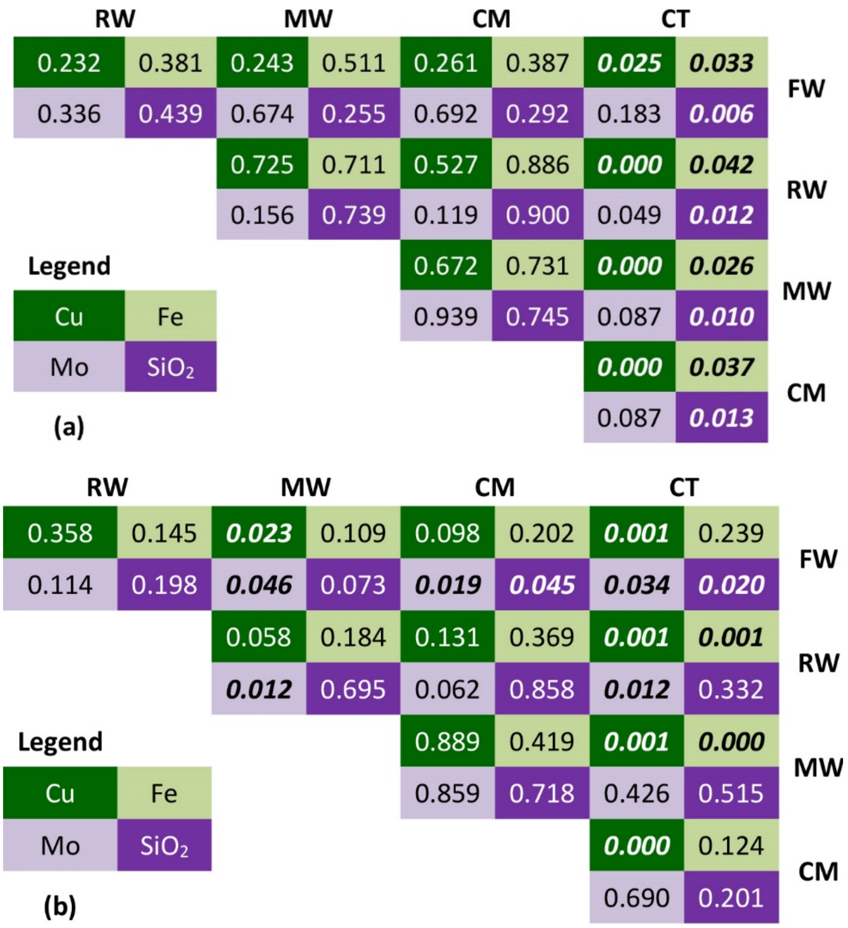

Fig. 2. Results (p-values) of reliability analysis for (a) grade and (b) recovery of flotation tests using different waters

overflow (CT) has greatly reduced the copper grade and recovery; while the grade and recovery of silica have increased significantly. Meanwhile, other sources of water have not had any significant impact on the metallurgical behavior of the process. Comparing the quantitative analytical results of water sources in Table 4 clearly shows that the amount of suspended solid particles in CT is much higher than the rest of the water sources. Therefore, the effect of CT can be summarized in the following cases:

- Because CT belongs to copper concentrate thickener, suspended particles are mainly fine particles (slimes) of copper minerals (with d_{80} < 18 µm and a concentration of 3-10 mg/L, depending on the performance of the thickener (Fatahai, 2020)). Therefore, these particles can compete with the coarse mineral particles in the absorption of the collector and reduce the recovery of copper and iron minerals due to the decrease in the concentration of the collector (due to higher specific surface area and absorption capacity) (Khoshdast, 2019; Zahab-Nazouri et al., 2022; Safari et al. 2022; Taguta et al. 2023). On the other hand, due to their small size, these particles can reduce the carrying capacity of bubbles and decrease the floating of coarse particles. Also, the coating effect of fine copper particles on the surface of silica particles increases their flotation rate and while increasing the amount of these particles in the concentrate, the recovery of copper and iron decreases.
- Fine particles may increase the suspension of coarse particles by intensifying the viscosity of the pulp and thus enhance the recovery of silica particles by entrainment (Paryad et al., 2017; Hoseinian et al., 2019a and 2020; Asgari et al., 2023).

According to Fig. 3c, although the molybdenum grade has not increased significantly, the recovery using CT has grown significantly. In the molybdenum processing plant, a small amount of diesel oil is used to improve molybdenite flotation separation. Therefore, the improvement of molybdenum recovery using CT may be caused by the presence of residual diesel in the copper concentrate thickener overflow.

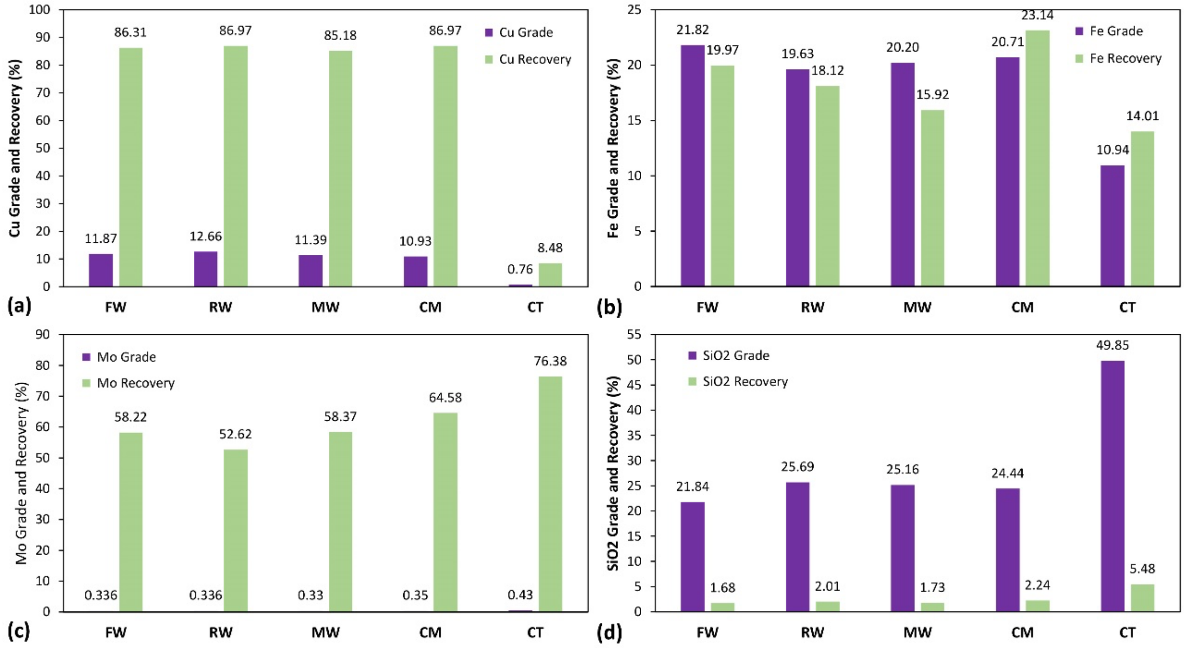

Fig. 3. Effect of process water sources on flotation metallurgical response of (a) Cu, (b) Fe, (c) Mo, and (d) SiO_2

According to Fig. 2b, it can be seen that CM improved iron and silica grades compared to other waters. Referring to Table 3, the amount of Cu^{2+}, Fe^{2+} and Mo^{2+} ions in this water is higher than other waters. These ions can act as an activator and by increasing the surface activity of gangue minerals to absorb the collector, increase the amount of gangues in the concentrate by non-selective flotation. These results have been reported by some other researchers (Liu et al., 2013; Boujounoui et al., 2015; Wang et al., 2016; Hoseinian et al., 2019b). According to Table 3, the amount of sulfate ions in all process waters is almost equal, and therefore, it is difficult to compare its possible effect on flotation behavior. Also, the amount of Na^+ ions in CM water is much lower than other waters. This ion can change the pH of the pulp by consuming hydroxyl anions in the system (Ramos et al., 2013; Feo et al., 2021). Since the pH is fixed in batch studies, the influence of Na^+ and other similar ions from soluble salts can be neglected. Regardless of the above explanations, visual observations of the structure and quality of the froth phase in the flotation tests showed that the water quality may be also effective on the frothing behavior of the system. Studies have well shown that the presence of impurities, especially electrolytes, are effective on foaming ability, foam volume, and structure, and finally, the efficiency of mineral flotation (e.g., Farrokhpay and Zanin, 2012; Ramos et al., 2013; Jeldres et al., 2017; Khoshdast et al., 2022). Therefore, a detailed evaluation of the effect of the elements present in the studied process waters is strongly beneficial.

3.4. Individual effect of water quality measures

To evaluate the effect of water quality criteria on the metallurgical behavior of copper ore flotation, the significance of each effect was investigated by one-way ANOVA. The sign assigned to each criterion is shown in Table 5. To compare the effect of parameters on each metallurgical response, as well as to reduce the number of individual main effect plots (i.e., 11 plots for each response), perturbation plots were used (Khoshdast et al., 2017). The main effects plots are shown in Fig. 4. As can be seen, the greatest effect on all metallurgical responses is related to TSS (B). This effect is negative for copper and iron and positive for molybdenum and silica; these effects are consistent with the interpretations presented in Section 3.3. The effect of increasing the electrical conductivity of water (A) is positive on the flotation behavior of copper and iron and negative but small on the flotation response of molybdenum and silica. The electrical conductivity of water comes from metal ions. According to Fig. 4, it can be seen that copper ion (D) has the greatest effect on metallurgical responses; whereas, other cations have no significant effect. The interesting point is that the presence of copper ions has improved the flotation efficiency (recovery, grade, or both) of metallic minerals. This effect can be attributed to the activation

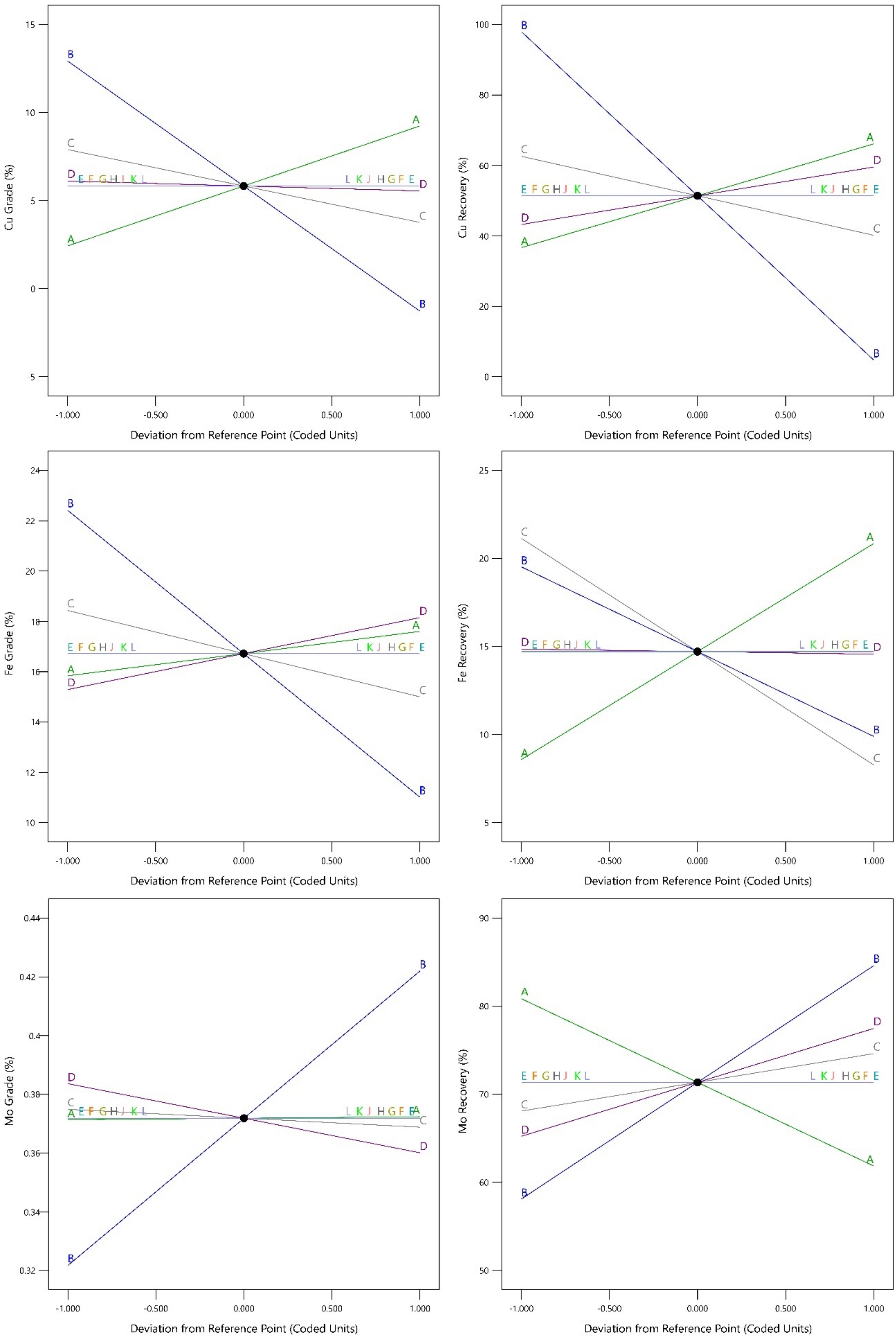

Fig. 4. Perturbation plots illustrating the effect of water quality measures on metallurgical responses

effect of this ion. Meanwhile, increasing the concentration of copper ions has reduced the efficiency of silica flotation. Obviously, with the increase in the amount of other minerals in the concentrate, the recovery and grade of silica decreases. Another effective parameter is the total hardness (C), which generally has a negative effect on the flotation efficiency of copper and iron and has slightly improved the flotation efficiency of molybdenum and silica. The negative effect of hardness on copper and iron flotation efficiency can be ascribed to the retention of these minerals and the partial improvement of molybdenum and silica flotation can be attributed to the same decrease in copper and iron flotation efficiency. Another noteworthy point is that anions did not have a significant effect on the metallurgical responses. According to Levay et al. (2001) and Boujounoui et al. (2015), the presence of anions, especially sulfates, reduces the efficiency of xanthates. The negligible effect of anions in this research study may be attributed to the possible presence of the residual collector in the process water and, as a result, reducing the effect of anions. In this context, investigating the possible presence of various flotation reagents as well as flocculants in process waters is very necessary.

Table 5. Designation of water quality measures used in one-way ANOVA plots

Measure	EC	TSS	TH	Cu^{2+}	Ca^{2+}	Fe^{2+}	Na^{+}	Mo^{2+}	Pb^{2+}	SO_4^{2-}	Cl^{-}
Unit	μS/cm	mg/L	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Sign	A	B	C	D	E	F	G	H	J	K	L

4. Conclusions

In this case study, the effect of the process water source on the metallurgical efficiency of copper ore flotation in Sarcheshmeh Copper Complex (Iran, Rafsanjan) was investigated. The results showed that the thickener concentrate overflow of the copper and molybdenum (CT) processing plant had the greatest effect on the flotation behavior of copper ore. Considering that all operating conditions were constant during the flotation tests, the changes could be directly attributed to the water quality. Therefore, according to the results of the qualitative and quantitative analysis of the investigated waters, the effect of CT was mainly attributed to the presence of fine suspended solid particles of copper. These particles reduced the efficiency of copper flotation by consuming the collector, reducing the carrying capacity of the bubbles and the coating effect of the gangue minerals. Compared to the results reported by other researchers, regardless of the residual reagents and soluble ions, slime suspended in the water source can significantly contribute to the way water may influence the flotation performance of copper ore. However, the type and source, i.e., concentrate or tailings thickener overflow, of such suspended slimes, may affect the flotation process in different ways. Although the results of this research clearly confirm the effect of the type of process water source on the flotation behavior of copper ore, more studies are needed to describe the precise effect of water quality on the flotation process.

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References

ASGARI, K., KHOSHDAST, H., NAKHAEI, F., GARMSIRI, M.R., HUANG, Q., HASSANZADEH, A., 2023. *A review on floc-flotation of fine particles: technological aspects, mechanisms, and future perspectives*. Mineral Processing and Extractive Metallurgy Review, 1-28.

AZIZI, A., HASSANZADEH, A., FADAEI, B., 2015. *Investigating the first-order flotation kinetics models for Sarcheshmeh copper sulfide ore*. International Journal of Mining Science and Technology, 25(5), 849-854.

BAHMANI-GHAEDI, A., HASSANZADEH, A., SAM, A., ENTEZARI-ZARANDI, A., 2022. *The effect of residual flocculants in the circulating water on dewatering of Gol-e-Gohar iron ore*, Minerals Engineering, 179, 30, 107440.

BIÇAK, Ö., EKMEKÇI, Z., ÖZTÜRK, Y., 2012. *The effect of water chemistry on froth stability and surface chemistry of the flotation of a Cu–Zn sulfide ore*. International Journal Mineral Processing, 102–103, 32–37.

BOUJOUNOUI, K., ABIDI, A., BACAOUI, A., El AMARI, K., YAACOUBI, A., 2015. *The influence of water quality on the flotation performance of complex sulphide ores: Case study at Hajar Mine, Morocco*. The Journal of The South African Institute of Mining and Metallurgy, 115(12), 1243–1251.

CASTRO, S., LASKOWSKI, J.S., 2015. *Depressing effect of flocculants on molybdenite flotation*. Miner. Eng. 74, 13–19.

CHEN, J.M., LIU, R.Q., SUN, W., QIU, G.Z., 2009. *Effect of mineral processing wastewater on flotation of sulfide minerals.* Transactions of Nonferrous Metals Society of China, 19(2), 454–457.

CORIN, K.C., REDDY, A., MIYEN, L., WIESE, J.G., HARRIS, P.J., 2011. *The effect of ionic strength of plant water on valuable mineral and gangue recovery in a platinum bearing ore from the merensky reef.* Minerals Engineering, 24(2), 131–137.

DEBOER, J., LINSTEDT, K.D., 1985. *Advances in water reuse applications*. Water Research, 19(11), 1455–1461.

FARROKHPAY, S., ZANIN, M., 2012. *An investigation into the effect of water quality on froth stability*. Advanced Powder Technology, 23(4), 493–497.

FATAHI, M., 2020. O*ptimization of Shahr-e Babak copper concentrate thickener using Response Surface Methodology*. MSc. Thesis. Higher Education Complex of Zarand, Iran.

FEO, A.D., HILL-SVEHLA, C.M., HART, B.R., VOLVHEK, K., MORIN, L., DEMERS, A., 2021. *The effects of water recycling on flotation at a North American concentrator.* Minerals Engineering, 170, 107037.

FOZOONI, S., KHOSHDAST, H., HASSANI, H., HAMIDIAN, H., 2017. *Synthesis of oxazolone and imidazolone derivatives in presence of H_2O_2 promoted fly ash as a novel and efficient catalyst.* Journal of Sciences. 28(3), 221–230.

GHOLAMI, A.R., ASGARI, K., KHOSHDAST, H., HASSANZADEH, A., 2022. *A hybrid geometallurgical study using coupled Historical Data (HD) and Deep Learning (DL) techniques on a copper ore mine*. Physicochemical Problems of Mineral Processing. 58(3):147841.

GHOLAMI, A.R., KHOSHDAST, H., HASSANZADEH, A., 2021. *Applying hybrid neural genetic and artificial bee colony algorithms to simulate the bio-treatment of dye-polluted wastewater using rhamnolipid biosurfactants*. Journal of Environmental Management. 299, 113666.

HAO, F., DAVEY, K.J., BRUCKARD, W., WOODCOCK, J., 2008. *Online analysis for xanthate in laboratory flotation pulps with a UV monitor.* International Journal Mineral Processing, 89(1–4), 71–75.

HASSANZADEH, A., and HASANZADEH, M., 2017. *Chalcopyrite and pyrite floatabilities in the presence of sodium sulfide and sodium metabisulfite in a high pyritic copper complex ore*, Journal of Dispersion Science and Technology 38(6), 782–788.

HOSEINIAN, F.S., RAMSHINI, S., REZAI, B., KOWSARI, E., SAFARI, M., 2023. *Toxic heavy metal ions removal from wastewater by ion flotation using a nano collector.* Minerals Engineering 204, 108380.

HOSEINIAN, F.S., REZAI, B., KOWSARI, E., SAFARI, M., 2020. *The effect of water recovery on the ion flotation process efficiency.* Physicochemical Problems of Mineral Processing 56(5), 919-927.

HOSEINIAN, F.S., REZAI, B., SAFARI, M., DEGLON, D., KOWSARI, E., 2021. *Separation of nickel and zinc from aqueous solution using triethylenetetramine.* Hydrometallurgy, 202, 105609.

HOSEINIAN, F.S., REZAI, B., SAFARI, M., DEGLON, D., KOWSARI, E., 2019a. *Effect of hydrodynamic parameters on nickel removal rate from wastewater by ion flotation*. Journal of Environmental Management 244, 408-414.

HOSEINIAN, F.S.; REZAI, B.; SAFARI, M., 2019b. *A new kinetic model for zinc ion removal from synthetic wastewater*. In Proceedings of the 10th European Metallurgical Conference (EMC 2019), Düsseldorf, Germany, 23–26 June 2019; pp. 1409–1416.

JELDRES, R.I., ARANCIBIA-BRAVO, M.P., REYES, A., AGUIRRE, C.E., CORTES, L., CISTERNAS, L.A., 2017. *The impact of seawater with calcium and magnesium removal for the flotation of copper-molybdenum sulphide ores.* Minerals Engineering, 109, 10–13.

KHOSHDAST H., HASSANZADEH A., KOWALCZUK P.B., FARROKHPAY, S., 2022. *Characterization of flotation frothers – A review*. Mineral Processing and Extractive Metallurgy Review. 44(2), 77-101.

KHOSHDAST, H., 2019. *Practical problems in froth flotation.* Hormozgan University Press, Tehran, Iran.

KHOSHDAST, H., SHOJAEI, V., KHOSHDAST, H., 2017. *Combined application of computational fluid dynamics (CFD) and design of experiments (DOE) to hydrodynamic simulation of a coal classifier*. International Journal of Mining and Geo-Engineering 51(1), 9–24.

LEVAY, G., SMART, R.St.C., SKINNER, W.M., 2001. *The impact of water quality on flotation performance*. The Journal of The South African Institute of Mining and Metallurgy, 101(2), 69–76.

LIU, L., RAO, S.R., FINCH, J.A., 1993. *Technical note laboratory study of effect of recycle water on flotation of a Cu/Zn sulphide ore*. Minerals Engineering, 6(11), 1183–1190.

LIU, W., MORAN, C.J., VINK, S., 2013. *A review of the effect of water quality on flotation.* Minerals Engineering, 53, 91–100.

LUTANDULA, M.S., MWANA, K.N., 2014. *Perturbations from the recycled water chemical components on flotation of oxidized ores of copper – The case of bicarbonate ions*. Journal of Environmental Chemical Engineering, 2(1), 190–198.

MANENZHE, R.M., MANONO, M.S., WIESE, J.G., MUSUKU, B., CORIN, K.C., 2023. *Exploring the effects of different process water sources on xanthate adsorption and flotation performance.* Minerals Engineering, 204, 108376.

MIRSHRKARI, S., SHOJAEI, V., KHOSHDAST, H., 2022. *Adsorptive study of cadmium removal from aqueous solution using a coal waste loaded with Fe_3O_4 nanoparticles*. Journal of Mining and Environment 13(2), 527–545.

MONTGOMERY, D.C., 2020. *Design and Analysis of Experiments*. 10th Edition, Wiley, USA.

MORENO, P.A., ARAL, H., CUEVAS, J., MONARDES, A., ADARO, M., NORGATE, T., BRUCKARD, W., 2011. *The use of seawater as process water at Las Luces copper molybdenum beneficiation plant in Taltal (Chile).* Minerals Engineering, 24(8), 852–858.

MUZENDA, E., 2010. *An investigation into the effect of water quality on flotation performance*. International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering, 4(9), 237–241.

MUZINDA, I., SCHREITHOFER, N., 2018. *Water quality effects on flotation: Impacts and control of residual xanthates.* Minerals Engineering, 125, 34–41.

PARYAD H., KHOSHDAST H., SHOJAEI V., 2017. *Effects of operating parameters on time-dependent ash entrainment behaviour of a sample coal flotation*, Journal of Mining and Environment. 8(3), 337–357.

RAMOS, O., CASTRO, S., LASKOWSKI, J.S., 2013. *Copper–molybdenum ores flotation in sea water: Floatability and frothability*. Minerals Engineering, 53, 108–112.

RAO, S.R., ESPINOSA-GOMEZ, R., FINCH, J.A., BISS, R., 1988. *Effects of water chemistry on the flotation of pyrochlore and silicate minerals*. Minerals Engineering, 1(3), 189–202.

RAO, S.R., FINCH, J.A., 1989. *A review of water re-use in flotation*. Minerals Engineering, 2(1), 65–85.

SAFARI, M., HOSEINIAN, F.S., DEGLON, D., L. LEAL FILHO, T.C. SOUZA PINTO, 2022. *Impact of flotation operational parameters on the optimization of fine and coarse Itabirite iron ore beneficiation*, Powder Technol. 408, 117772,

SHAMI R.B., SHOJAEI V., KHOSHDAST H., 2021. *Removal of some cationic contaminants from aqueous solutions using sodium dodecyl sulfate-modified coal tailings*, Iranian Journal of Chemistry and Chemical Engineering, 40(4), 1105–1120.

SHOJAEI, V., KHOSHDAST, H., 2018. *Efficient chromium removal from aqueous solutions by precipitate flotation using rhamnolipid biosurfactants*. Physicochemical Problems of Mineral Processing 54(3), 1014–25.

TAGUTA, J., SAFARI, M., GOVENDER, V., CHETTY, D., 2023. *Investigating the Amenability of a PGM-Bearing Ore to Coarse Particle Flotation*. Minerals, 13, 698.

WANG, Y., PENG, Y., NICHOLSON, T., LAUTEN, R.A., 2016. *The role of cations in copper flotation in the presence of bentonite*. Minerals Engineering 96–97, 108–112.

WEI, T., PENG, Y., VINK, S., 2016. *The joint action of saline water and flotation reagents in stabilizing froth in coal flotation.* International Journal of Mineral Processing 148, 15–22.

ZAHAB-NAZOURI, A., SHOJAEI, V., KHOSHDAST, H., HASSANZADEH, A., 2022. *Hybrid CFD-experimental investigation into the effect of sparger orifice size on the metallurgical response of coal in a pilot scale flotation column*. International Journal of Coal Preparation & Utilization 42(3), 349–68.