Crossref
DOI: 10.31643/2023/6445.06
Metallurgy

Testing of the optimum extragent for solvent-extraction of Almaly deposit copper

[1]Chepushtanova T.A., [1]Yessirkegenov M.I., [1*]Mamyrbayeva K.K., [1]Merkibayev Y.S., [2]Nikolosky A.

[1]Satbayev University, Almaty, Kazakhstan
[2]Murdock University, Pert, Australia

** Corresponding author email: k.mamyrbayeva@satbayev.university*

Received: *April 29, 2022*
Peer-reviewed: *June 3, 2022*
Accepted: *July 15, 2022*

ABSTRACT

For the solvent extraction of copper from pregnant leach solutions, (PLS) a wide range of modern extractants is currently offered on the market, and its choice is a very important issue in the production of copper using the SX-EW (Solvent Extraction and Electrowinning) technology. The purpose of this work was to determine the optimal copper extractant for processing productive solutions of the Almaly deposit using the SX-EW. The studies were carried out with a productive solution obtained by leaching copper ores from the Almaly deposit of composition, g/dm3: 1) Cu–0.262, Fe–17.97, SiO2–0.36. The results of copper extraction from model solutions showed that the maximum extraction of copper (94%) is observed when using the extractant 5% Acorga 5640, while the other extractants did not provide a high degree of extraction of 10% Lix984 - 93%; 10% Acorga 5640 - 91%; 10% Acorga 5910 and 10% Acorga 5747 - 85% each. According to the results of the retraction process, a high degree of copper extraction from the organic phase (90.2 and more) was ensured when using extractants of 5% Acorga 5640, 10% Lix984, and 10% Acorga 5640, the minimum - at 10% Acorga 5910 (88.2%). For the extraction of copper from the productive solution of the Almaly deposit 5% Acorga 5640 was chosen as the optimal extractant.

Keywords: copper, SX-EW technology, Acorga 5640, extraction, selectivity.

Information about authors:

Chepushtanova Tatyana Aleksandrovna	*Candidate of Technical Sciences, Ph.D., Head of Department "Metallurgical processes, heat engineering and technology of special materials", Associate Professor, Mining and Metallurgical Institute, Satbayev University, 22a Satpaev str.050013, Almaty, Kazakhstan. Email: T.Chepushtanova@satbayev.university; ORCID ID: https://orcid.org/0000-0002-6526-0044*
Yessirkegenov Meirbek Ibragimovich	*Ph.D. student, Department "Metallurgical processes, heat engineering and technology of special materials", Mining and Metallurgical Institute, Satbayev University, 22a Satpaev str.050013, Almaty, Kazakhstan. Email: m.yesirkegenov@satbayev.university; ORCID ID: https://orcid.org/0000-0001-8539-1837*
Mamyrbayeva Kulzira Kaldybekovna	*Ph.D., Associate Professor, Department "Metallurgical processes, heat engineering and technology of special materials", Mining and Metallurgical Institute, Satbayev University, Almaty, Kazakhstan. Email: k.mamyrbayeva@ satbayev.university; ORCID ID: https://orcid.org/0000-0002-1094-5345*
Merkibayev Y.S.	*Master's degree, head of laboratories of the JSC "Satbayev University", Mining and Metallurgical Institute, 22a Satpaev str.050013, Almaty, Kazakhstan. Email: y.merkibayev@satbayev.university; ORCID ID: https://orcid.org/0000-0003-3869-6835*
Alexandar Nikolosky	*Associated professor, Murdock University, 90 South St, Murdoch WA 6150, Australia. Email: a_nikoloski@mail.ru; ORCID: https://orcid.org/0000-0002-5267-7262*

Introduction

In recent years, in the production of copper from poor refractory oxidized and transit copper ores, dumps and tailings of concentrating plants, the SX-EW technology, which consists of the stages of leaching, extraction and stripping, and electrowinning, has been increasingly used. The share of copper produced using SX-EW technology in the world has already reached 30% of the total copper production, and this is due to numerous developments in the field of synthesis of selective extractants for copper [[1], [2]].

Currently, the development of the copper ore base in the Republic is associated not only with the commissioning of new rich deposits, but, first of all, with the involvement in the processing of previously unprocessed poor oxidized ores, dumps of substandard ores, overburden mineralized rocks, enrichment tailings, waste from metallurgical production etc. using cost effective SX-EW technology. A typical example of refractory oxidized copper ores is the Almaly porphyry copper deposit.

As the practice of operating plants using SX-EW technology shows, productive solutions obtained by leaching copper ores contain a number of elements, compounds and suspended solids, some of which can create problems during extraction [[3], [4]] and electrolysis [[5], [6]]. The main constituents to be constantly monitored are Cu2+, Fe3+ and/or pH [[7], [8]]. The main undesirable impurities in the productive solution are ions of iron, manganese [[9], [10]], silica [10].

Currently, a number of extractants are offered on the market that meets the highest technological requirements [11], but in each specific case, they must be selected on the basis of preliminary studies. For the extraction recovery of copper at each enterprise of a particular deposit, depending on the composition of the productive solution [[12], [13], [14]], it is first necessary to select the appropriate extractant with high selectivity to copper [[15], [16], [17]]. The purpose of this work was to study the extraction properties of a number of reagents that can be used for the efficient extraction of copper from the productive solutions of the Almaly deposit for the subsequent development of the SX-EW technology.

Experimental part

Studies to determine the selectivity of reagents were carried out with modified extractants of the Acorga series (5747, 5910, 5640) and unmodified Lix 984N reagent. Lighting kerosene brand KO-30 was used as a diluent. Productive solutions of copper ores of the Almaly deposit were obtained by multi-stage non-oxidizing sulfuric acid leaching.

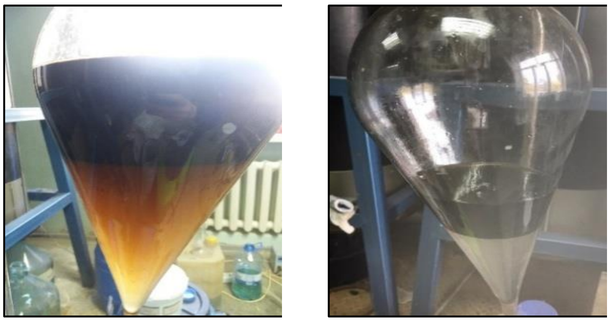
In order to determine the selectivity of each type of extractant, as well as a sample for comparing the duration of phase separation, in addition to the productive solution from the field, a model solution was used. The specified concentration of copper in the model solution was 1 g/l, total iron was 2.4 g/l (Fe2+: Fe3+ ≈ 1:1), the pH was adjusted to 1.7 with sulfuric acid (according to pH = 1.7 in a productive solution). To prepare a model solution, copper sulfate $CuSO4{\cdot}5H_2O$ was used in terms of the molecular fraction of copper (25%) - 4 g/l of copper sulfate to achieve 1 g/l of Cu2+ ions. Iron salts were dissolved in a similar way to achieve the specified concentration of Fe^{2+}/Fe^{3+} ions = 2.4 g/l. Sulfuric acid and sodium hydroxide solutions were used to adjust the pH of the solution. All reagents used to prepare the model solutions were analytical grade. or "h.ch.".'

The content of copper in the solution was determined by iodometric titration, iron - photocolorimetrically. The extraction of metals was calculated from the balance of the distribution of metals between the organic and aqueous phases. To determine the dependence of copper extraction on various parameters, 25 cm3 of a freshly prepared solution of copper sulfate with a concentration of 4 g/dm3 were mixed for 5 minutes with 10% extractants dissolved in kerosene [[18], [19], [20]].

Discussion of the results

Effect of phase separation time on copper extraction one of the main stages of solvent extraction is the separation or separation of phases into an extract and refined [12]. Depending on the composition of the extractant, the duration of separation of the organic and aqueous phases may be different. The larger it is, the more it can lead to a decrease in the efficiency of the process. It is recommended that for hydrometallurgical production of cathode copper using SX-EW technology, the phase separation time should not exceed 30 seconds. This test, under production conditions, is carried out by taking a sample of a mixture of organic matter and an aqueous phase from the mixer chamber, followed by fixing the moment of complete separation. The research results are shown in Figures 1 and 2.

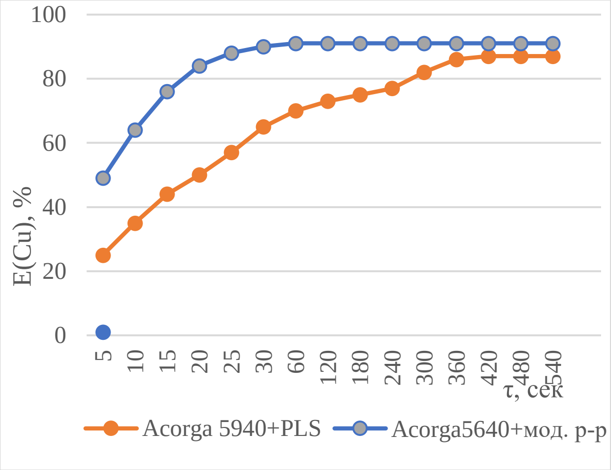
Studies on the extraction of copper were carried out under the following conditions: the concentration of extractants was 10%, the ratio of the aqueous and organic phases O/W=1:1, the duration of mixing of the organic and aqueous phases was 5 minutes, the temperature was 20 °C, pH was 1.7.



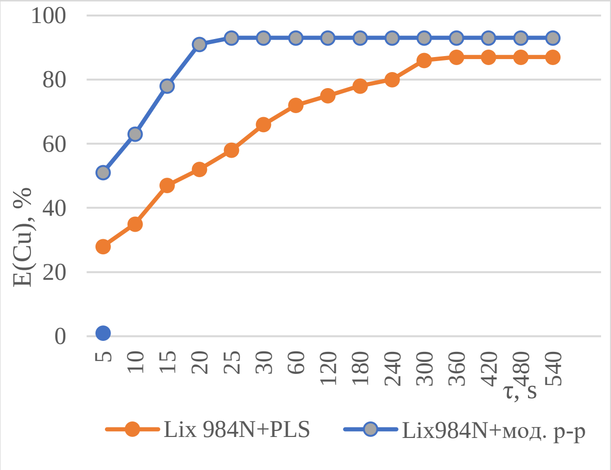
1a - productive solution

1b - model solution

Figure 1 - Separation of organic and aqueous phases, productive and model solutions in a separating funnel



a - the dependence of the degree of extraction of copper on the duration of phase separation during the extraction of copper Acorga 5640



b - Dependence of the degree of extraction of copper on the duration of phase separation during the extraction of copper Lix984N

Figure 2 - Results of copper extraction with Acorga 5640 and Lix984N extractants

The studies carried out to determine the duration of phase separation after extraction led to the following results: the complete separation of the aqueous and organic phases in productive solutions (Fig. 1a) took a longer time (after more than 5-7 minutes), while the complete separation of phases for model solution was reached in 20 seconds (Fig. 1b). In addition to a long phase separation, in the productive solutions, the fuzziness of the interfacial separation was also observed - in the upper layer of the aqueous phase, there were noticeable traces of the third phase, i.e. interfacial suspension "crud".

During the subsequent stripping of the organic phase with a solution of sulfuric acid with a concentration of 200 g/dm^3 and regeneration of the electrolyte by washing the organics with a 20% solution of sulfuric acid, phase separation occurred within the required duration of no more than 30 seconds. At the same time, the electrolyte obtained by washing the organics after the extraction of the productive solution differed markedly in color from the electrolytes obtained by processing the model solutions.

As you know, one of the main parameters affecting the extraction performance is the concentration of the extractant. Often, 10% extractants in various diluents are used as organic phases in production. Most 10% organic extractants are able to accumulate more than 10 g/l of copper and this leads to an increase in the viscosity of the organic phase. Therefore, saturation of the organic phase with copper is desirable not to produce more than 5 g/l. As noted earlier, after stripping, washing, a certain amount of metal will continue to be constantly on the balance in the organic matter. The results of solvent extraction experiments are shown in table 1

Table 1 - Results of copper extraction with various extractants

Extractant name	C(Cu) in ., g/l	C_{Cu} in el. ., g/l	$V_{эл-та}$, l	E_{Cu}, % l	E_{Cu}, % (main)
Acorga 5910 - 10%	2.55	4.5	0.1	88.2	75.0
Acorga 5747 - 10%	2.55	4.6	0.1	90.2	76.7
Acorga 5640 - 10%	2.73	5.0	0.1	91.6	83.3
Acorga 5640 - 5%	2.82	5.25	0.1	93.1	87.5
Lix984 - 10%	2.79	5.14	0.1	92.1	85.7

As the results of copper extraction from the model solution show, the maximum extraction of copper (94%) is observed when using the extractant 5% Acorga 5640, while the extractants 10% Acorga 5910 and 10% Acorga 5747 did not provide a high degree of extraction - the extraction of copper does not exceed 85% in both cases. 10% Acorga 5640 and 10% Lix984 showed relatively high copper recovery of 91% and 93% respectively.

Stripping results

After each extraction stage, the process of copper stripping from the organic phase followed with a sulfuric acid solution with a concentration of 200 g/dm^3 at a ratio of O:B=1:2, the total number of stripping stages was 3. The results of experiments on copper stripping are shown in Table 2.

Table 2 - Results of copper stripping from various organic phases

Extractant name	C_{Cu} in ., g/l	C_{Cu} in ., g/l	E_{Cu}, % during re-extraction	E_{Cu}, % through
Acorga 5910 - 10%	2.55	4.50	88.2	75.0
Acorga 5747 - 10%	2.55	4.60	90.2	76.7
Acorga 5640 - 10%	2.73	5.00	91.6	83.3
Acorga 5640 - 5%	2.82	5.25	93.1	87.5
Lix984 - 10%	2.79	5.14	92.1	85.7

As the results of the retraction process show, a high degree of copper extraction from the organic phase (90.2% or more) was ensured when using extractants 5% Acorga 5640, 10% Lix984 and 10% Acorga 5640, the minimum - with 10% Acorga 5910 (88.2%). To select the optimal extractant, we calculated the residual concentration in various organic phases (Table 3).

Table 3 - Residual concentration of copper in the organic phase after extraction and stripping processes

Residual Cu in org. Phase g/l	Acorga 5910 10 %	Acorga 5747 - 10 %	Acorga 5640 - 10%	Acorga 5640 – 5%	Lix984 - 10%
	0.3	0.25	0.23	0.195	0.22

The data in tables 1, 2, and 3 demonstrate the highest efficiency when using 5% Acorga 5640 extractant - the final transfer of copper from the productive solution to the electrolyte is 87.5%, and at the extraction stage, the extraction of copper into the organic phase is 94%, during stripping - 93.1. For a productive solution with a copper concentration of 1 g/l, the concentration of Acorga 5640 extractant equal to 5% is the best in comparison with 10%, which is due to the transfer mechanism.

Large-scale laboratory studies Studies on the extraction of copper from a productive solution of the composition, g/dm^3: Cu-2.62, Fe-17.97, SiO_2-0.36, were carried out using the extractant 5% Acorga 5640 in kerosene. The composition of the productive solution included the following components, g/dm^3: copper - 0.262; total iron - 17.97, colloidal insoluble silicates - 0.36. The total volume of the solution supplied for extraction was 5000 ml. The ratio O:B=1:1 was set using flows, the number of extraction stages was 3, the pH of the solution was 1.7. The results of the extraction experiments are shown in Table 4.

Table 4 - Results of extraction of the components of the productive solution of the Almaly deposit with 5% extractant Acorga 5640.

Element	C_{Cu2+} in PLS solution , g/l	$C_{Fe\ в}$ Raffinate , g/l	E, %	D	β
Cu^{2+}	0.26	0.006	97.7	43.33	-
$Fe^{3+/2+}$	17.97	15.7	12.6	1.14	Cu/Fe – 37.86
SiO_2	0.36	0.26	27.8	1.38	Cu/SiO_2 - 31.30

The results of extraction studies showed a rather high transition of iron ions and silicate compounds into the organic phase. Despite the high copper extractability of 97.7%, 12.6% of iron and 27.8% of silicate compounds passed into the organic phase from the productive solution.

Comparison of distribution coefficients shows that the extractant has a sufficiently high selectivity, the distribution coefficient of copper ions is high and is 43, compared with iron and silicon (1.14 and 1.38, respectively). Separation factors β (Cu/Fe) = 38 and β (Cu/SiO_2) = 31.

At the stage of stripping from the organic phase, 64% of iron passed into the electrolyte, with an iron concentration of 7.26%. At the same time, the residual concentration of iron in the organic matter was 4.09 g/l. The silicate compounds extracted from the productive solution subsequently also passed into the electrolyte (38%), the rest (62%) polluted the organic phase, forming an interfacial suspension - krad. The residual content of silicate compounds in organic matter was 0.31 g/l.

In addition to the accumulation of crud, an incomplete transition of copper into the electrolyte was also observed at the stage of stripping. This may be due to the fact that part of the copper, along with silicate and iron compounds, entered the formed thief [13], the prevention and removal of which will be studied by us further.

Conclusions

For the processing of productive solutions obtained by leaching of refractory oxidized ores of the Almaly deposit, the SX-EW technology is the most suitable.

Effective extractants of copper from sulfate solutions are the modified extractant Acorga 5640 and unmodified Lix984, from the productive solution of the Almaly deposit composition, g/l: Cu 2, 62; Fe 17.97; SiO2 0.36 - 5% Acorga 5640 extractant.

The best selectivity for Cu2+/(Fe3+/Fe2+) ions is shown by estragents of the Lix984 and Acorga 5640 series (5 and 10%). The use of the extractant - 5% Acorga 5640 allows up to 93.1% to extract copper into the organic phase and avoid the accumulation of iron in it. As a result of 3-stage extraction and stripping of copper from the productive solution with 5% Acorga 5640 extractant, a more concentrated electrolyte was obtained with a copper content of 9.12 g/l.

To prevent and remove the formation of the third phase - steal, it is recommended to add various modifiers, flocculants and additives, the effects of which will be studied in the future.

Cite this article as: Chepushtanova TA, Yessirkegenov MI, Mamyrbayeva KK, Merkibayev YS, Nikolosky A. Testing of the optimum extragent for solvent-extraction of almaly deposit copper. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2023;324(1):43-49. https://doi.org/10.31643/2023/6445.06

Алмалы кенорнындағы мыстың сұйық экстракциясы үшін тиімді экстрагентті анықтау бойынша зерттеулер

[1]Чепуштанова Т.А., [1]Есиркегенов М.И., [1]Мамырбаева К.К., [1]Меркибаев Е.С., [2]НиколоскиА.

[1]Сәтбаев Университеті, Алматы, Қазақстан
[2] Мёрдок Университеті, Перт, Австралия

Мақала келді: *27 сәуір 2022*
Сараптамадан өтті: *03 маусым 2022*
Қабылданды: *15 шілде 2022*

ТҮЙІНДЕМЕ

Мысты шаймалау ерітінділерінен бөліп алу үшін қазіргі уақытта нарықта заманауи экстрагенттердің кең спектрі ұсынылған және оны таңдау мысты SX-EW (Solvent Extraxtion and Electrowinning, Сұйықтық экстракция және электролиз) технологиясымен жұмыс жасайтын өндіру орындарында өте маңызды мәселе болып табылады. Бұл зерттеудің мақсаты Алмалы кенорнының өнімді ерітінділерін сұйықтық экстракция технологиясымен өңдеу үшін оңтайлы мыс экстрагентін анықтау болып табылды. Өнімді ерітінді ретінде Алмалы мыс кендерін концентрациясы 25 г/л күкірт қышқылы ерітіндісімен тотықтырусыз шаймалау нәтижесінде алынған құрамы келесідей ерітінді алынды, г/дм^3: 1) Cu – 0,262 , Fe– 17,97, SiO2 – 0,36. Модельді ерітіндіден мысты бөліп алу нәтижелері келесідей болды: мысты бөліп алу дәрежесі 5% Acorga 5640 экстрагентін пайдаланған кезде максималды болатыны (94%), ал басқа экстрагенттер экстракцияның жоғары дәрежесін қамтамасыз етпейтінін көрсетті: 10% Lix984 - 93%; 10% Acorga 5640 - 91%; 10% Acorga 5910 және 10% Acorga 5747 - әрқайсысында 85%. Реэкстракция процесінің нәтижелері бойынша 5% Acorga 5640, 10% Lix984 және 10% Acorga 5640 экстрагенттерін пайдаланған кезде органикалық фазадан мысты бөліп алудың жоғары дәрежесі (90,2 және одан да көп) қамтамасыз етілді, ал 10% Acorga 5910 жағдайында бұл көрсеткіш минималды (88,2%) болды. Алмалы кенорнының өнімді ерітіндісінен мысты экстракциямен бөліп алу үшін тиімді экстрагент ретінде 5% Acorga 5640 таңдалды.

Түйін сөздер: мыс, SX-EW технологиясы, Acorga 5640, экстракция, селективтілік

	Информация об авторах:
Чепуштанова Татьяна Александровна	*Қауымдастырылған профессор, т.ғ.к., PhD докторы, «Металлургиялық процестер, жылутехника және арнайы материалдар технологиясы» кафедрасының меңгерушісі, Тау-кен металлургия институты, Сәтбаев Университеті, Алматы қ., Қазақстан. Email: T.Chepushtanova@satbayev.university; ORCID ID: https://orcid.org/0000-0002-6526-0044*
Есиркегенов Мейрбек Ибрагимович	*Ph.D докторанты, «Металлургиялық процестер, жылутехника және арнайы материалдар технологиясы» кафедрасы, Тау-кен металлургия институты, Сәтбаев Университеті, Алматы қ., Қазақстан. Email: m.yesirkegenov@satbayev.university; ORCID ID: https://orcid.org/0000-0001-8539-1837*
Мамырбаева Кульзира Калдыбековна	*PhD докторы, «Металлургиялық процестер, жылутехника және арнайы материалдар технологиясы» кафедрасының қауымдастырылған профессор, Тау-кен металлургия институты, Сәтбаев Университеті, Алматы қ., Қазақстан. Email: k.mamyrbayeva@ satbayev.university; ORCID ID: https://orcid.org/0000-0002-1094-5345*
Меркибаев Ерик Серикович	*Магистр, «Металлургиялық процестер, жылутехника және арнайы материалдар технологиясы» кафедрасының оқу зертханаларының меңгерушісі, Тау-кен металлургия институты, Сәтбаев Университеті, Алматы қ., Қазақстан. Email: y.merkibayev@satbayev.university; ORCID ID: https://orcid.org/0000-0003-3869-6835*
Александар Николоски	*Қауымдастырылған профессор, Мёрдок Университеті, Перт, Австралия. Email: a_nikoloski@mail.ru; ORCID: https://orcid.org/0000-0002-5267-7262*

Исследования по определению оптимального экстрагента для жидкостной экстракции меди месторождения Алмалы

[1]Чепуштанова Т.А., [1]Есиркегенов М.И., [1]Мамырбаева К.К., [1]Меркибаев Е.С., [2]Николоски А.

[1]Satbayev University, Алматы, Казахстан
[2] Университет Мёрдок, Перт, Австралия

Поступила: *29 апреля 2022*
Рецензирование: *03 июня 2022*
Принята в печать: *15 июля 2022*

АННОТАЦИЯ

Для экстракции меди из растворов выщелачивания в настоящее время на рынке предлагается большой ассортимент современных экстрагентов и его выбор является весьма важной проблемой в производстве меди по технологии SX-EW (Solvent Extraxtion and Electrowinning; Жидкостная экстракция и Электролиз). Целью настоящей работы явилось определение оптимального экстрагента меди для переработки продуктивных растворов месторождения Алмалы. Исследования проводились продуктивным раствором, полученный выщелачиванием медных руд месторождения Алмалы состава, г/дм3: 1) Cu – 0,262, Fe –17,97, SiO2 – 0,36. Результаты экстракции меди из модельных растворов показали, что максимальное извлечение меди (94%) наблюдается при использовании экстрагента 5% Acorga 5640, тогда как остальные экстрагенты не обеспечили высокую степень экстракции: 10% Lix984 - 93%; 10% Acorga 5640 - 91%;10% Acorga 5910 и 10% Acorga 5747 – по 85%. По результатам процесса реэкстракции высокая степень извлечения меди из органической фазы обеспечивалась при использовании экстрагентов 5% Acorga 5640, 10% Lix984 и 10% Acorga 5640, минимальное – при 10%Acorga 5910. Для экстракции меди из продуктивного раствора месторождения Алмалы в качестве оптимального экстрагента был выбран 5 % Acorga 5640, показавший лучшие показатели.

Ключевые слова: медь, технология SX-EW, Acorga 5640, экстракция, селективность

	Информация об авторах:
Чепуштанова Татьяна Александровна	*Ассоциированный профессор, кандидат технических наук, PhD доктор, ассоциированный профессор, заведующая кафедрой «Металлургические процессы, теплотехника и технология специальных материалов», Горно-металлургический институт, Satbayev University, Алматы, Казахстан. Email: T.Chepushtanova@satbayev.university; ORCID ID: https://orcid.org/0000-0002-6526-0044*
Есиркегенов Мейрбек Ибрагимович	*Докторант Ph.D, «Металлургические процессы, теплотехника и технология специальных материалов», Горно-металлургический институт, Satbayev University, Алматы, Казахстан. Email: m.yesirkegenov@satbayev.university; ORCID ID: https://orcid.org/0000-0001-8539-1837*
Мамырбаева Кульзира Калдыбековна	*PhD доктор, ассоциированный профессор кафедры «Металлургические процессы, теплотехника и технология специальных материалов», Горно-металлургический институт, Satbayev University, Алматы, Казахстан. Email: k.mamyrbayeva@ satbayev.university; ORCID ID: https://orcid.org/0000-0002-1094-5345*
Меркибаев Ерик Серикович	*Магистр, заведующий учебными лабораториями кафедры «Металлургические процессы, теплотехника и технология специальных материалов», Горно-металлургический институт, Satbayev University, Алматы, Казахстан. Email: y.merkibayev@satbayev.university; ORCID ID: https://orcid.org/0000-0003-3869-6835*
Александар Николоски	*Ассоциированный профессор, Университет Мёрдока, Перт, Австралия. Email: a_nikoloski@mail.ru; ORCID: https://orcid.org/0000-0002-5267-7262*

References

[1] Kreyn F. Ekstraktsiya v gidrometallurgii medi: Razvitiye i sovremennoye sostoyaniye [Extraction in copper hydrometallurgy: Development and current state]. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2004;2:36-55. (in Russ).

[2] Mark E Schlesinger. Extractive Metallurgy of Copper - Sixth Edition. 2022;407-436.

[3] Virnig MJ, Olafson SM, Kordosky GA, and Wolfe GA. Crud formation: field studies & fundamental studies, Henkel Corporation, Arizona. 1999.

[4] Zheng Qi 2007. Influences of solid particles on the formation of the third phase crud during solvent extraction. Rare Metals. 2007;26(1):89-96.

[5] BEDNARSKI T. Behavior of iron and manganese in electrowinning solutions – a Hull cell study. Tucson SME, December, 2008. Cytec Industries Inc.

[6] Jovana Djokić, Dragana Radovanović, Zlatko Nikolovski, Zoran Andjić, Željko Kamberović. Influence of Electrolyte Impurities from E-Waste Electrorefining on Copper Extraction Recovery. Metals. 2021;11(9):1383.

[7] Liu Jian-she, Lan Zhuo-yu, Qiu Cuan-zhou, Wang Dian-zuo. Mechanism of crud formation in copper solvent extraction”, School of Resources Processing and Bioengineering, Central South University, Changsha 410083, China.

[8] Cupertino DC, Charlton MH, Buttar D, Swart RM. A study of copper/iron separation in modern solvent extraction plants. Copper. ed. SK Young, DB Dreisinger, RP Hackl, DG Dixon. Montreal Quebec: Canadian Institute of Mining, Metallurgy and Petroleum. Phoenix; Arizona. 1999;10-13:263-276.

[9] Miller G. Methods of managing manganese effects on copper SX-EW plants. Proceedings of the ALTA 2010 Nickel Cobalt Copper Conference. ALTA Metallurgical Services, Melbourne, Australia, 2010.

[10] Liu Jian-she, Lan Zhuo-yu, Qiu Cuan-zhou, Wang Dian-zuo. Mechanism of crud formation in copper solvent extraction", School of Resources Processing and Bioengineering, Central South University, Changsha 410083, China.

[11] Ruiz MC, Risso J, Seguel J, Padilla R. Solvent extraction of copper from sulfate-chloride solutions using mixed and modified hydroxyoxime extractants. Minerals Engineering. 2020;146:106109. https://doi.org/10.1016/j.mineng.2019.106109.

[12] Ritcey G M, Ashbrook A W. Solvent extraction: principles and applications to process metallurgy. Amsterdam by Elsevier. 1984;1.

[13] Chepushtanova TA, Yessirkegenov M, Mamyrbaeva KK, Nikoloski A, Luganov VA. Interphase formations in copper extraction systems. Journal of mining and geological sciences. 2020; 63:25-31.

[14] Murashova NM, Yurtov EV. State of the Art and Prospects for Studies of Structure Formation in Extraction Systems with Metal Compounds. Theoretical Foundations of Chemical Engineering. 2022;56(1):53-68.

[15] Li Y, Liu L, Wei Q, Ren X, An M. Highly selective separation of acetic acid and hydrochloric acid by alkylamide based on double hydrogen bond coupling mechanism. Separation and Purification Technology 275,119110, 2021.

[16] Ahmadov IA, Pashajanov AM. Spectrophotometric Research Into Multi-Ligand Complexes Formed By Zirconium (Iv) With Stilbazole And Cetylpyridinium Chloride. Chemical Problems. 2021;9(4):241-249.

[17] Golubina E, Kizim N, Alekseeva N. Intensification of the extraction of rare earth elements at the local mechanical vibration in the interfacial layer. Chemical Engineering and Processing - Process Intensification. 2018;132:98-104.

[18] Val'kov AV, Khmelevskaya ND. Extraction of rare-earth elements by mixes of isomers of tributylphosphate with nitrate trialkylmethylammonium. ChemChemTech. 2018;61(7):55-61.

[19] Sumit Verma, Yuki HamasakiYuki Hamasaki, Chaerin Kim, Wenxin Huang, Shawn Lu, Huei-Ru Molly Jhong, Andrew A. Gewirth, Tsuyohiko Fujigaya, Naotoshi Nakashima, and Paul J. A. Kenis. Insights into the Low Overpotential Electroreduction of CO2 to CO on a Supported Gold Catalyst in an Alkaline Flow Electrolyzer. ACS Energy Letters. 2018;3(1):193-198. https://doi.org/10.1021/acsenergylett.7b01096

[20] Wang S, Yin N, Li Y et al. Copper-based metal-organic framework impedes triple-negative breast cancer metastasis via local estrogen deprivation and platelets blockade. Nanobiotechnol. 2022;20:313. https://doi.org/10.1186/s12951-022-01520-8