Physicochemical Problems of Mineral Processing, 42 (2008), 119-130
Fizykochemiczne Problemy Mineralurgii, 42 (2008), 119-130

Abdel-Hady M. Saleh*, Atef M. Ramadan *, Mohamed R. Moharam*

BENEFICIATION OF EGYPTIAN ABU-SWAYEL COPPER ORE BY FLOTATION

Received March 15, 2008; reviewed; accepted July 31, 2008

In this study, an attempt was made to recover copper from Abu-Swayel deposit. A reverse flotation technique was applied leading to flotation of the accompanying oxide and sulfide minerals and gathering copper oxide minerals in the sink product. The results showed that the application of such technique is possible under the optimum flotation conditions. Studying the main factors that affect such flotation system indicated that the optimum flotation conditions are at 1.5 kg/t oleic acid as the collector, pH=10, air flow rate=7 1/min and 5 min flotation time. In the context, about 90% of copper recovery with 10% copper grade was obtained. It was also found that the copper mineral particles lost in the froth product by mechanical carryover mechanism can be recovered through concentrate cleaning under the same flotation conditions. Hence, one may conclude that the results of this study are useful and may help in reassessment of exploitation of such copper deposit.

key words: flotation, upgrading, copper ore, copper minerals, copper oxides

INTRODUCTION

The application of flotation in copper ore treatment plants is used on a wide scale. Hosten and Tezcan (1990) used kinetic analysis and separation efficiency factors for comparison of frother performance in flotation of a massive copper sulfide ore. The studied frothers included polyglycols, pine oil and methyl isobutyl carbinol (MIBC). No obvious differences in the frother selectivity were observed. However, polypropylene glycol frother gave the highest flotation rate. Heyes and Trahar (1977) studied natural floatability of chalcopyrite. It appeared that the particle surface is rendered hydrophobic in an oxidizing environment and hydrophilic in a reducing environment. They stated that the principal side effect of grinding in an iron mill is the strongly cre-

* Mining & Petroleum Eng. Dept., Faculty of Engineering, Al-Azhar University, Cairo, Egypt

ated reducing environment. Such environment suppresses the normal floatability of chalcopyrite which can be reestablished by raising the pulp potential either by aeration or by addition of oxidants.

The electrokinetic behavior of copper sulfide ores and their flotation response was investigated by many authors (Acar and Somasundaran, 1992; Uribe-Salas, 2000; Leppinen, 1998; Hanson and Fuerstenau, 1991) . The results obtained by Acar and Somasundaran (1992) showed that covellite and millerite exhibit two charge reversals, one from negative to positive in the neutral pH range, and another from positive to negative in the alkaline pH range. Uribe-Salas, et al.,(2000) studied the selective flotation of chalcopyrite contained in a fine-grained complex ore by increasing the pulp potential using hydrogen peroxide. The results showed that the recovery of chalcopyrite flotation occurs near Eh = 0.3V. Leppinen et al., (1998) found that the grinding medium had a strong effect on electrode potential and flotation results. Copper recovery increased by 80% within a narrow potential range in the flotation of an "easy" ore type whereas only 15% increase in copper recovery occurred in the flotation of "difficult" copper ore. Hanson and Fuerstenau (1991) studied the electrochemistry and wetting behavior of chalcocite in aqueous solutions of potassium salts of octyl hydroxamate and ethyl xanthate. The results showed that hydroxamate may be promising as a collector, not only for copper sulfide ores but also for oxidized copper ores. It was concluded that the selective separation of copper minerals (sulfides and/or oxides) may be possible by controlling the flotation pulp potential.

Evaluation of flotation collectors for copper sulfides was performed by Ackerman et al.,(1987) and Senior et al. (2006) using criteria of recovery and flotation rate. The flotation of copper sulfides with sulphydryl collectors was found to follow the order: xanthate > dithiophosphate = thionocarbamate > dixanthogen. Separability curves in the form of mineral recovery versus yield have been used to characterize the copper flotation process both at batch laboratory scale and industrial plant scale Yianatos et al.,(2003). A comparison was made at the maximum separation efficiency point in both operations. The results showed a good consistency for scaling up the rougher flotation recovery from batch tests to industrial within 1 percentage point error range. Laboratory experiments carried out on flotation of copper oxides by Aplan and Fuerstenau (1984) demonstrated that chrysocolla and malachite can be floated with a mercaptan collector. Higher xanthate homolog (hexyl, dodecyl), when used in large quantities, will float malachite but not chrysocolla. In the presence of finely ground gangue particles, an addition of the mercaptan to the grinding mill gave superior recoveries over its addition to flotation cell. A model for the attachment of the mercaptan to the chrysocolla surface is proposed which involves a reaction of mercaptan molecules with copper sites which leads to the formation of insoluble copper mercaptide and splitting off water molecule at the surface.

The Abu–Swayel ore deposit is located at about 185 km south of Aswan, near the Wadi Haimour (Egypt). The ore body includes both massive and disseminated mineralization hosted in a lens–like body of amphibolite. The amphibolite lens is surrounded by biotite–garnet schist of basic origin Hussein (1990). The deposit consists of copper, nickel, and iron minerals in the form of oxides and sulfides and is not exploit. A few studies was carried out on the extraction of copper from this deposit by heap and agitation leaching (Fathy, 2005; Abbas, 1983).

An important problem facing the copper industry in the world is the recovery of oxide copper minerals because they float poorly. It is expected that the reverse flotation technique may be appropriate to recover such oxide copper minerals from the accompanying mineral oxides/sulfides.

This work aimed to separate or recover copper mineral oxides in the sink product and other minerals in float product by reverse flotation technique. Hence, a study that adds information and/or investigates the effect of various parameters on such flotation is of a great interest.

EXPERIMENTAL

MATERIAL

The experimental work was carried on a sample of Abu-Swayel copper ore deposit. This deposit consists of copper, nickel and iron minerals in the form of oxides and sulfides. The mineralogical composition of this deposit was studied by X-ray diffraction and microscopic examination (Fathy, 2005; Abbas 1983), and the founding are shown in Table 1. A bulk sample was collected from some outcropping areas of the deposit. A representative sample was taken to determine the percentage of copper in the flotation feed. The experiments showed that it contains about 6% Cu. The chemical analysis of other elements, carried out in the laboratory of Egyptian Geological Survey and Mining Authority (EGSMA) are shown in Table 2 (Abbas 1983).

Table 1. Mineralogical composition of Abu-Swayel ore deposit

Mineral	Chemical formula	Mineral	Chemical formula
chalcopyrite	$CuFeS_2$	violarite	$(Ni_2 Fe)SO_4$
malachite	$CuCO_3(OH)_2$	ilmenite	$FeTiO_3$
calcanthite	$CuSO_4.5H_2O$	goethite	FeOOH
brochiantite	$Cu_4 (SO_4).(OH)_6$	hematite	Fe_2O_3
bravoite	$(NiFe)S_2$		

Table 2. Chemical analysis of the representative sample

Chemical constituent	Si	Fe	Mg	Ca	Ni	L.O.I
Percentage, %	20.14	16.86	9.16	1.20	1.80	8.50

Oleic acid was used as collector and pine oil at fixed dosage of 250 mg/dm^3 was applied as a frother.

METHODS

The raw material was received as coarse lumps. These lumps were crushed in a laboratory jaw crusher to 1 mm size. The product from jaw crusher was dry ground in a closed circuit disk crusher to a –0.5 mm size. After each run, the product was screened on a 0.5 mm screen using Ro-tap shaker. The +0.5 mm fraction was returned to the mill while the -0.5 mm fractions were collected to form the flotation feed.

Flotation tests were carried out in a laboratory subaeration mechanical flotation machine equipped with 1 dm^3 capacity cell. Flotation tests were carried out using tap water at 20% pulp density (i.e., 20% solids by wt.). The sample was agitated for 5 min to ensure complete wetting of particle surface. The pulp was conditioned for 5 min with collector and for 1 min with frother. The parameters studied and their ranges of study are shown in Table 3.

Table 3. Parameters studied and their ranges of study

Parameter	Range of investigated parameter
collector dosage (oleic acid)	0.5 - 3.0 kg/Mg
pH	6 - 12
air rate	3 - 15 l/min
flotation time	1 - 5 min

In the tests designed to study the effect of time, the concentrate was collected after 1, 2, 3, 4, and 5 min flotation time. However, one concentrate was collected after the barren bubbles were observed. The time was measured from the moment at which the air is introduced into the cell. The pulp density and impeller speed (1000 rpm) were kept constant during all tests. pH was controlled using HCl and NaOH solutions. The pulp level was kept constant by adding more water during flotation.

A given tested parameter was changed or studied at the mentioned range while other parameters were fixed or kept constant. The concentrate (float) as well as the tailing (sink) were filtered in a vacuum filter and dried in an electric drier at 80 – 100^{o}C, weighed with a balance and analyzed for copper content.

Although the type of flotation machine has a self–inducing aerator, in which the gas flow rate is dependent on the impeller speed, the gas flow rate to the machine was controlled and measured to study its effect. The applied system in this work was a batch system consisting of water–air–solid phases.

RESULTS AND DISCUSSION

It is worth to mention that all tests were carried out at 200 g in one dm^3 i.e. at 20% solid/liquid ratio by wt., 250 mg/dm^3 pine oil as a frother and at1000 rpm impeller speed. Four groups of tests were considered. The first aimed to study the effect of collector dosage. In this group a selective values for pH and air flow rate (8 and 6 dm^3/min) were considered. The second illustrates the effect of pH value on the considered flotation system where the optimum collector dosage from the first group and 6 dm^3/min flow rate were considered. The third investigates the effect of air flow rate as the optimum collector dosage from the first group and optimum pH value from the second group were considered. The fourth aimed to study the effect of optimum flotation time. In this fourth group, the optimum values obtained for collector dosage, pH and air flow rate were considered to determine the optimum flotation time. Except the fourth group of tests, the flotation was continued until barren bubbles were observed.

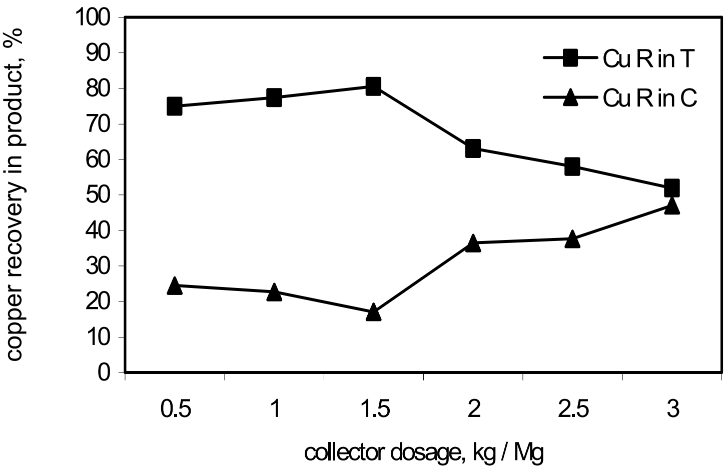

Fig. 1. Effect of collector dosage on copper recovery in flotation concentrate and tailing

Figure 1 shows the effect of collector dosage on copper recovery in flotation concentrate and tailing. Figure 2 reflects the same information with regard to product grade, i.e. copper content % in concentrate and tailing products. It is clear that the recovery of copper in the float product (concentrate) is low at low collector dosage (< 1.5 kg/Mg) and increases as the collector dosage increase (> 1.5 kg/Mg). The concentrate grade decreases to about 1.5 kg/Mg collector dosage and then begins to increase at higher dosages. The recovery of copper as well as the product grade are higher in the sink product than float product. This means that the floatability of copper minerals is poor with oleic acid collector. The increase in copper recovery in float product at high collector dosages may be related to mechanical carryover mechanism or overdosage of collector which must be added in starving amounts in these flotation systems.

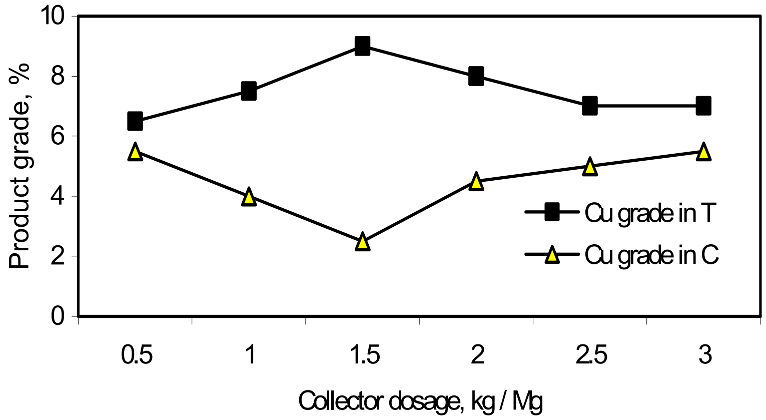

Fig. 2. Effect of collector dosage on copper grade in flotation concentrate and tailing.

It is expected that the accompanied minerals in feed, i.e, other oxides such as Fe_2O_3 or SiO_2 have been floated leaving copper oxide minerals in the tailing product. It is clear that the best collector dosage is about 1.5 kg/Mg, which gave the highest copper recovery (≈80%) in the sink product and at the same time a high copper grade. Hence, one may conclude that the recovery of copper minerals from such an ore is possible with reverse flotation.

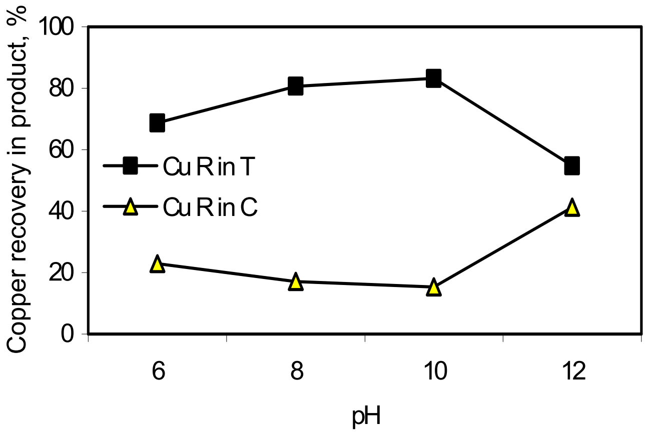

Fig. 3. Effect of pH on copper recovery in flotation concentrate and tailing

Figures 3 and 4 illustrate the effect of pH on the reverse flotation concentrating copper minerals in the sink product. The recovery of copper increases with increasing pH from 6 to 10, then it decreases above pH 10. The recovery of copper is about 84% at pH 10 which represents the highest value. The highest product grade, ~ 10% is obtained at the same pH. This means that the optimum pH to float other accompanying oxides from copper minerals is about pH 10. Such a pH is similar to the pH applied in floating iron oxides and silica.

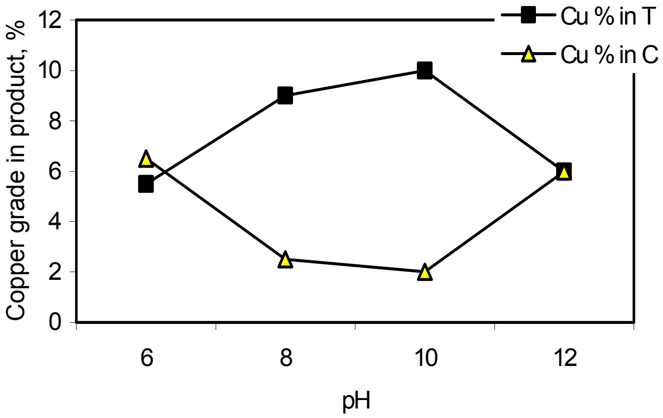

Fig. 4. Effect of pH on copper grade in flotation concentrate and tailing

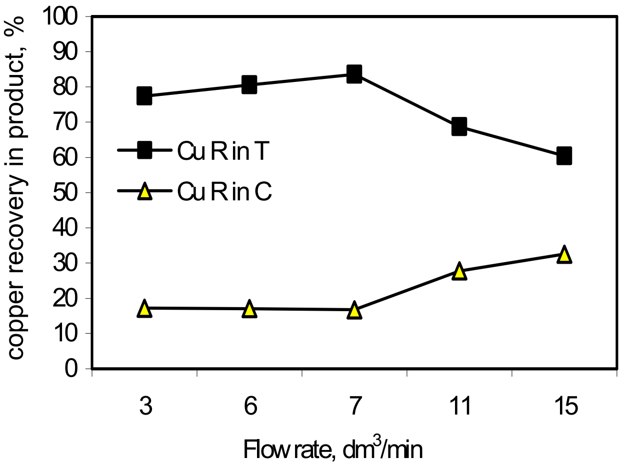

Fig. 5. Effect of air flow rate on copper recovery in flotation concentrate and tailing

Figures 5 and 6 show the effect of air flow rate with regard to copper recovery and copper grade in float and sink products. Below 7 dm^3/min, the copper recovery increases slightly in the sink product and still, more or less, constant in the float product. Above 7 dm^3/min flow rate, the copper recovery decreases in the sink product and increases in the float product. Similar trends are obtained for copper grade in froth and sink products. It is obvious that the best flow rate is about 7 dm^3/min as the highest copper recovery and copper grade are attained in sink product at this value.

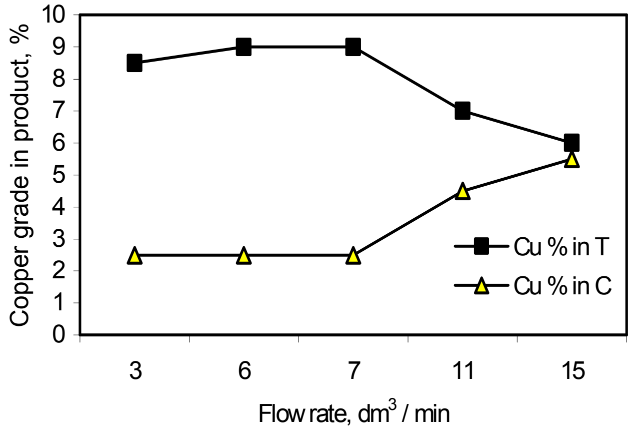

Fig. 6. Effect of air flow rate on copper grade in flotation concentrate and tailing

This result is in agreement with the results mentioned in flotation literature which state that the flotation recovery of floating particles increases with flow rate increase until a definite limit (optimum flow rate), and then begins to decrease. An increase of the copper recovery and copper content in the float product (concentrate) which is accompanied with a decrease in the copper recovery and grade in the sink product at high flow rates (> 7dm^3/min) may be due to a mechanical carryover mechanism and not due to a real flotation mechanism. It is well known in the flotation literature, that the mechanical carryover mechanism does not distinguish between hydrophobic and hydrophilic particles.

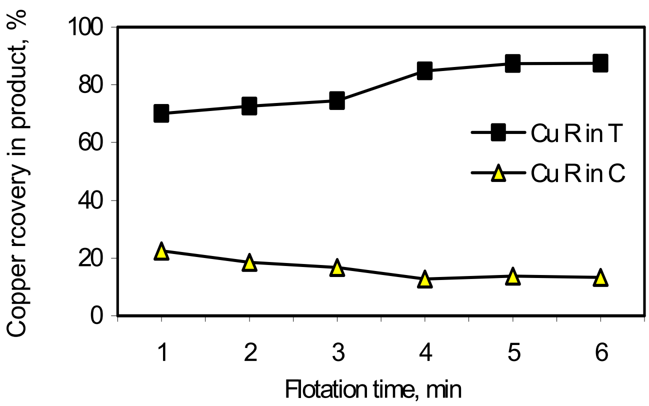

Fig. 7. Effect of flotation time on copper recovery in concentrate and tailing

Figure 7 represents the effect of flotation time on the recovery of copper in concentrate (float product) and in tailing. This test aimed to illustrate the optimum flotation time. The recovery of copper increases in the sink product and decreases in the float product until 5 min flotation time. It is clear from this figure that the optimum flotation time is about 5 min as after such time the recovery of copper in sink product becomes constant.

The reverse flotation of copper minerals at the optimum flotation conditions obtained previously, i. e, at 1.5 kg/Mg collector dosage, pH =10, 7 dm^3/min air flow rate and 5 min flotation time is considered. This experiment was carried out at 800 g in 4 dm^3 flotation cell capacity, i. e, at 20% by wt solid/liquid ratio. The obtained results indicated that about 90% of copper is recovered in the sink product at about 11% Cu content. The froth product (float) from this test was found to have about 1.5 % Cu content. An attempt was carried out also to recover such a small amount of copper from the concentrate product (float).

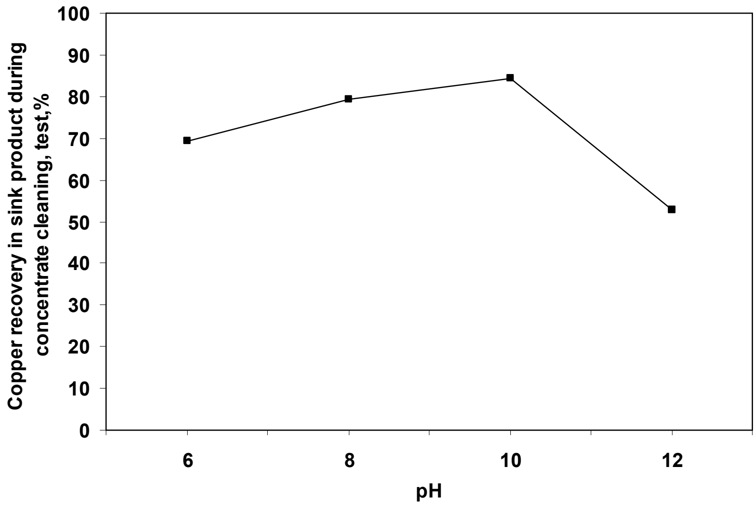

Fig. 8. Effect of pH on Cu recovery in sink product during concentrate reverse flotation cleaning test

Figure 8 shows the effect of pH on such cleaning test, i.e, recovering copper mineral particles present in the froth product (concentrate) during reverse flotation. The reverse flotation technique and the optimum flotation conditions obtained above were applied except that of collector dosage and pulp density. The pulp density in this test was 10% by wt solid/liquid ratio and the applied collector dosage was 0.5 kg/Mg. It was found that the recovery of copper increases as pH increases until pH 10, and then begins to decrease.

At pH 10, about 90% of copper in the concentrate (float) of the first flotation stage is recovered in the sink product of the second flotation stage. This test is beneficial in illustrating the possibility of waste treatment of copper processing plants and recovering such an important element. Also, it may be useful for environment protection by removing such a heavy metal from discarded plant wastes.

CONCLUSION

In this study, the recovery of copper from Abu–Swayel (Eastern Desert, Egypt) ore deposit by reverse flotation was attempted. The copper minerals contained in this copper deposit are mainly copper oxide minerals. The important factors that affect such flotation system were studied to determine the optimum conditions. The results showed that the flotation response of copper minerals is poor and it is difficult to recover such copper minerals in froth or float product (concentrate) by direct flotation technique. The reverse flotation technique was applied to float the minerals accompanying minerals such as hematite, silica and others (as a float) and obtaining copper minerals in the sink product. Oleic acid was used as the collector and pine oil was applied as the frother. Encouraging results were obtained since about 90% of copper content at 10% copper grade have been recovered in sink product. The optimum flotation conditions for such a reverse flotation system were obtained and recorded at 1.5 kg/Mg oleic acid collector dosage, pH =10, 7 dm^3/min air flow rate, and 5 min flotation time. Also, it was found that the copper mineral particles which have been lost in the float product (concentrate) due to mechanical carryover mechanism may be recovered by concentrate cleaning under the same flotation conditions.

The results of this work are promising because it may help exploitation of such copper deposit and hence obtaining a high value industrial element. It may be useful also for environment protection since enables removal of heavy metal from discarded wastes.

REFERENCES

ABBAS, M. H., "Extraction of copper from the Egyptian copper ore of Abu – Swayel", Ph.D. Thesis, Mining & Pet. Dept., Faculty of Engineering, Alazhar University, Cairo, 1983.

ACAR, S. SOMASUNDARAN, P. "Effect of dissolved mineral species on the electrokinetic behaviour of sulfides", Minerals Engineering, Vol.5, No 1, 1992, 27-40.

ACKERMAN, P. K. , HARRIS, G. H., KLIMPEL, R. R. APLAN , F.F., "Evaluation of flotation collectors for copper sulfides and pyrite" , Inter. J. of Mineral Processing, 21 (1987), 105 – 127.

APLAN, F. F. FUERSTENAU, D. W.," The flotation of chrysocolla by mercaptan reagents", Inter. J. of Mineral Processing, Vol. 13, issue 2, August 1984, 105 – 115.

FATHY, W.M., "Application of heap leaching technique in hydrometallurgical treatment of Abu – Swayel copper oxide ore", Msc. Thesis, Mining & Pet Dept., Faculty of Engineering, Alazhar University, Cairo, 2005.

HANSON, J.S. FUERSTENAU, D. W., "The electrochemical and flotation behavior of chalcocite and mixed oxide / sulfide ores" , Inter. J. of Mineral Processing, Vol. 33, issue 1-4, Novemmber 1991, 33 – 47.

HEYES , G.W. TRAHAR , W.J., " Natural floatability of chalcopyrite" , Inter. J. of Mineral Processing, 4 (1977), PP. 317 – 344.

HOSTEN, C., TEZCAN, A. "The influence of frother type on flotation kinetics of a massive copper sulfide ore", Minerals Engineering, Vol.3, No 6, 1990, PP. 637-640.

HUSSEIN, A. A., " Mineral deposits of Egypt", In: Geology of Egypt, Said, R. (ed), Balkema Pub. Com., Amsterdam, 1990, 511.

LEPPINEN, J.O., HINTIKKA, V.V., KALAPUDAS, R.P., "Effect of electrochemical control on selective flotation of copper and zinc from complex ores ", Minerals Engineering, Vol. 11, Issue 1, January 1998, 39 –51.

SENIOR, G. D., GUY, P.J., BRUCKARD, W.J., "The selective flotation of energite from other copper minerals – Asingle mineral study in relation to beneficiation of Tampakan deposit in the Philippines", Inter. J. of Mineral Processing, Vol. 81, issue 1, October 2006, 15 – 26.

URIBE-SALAS, A., MARTINEZ, CAVAZOS, T.E., NAVA – ALONSO, F.C., MENDEZ- NONELL, J., LARA – VALENZUELA, C. "Metallurgical improvement of lead / copper flotation by pulp potential control" , Inter. J. of Mineral Processing, Vol. 59, issue 1, Apr. 2000, 69 – 83.

YIANATOS, J.B., BERGH, L.G., AGUILERA , J., " Flotation scale up : use of separability curves", Minerals Engineering, Vol.16, issue 4, April 2003, 347 – 352.

Saleh A.-H. M., Ramadan A. M., Moharam M. R., Wykorzystanie Egipskiej rudy miedziowej z Abu-Swayel metodą flotacji, Physicochemical Problems of Mineral Processing, 42 (2008), 119-130 (w jęz. ang)

W pracy podjęto próbę odzysku miedzi z egipskiego złoża Abu-Swayel. Zastosowano flotację odwrotną polegającą na flotacji towarzyszących tlenków i siarczków, gromadząc minerały tlenkowe miedzi w produkcie tonącym. Stwierdzono, że technika ta jest użyteczna, ale w warunkach optymalnych. Badania głównych czynników wpływających na stosowany układ flotacyjny wskazują, że optymalne warunki flotacji to 1.5 kg/Mg kwasu oleinowego jako kolektora, pH=10, przepływ powietrza 7 dm^3/min a czas flotacji to 5 minut. W tych warunkach otrzymano 10% koncentraty miedziowe przy uzysku około 90%. Stwierdzono także, iż ziarna minerałów miedzi stracone w produkcie pianowym są wynoszone mechanicznie i mogą być odzyskiwane przez czyszczenie koncentratu w tych samych warunkach flotacji. Można zatem powiedzieć, że wyniki tych badań są pozytywne i mogą pomóc przy ponownej ocenie możliwości eksploatacji złóż miedziowych tego typu.

słowa kluczowe: flotacja, wzbogacanie, ruda miedzi, minerały miedzi, tlenki miedzi