METALLURGY OF NON-FERROUS METALS / МЕТАЛЛУРГИЯ ЦВЕТНЫХ МЕТАЛЛОВ

UDC 669.334.6
https://doi.org/10.17073/0021-3438-2025-1-5-13

Research article
Научная статья

Pilot tests for processing oxidized copper ores from the Erdenetiin Ovoo deposit using heap leaching

S. Gantulga[1], **Ts. Tsend-Ayush**[2], **B. Altantuyaa**[1], **S.V. Mamyachenkov**[3]

[1] **Mongolian University of Science and Technology**
34 Sukhebator Str., Ulaanbaatar 14191, Mongolia

[2] **SOE "Erdenet Enterprise"**
Friendship Square, Erdenet, Orkhon aimag 61027, Mongolia

[3] **Ural Federal University n.a. the First President of Russia B.N. Eltsin**
19 Mira Str., Ekaterinburg 620002, Russia

✉ Sergey V. Mamyachenkov (svmamyachenkov@yandex.ru)

Abstract: In the current context of declining reserves of high-grade copper sulfide ores, oxidized ores are becoming an important source of mineral raw materials containing non-ferrous and precious metals. Traditional flotation processing of these ores results in low-grade concentrates with poor metal extraction rates (40–60 %). Heap leaching is considered the most promising method for processing such ores. As a result of prolonged intensive mining at the Erdenetiin Ovoo deposit (Erdenet, Mongolia), approximately 800 million tonnes of oxidized ore dumps with an average copper content of 0.45–0.48 % have accumulated within the open-pit boundary. Global experience in processing such secondary raw materials demonstrates the high economic efficiency of copper extraction through heap leaching, followed by solvent extraction and electrowinning (SX-EW) of copper from the pregnant leach solution. For the State-owned Enterprise Erdenet, it is essential to conduct leaching studies on oxidized ores and pilot testing of this technology on the ore from existing ore dumps. To achieve this, 35 boreholes were drilled in the dumps (16 in dump No. 8a and 19 in dump No. 12), from which core samples were collected. The mineralogical composition of the oxidized copper ore samples was analyzed, and the effect of heap leaching parameters (ore particle size, solution acidity, etc.) on copper recovery into the pregnant leach solution was determined. To more accurately assess the recoverable copper from the two dumps, composite samples were collected from each borehole, and large-scale heap leaching tests were conducted in 30 open-cycle columns. The test results showed that copper extraction rate from dump No. 8a ranged from 35.8 % to 69.1 %, with an average of 56.0 %, while dump No. 12 exhibited extraction rates ranging from 51.8 % to 77.4 %, with an average of 63.6 %.

Keywords: Erdenetiin Ovoo oxidized copper ore, mineralogical analysis, heap leaching, sulfuric acid consumption, particle size, copper extraction.

For citation: Gantulga S., Tsend-Ayush Ts., Altantuyaa B., Mamyachenkov S.V. Pilot tests for processing oxidized copper ores from the Erdenetiin Ovoo deposit using heap leaching. *Izvestiya. Non-Ferrous Metallurgy*. 2025;31(1):5–13.
https://doi.org/10.17073/0021-3438-2025-1-5-13

Полупромышленные испытания переработки окисленных медных руд месторождения Эрдэнэтийн Овоо методом кучного выщелачивания

С. Гантулга[1], Ц. Цэнд-Аюуш[2], Б. Алтантуяа[1], С.В. Мамяченков[3]

[1] **Монгольский университет науки и технологии**
Монголия, 14191, Улан-Батор, ул. Сухэбатора, 34

[2] **ПГС «Предприятие Эрдэнэт»**
Монголия, 61027, Орхонский аймак, г. Эрдэнэт, Площадь Дружбы

[3] **Уральский федеральный университет им. первого Президента России Б.Н. Ельцина**
Россия, 620002, г. Екатеринбург, ул. Мира, 19

✉ Сергей Владимирович Мамяченков (svmamyachenkov@yandex.ru)

Аннотация: В современных условиях сокращения запасов богатых медных сульфидных руд источником минерального сырья, содержащего цветные и благородные металлы, становятся окисленные руды. При их переработке традиционным флотационным методом получают низкосортные концентраты при низком (40–60 %) извлечении металлов. Наиболее перспективным направлением переработки подобных руд является кучное выщелачивание. В результате многолетней интенсивной эксплуатации месторождения Эрдэнэтийн Овоо (г. Эрдэнэт, Монголия) в контуре карьера накоплено около 800 млн т отвалов окисленной руды со средним содержанием меди 0,45–0,48 %. Мировой опыт переработки такого техногенного сырья показывает высокую экономическую эффективность извлечения меди методом кучного выщелачивания с последующим извлечением меди из продуктивного раствора по технологии «экстракция–электролиз». Для ПГС «Предприятие Эрдэнэт» актуально проведение исследований выщелачивания окисленных руд и укрупненных испытаний технологии на руде существующих отвалов. Для решения поставленной задачи в отвалах пробурено 35 скважин (16 – в отвале № 8а и 19 – в отвале № 12), из которых получены керновые пробы. Изучен минералогический состав проб окисленной медной руды, определено влияние условий кучного выщелачивания (крупности руды, кислотности раствора и др.) на показатели перевода меди в продуктивный раствор. Для более точного определения количества меди, которое можно получить методом выщелачивания из двух отвалов, из каждой скважины отобрана составная (композитная) проба и в 30 колоннах проведены укрупненные испытания кучного выщелачивания в открытом цикле. В результате этих испытаний для отвала № 8а извлечение меди составило от 35,8 до 69,1 % (среднее значение – 56,0 %), а для отвала № 12 – варьировалось в диапазоне 51,8–77,4 % (среднее значение – 63,6 %).

Ключевые слова: окисленная медная руда Эрдэнэтийн Овоо, минералогический анализ, кучное выщелачивание, расход серной кислоты, крупность, извлечение меди.

Для цитирования: Гантулга С., Цэнд-Аюуш Ц., Алтантуяа Б., Мамяченков С.В. Полупромышленные испытания переработки окисленных медных руд месторождения Эрдэнэтийн Овоо методом кучного выщелачивания. *Известия вузов. Цветная металлургия*. 2025;31(1):5–13. https://doi.org/10.17073/0021-3438-2025-1-5-13

Introduction

As of January 1, 2022, the geological services of the state-owned mining and processing enterprise Erdenet Mining Corporation (Mongolia) estimated the reserves of oxidized copper ore in dumps No. 8a and 12 of the Erdenetiin Ovoo deposit at 49.0 million tonnes, with an average copper content of 0.48 %. In the near future, Erdenet Mining Corporation plans to construct a cathode copper production plant to process oxidized ore using the Heap Leach — Solvent Extraction/Electrowinning (HL-SX/EW) technology.

Mined ore that did not meet processing grade requirements was stockpiled in dumps No. 8a and 12 over many years. This long-term accumulation led to significant alterations in the ore properties due to natural environmental factors such as precipitation, wind, and temperature fluctuations. Representative samples were collected to determine copper content, phase composition, the suite of minerals present in the ore, and their solubility. These data were then used to forecast the potential technical and economic indicators of heap leaching for this material.

The hydrometallurgical heap leaching (HL-SX/EW) technology is considered one of the most promising methods for processing oxidized copper ore due to its low-cost and environmentally friendly characteristics [1—3]. Erdenet Mining Corporation aims to build a cathode copper production facility based on this process, using ore extracted from waste dumps [4; 5].

The ore in dumps No. 8a and 12 has a relatively high copper content (0.48 %). Since this oxidized ore was stockpiled over an extended period, it exhibits a high degree of oxidation influenced by natural weathering and climate conditions. Preliminary leaching tests on these dumps have been conducted since 2014 by institutions such as the Chinese BGRIMM Institute and the Technological Research Laboratory (TRL) of MAK LLC (Russia). Samples for these tests were collected from the dump surface using an excavator bucket at depths of 2.0—2.8 m. Consequently, the representativeness of these samples is considered insufficient [6; 7]. Column leaching tests conducted by BGRIMM established that copper extraction rates of 40—50 % could be achieved. Meanwhile, TRL tests, which employed additional leaching enhancement techniques, indicated that leaching could extract between 35 % and 80 % of the total copper into the pregnant leach solution. These results highlight a broad range of potential copper extraction rates [8; 9].

To obtain more accurate data, semi-industrial-scale tests were performed using samples from 35 boreholes drilled in dumps No. 8a and 12 at depths ranging from 18 to 75 m. These samples exhibited high representativeness, and composite samples were prepared based on the weight ratio of each borehole. These composite samples were then subjected to heap leaching in large-scale test columns (30 columns).

Sample preparation

Core samples from dumps No. 8a and 12 were screened through a 75 mm mesh sieve. The +75 mm fraction was crushed using a jaw crusher with a 35 mm discharge gap to achieve a particle size of –75 mm (100 % passing) for heap leaching tests.

The sequence of sample preparation and chemical analysis is shown in Fig. 1.

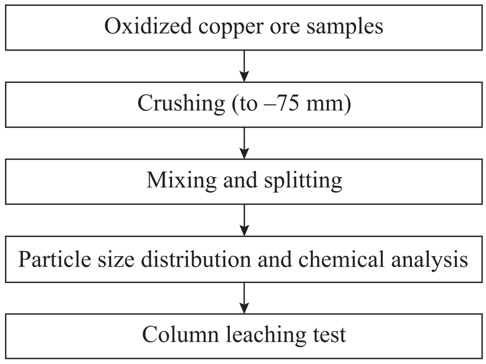

Fig. 1. Sequence of sample preparation and chemical analysis

Рис. 1. Последовательность пробоподготовки и химического анализа

Pilot column leaching tests

Pilot column leaching tests were conducted in accordance with widely used methodologies [10—12]. Copper extraction depends on numerous factors, such as the particle size distribution of the ore, total copper content, the distribution of primary sulfide and oxidized copper, mineral composition, temperature and leaching duration, initial solution concentration, and the flow rate of the diluted sulfuric acid solution [13—15].

The column leaching tests were carried out under the following conditions:

— ore particle size: 100 % passing –75 mm (with 80 % of the fraction in the range of 17.8—33.1 mm, corresponding to P_{80});

— leaching duration: 93—95 days;

— sulfuric acid concentration: 20 g/dm^3 during the first 5 days, 15 g/dm^3 from days 6 to 10, 10 g/dm^3 from days 11 to day 40, and 5 g/dm^3 for the remaining period;

— leachate application rate: 6.1 dm^3/(m^2·h);

— acid leaching method: uniform distribution from the top of the column;

— number of columns: 30.

The schematic diagram of the column leaching tests is shown in Fig. 2.

When the copper leaching rate slowed down, the process was halted by stopping the supply of the leaching solution. This was followed by rinsing with clean water for 24 h to drain the residual solution. After drainage, the moist ore samples were extracted from the columns, air-dried in an open area, screened using the standard method, and composite samples (collected while maintaining the ratio of the original sample and ore particle size) were analyzed for each fraction.

Mineralogical analysis

The results of the copper speciation analysis indicate that in dump No. 8a, the content of primary copper is 31.1 %, secondary copper is 42.9 %, and oxidized copper

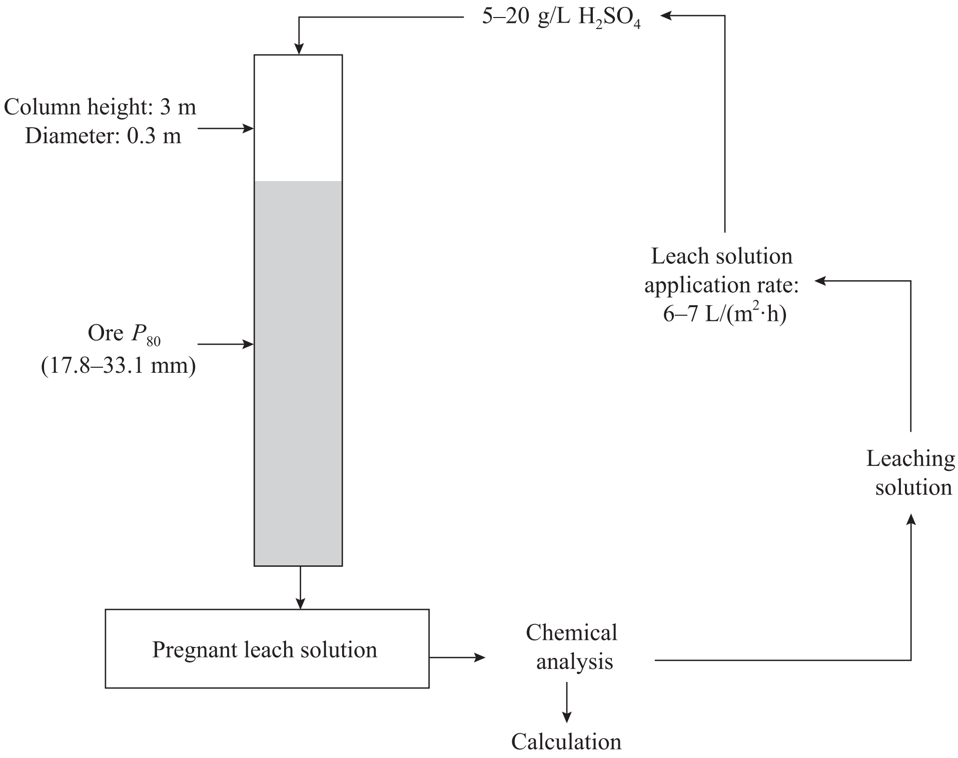

Fig. 2. Schematic diagram of the leaching tests

Рис. 2. Схема проведения испытаний

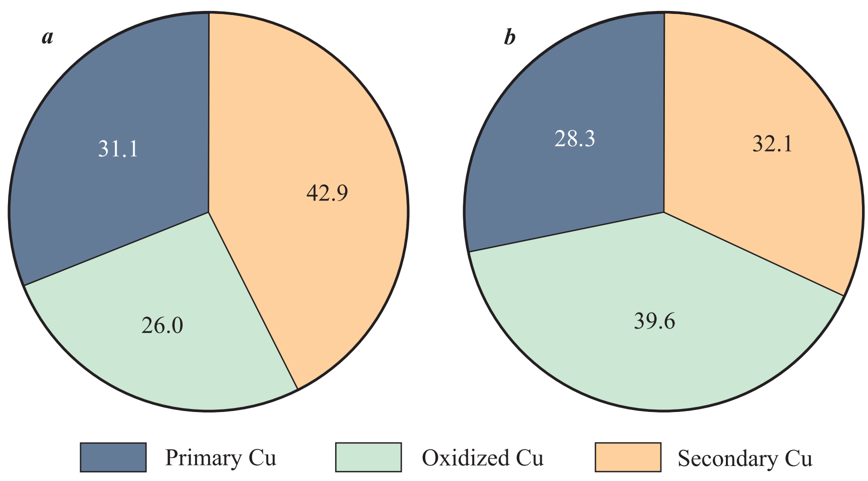

Fig. 3. Diagram of copper phase analyzes (%) in dumps No. 8a (***a***) and No. 12 (***b***)

Рис 3. Диаграмма анализов (%) медной фазы в отвалах № 8а (***a***) и 12 (***b***)

is 26.0 %. In dump No. 12, the average content of primary copper is 28.3 %, secondary copper is 32.1 %, and oxidized copper is 39.6 % (Fig. 3).

The results of the analysis of host rocks and ore minerals, conducted using *X*-ray diffraction (XRD) and a automated mineral analyzer (TIMA), are presented in Table 1.

The mineral composition of each dump differed significantly in the content of major rock-forming minerals such as quartz, plagioclase, potassium feldspar, muscovite, and pyrite, while the content of other minerals was similar.

Copper minerals are present as aggregates tightly intergrown with the gangue matrix. Spatially, covellite tends to displace and replace chalcopyrite and pyrite grains within the gangue matrix.

Table 1. **Mineral composition (%) of dumps No. 8a and 12**

Таблица 1. Минеральный состав (%) отвалов № 8а и 12

No.	Type	Mineral composition	Dump No.	
			8a	12
1	Gangue minerals	Quartz	25.8	28.7
2		Plagioclase	37.4	29.7
3		Feldspar	9.2	6.8
4		Muscovite	15.7	18.1
5		Clay minerals	7.43	13.05
6		Carbonates	0.36	0.35
7		Other minerals	1.27	1.34
8	Ore minerals	Pyrite	1.48	0.66
9		Copper-bearing minerals	0.82	0.76
10		Hematite	0.32	0.36
11		Sphalerite	0.13	0.14
12		Molybdenite	0.02	0.01
			100	100

Results of pilot column leaching tests

The relationship between copper extraction rate and leaching time is shown in Fig. 4.

It is evident that for the oxidized ore dumps No. 8a and 12, the copper dissolution process proceeded relatively quickly during the first 17 days, after which it began to stabilize.

Fig. 5 illustrates the total copper recovery, as well as copper extraction rate averaged for each phase and across different particle size classes.

A general trend observed is that oxidized copper minerals exhibit good solubility across all particle size classes, while primary and secondary sulfide copper minerals show relatively lower dissolution rates. Copper extraction rate into the solution is highest for samples with a particle size of –6.3 mm. For particle sizes ranging from –25 mm to +6.3 mm, the copper extraction can be described as moderate, while for coarser particles, it is minimal. This behavior is attributed to the fact that the leaching rate in a heterogeneous system strongly depends on the reactive surface area. Additionally, due to the large number of copper mineral particles in the finer fractions—liberated from the rock-forming materials—favorable conditions are created for effective interaction with sulfuric acid. This, in turn, enhances the leaching process [16—20].

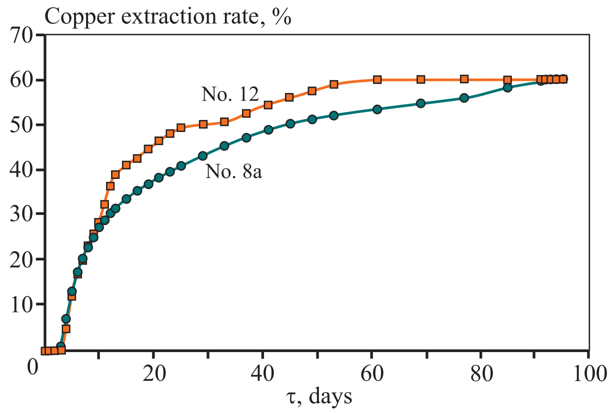

Fig. 4. Copper extraction rate during the leaching process

Рис. 4. Извлечение меди в процессе выщелачивания

For the pilot column leaching test samples, copper extraction values were calculated, chemical analyses were conducted, and the particle size distribution of the loaded samples (P_{80}) from dumps No. 8a and 12 was determined. The results are presented in Tables 2 and 3.

For dump No. 8a, copper extraction rate ranged from 35.8 % to 69.1 % with sulfuric acid consumption between 2.0 and 22.6 kg/t (average value — 23.11 kg/t). The ore particle size, represented by the P_{80} value (the sieve size through which 80% of the material passes), ranged from 17.8 to 33.1 mm. In dump No. 12, copper extraction rate ranged from 51.81 % to 77.4 %, with sulfuric acid consumption between 22.8 and 24.6 kg/t (average consumption — 23.3 kg/t), and the P_{80} value ranged from 18.1 to 29.3 mm.

Copper extraction rate was calculated using two methods based on the copper content in the leaching residue and the pregnant leach solution [21]:

— comparing the copper content in the leaching residue with the copper content in the pre-leaching samples;

— comparing the amount of copper in the total solution collected during leaching with the amount of copper in the pre-leaching sample.

Conclusions

1. Previously, the average copper content in the oxidized ore dumps No. 8a and 12 of the Erdenetiin Ovoo deposit was estimated using Micromine software at 0.47—0.49 %, with a degree of oxidation of 14.7—20.5 %. According to the results of this study, the average copper content was found to be 0.30—0.38 %, and the oxidation degree ranged from 25.6 % to 41.2 %. This demonstrates the influence of natural factors on changes in ore pro-

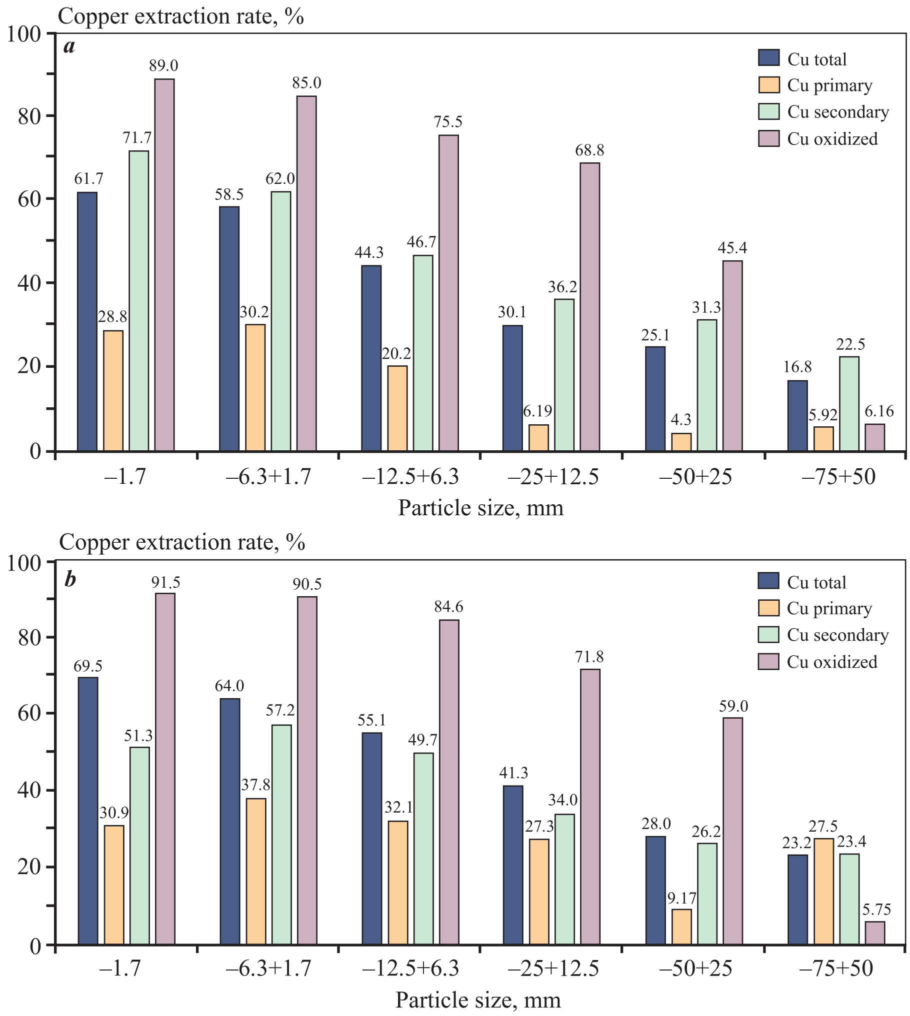

Fig. 5. Diagram of total copper recovery and copper extraction rate by particle size fraction for dump No. 8a (***a***) and dump No. 12 (***б***)

Рис. 5. Диаграмма общего извлечения меди и извлечения меди по каждой фракции для отвала № 8а (***a***) и отвала № 12 (***b***)

perties within the dumps. It was established that the oxidation rate of dump ores in the Erdenet region exceeds 0.6 % per year.

2. Based on the pilot column leaching tests, copper extraction rate ranged from 35.8 % to 69.0 % for dump No. 8a, with an average of 56.0 %, and from 51.8 % to 77.4 % for dump No. 12, with an average of 63.6 %. Since dump No. 12 has a higher oxidation degree, its copper extraction rate was also higher compared to dump No. 8a.

3. In borehole samples from dumps No. 8a and 12, the quartz content was 25.86 % and 29.46 %, plagioclase — 37.46 % and 34.72 %, potassium feldspar — 9.21 % and 6.88 %, muscovite — 15.74 % and 18.05 %, and pyrite — 1.48 % and 0.66 %, respectively. Summarizing the mineral composition for each dump revealed significant differences in the content of major rock-forming minerals (quartz, plagioclase, potassium feldspar, and muscovite), while the content of other minerals was similar. dump No. 8a showed higher pyrite content and the presence of sulfide minerals with relatively larger particle sizes. A distinctive feature of dump No. 12 samples was the relatively low number of pyrite particles, reduced grain sizes of sulfide minerals, and chalcopyrite observed as rims surrounded by secondary copper minerals.

4. Particle size and copper phase distribution significantly affect copper extraction rate during heap leaching. For both dumps, approximately 60 % of the total dissolved copper was extracted from the –1.7 mm size fraction, which accounted for less than 30 % of the total ore weight. However, the recovery of coarse fractions during screening and the copper extraction rate from coarse-grained fractions remained low.

5. It was determined that when the mass fraction of fine particles (–1.7 mm) exceeds 30 %, there is an increased risk of reduced solution permeability. Fine-

Table 2. **Generalized test results (dump No. 8a)**

Таблица 2. Обобщенные результаты испытаний (отвал № 8а)

No.	Time, days	Particle size P_{80}, mm	Cu_{total}	Phase analysis, %			Fe_{total}	Extraction, %	
				Cu_{prim}	Cu_{ox}	Cu_{sec}		Cu	Fe
1	95	18	0.36	26.4	25.6	48.0	3.17	54.5	2.5
2	95	25	0.26	29.3	27.4	42.9	3.28	61.7	3.4
3	95	22	0.29	28.1	31.5	40.1	2.91	68.1	8.3
4	95	18	0.34	35.2	34.6	29.9	2.96	50.8	4.1
5	95	27	0.45	20.3	27.1	52.6	2.56	69.1	10.5
6	95	33	0.29	34.3	23.1	42.7	2.84	61.0	8.7
7	95	21	0.32	25.0	36.4	38.6	2.63	54.7	8.6
8	95	25	0.28	28.3	20.4	51.3	3.27	57.3	5.1
9	95	25	0.27	35.1	18.7	46.3	2.96	46.5	6.6
10	93	22	0.25	37.5	15.1	47.4	2.99	47.5	8.6
11	93	21	0.32	26.7	32.6	40.7	3.11	60.7	6.0
12	95	18	0.27	46.4	16.1	37.1	3.31	35.8	8.4
13	95	19	0.25	34.4	24.3	41.3	3.10	50.0	6.4
14	93	20	0.29	18.9	25.2	55.9	3.61	66.1	10.2
Average values		**22**	**0.30**	**30.5**	**25.6**	**43.9**	**3.05**	**56.0**	**7.0**

Table 3. **Generalized test results (dump No. 12)**

Таблица 3. Обобщенные результаты испытаний (отвал № 12)

No.	Time, days	Particle size P_{80}, mm	Cu_{total}	Phase analysis, %			Fe_{total}	Extraction, %	
				Cu_{prim}	Cu_{ox}	Cu_{sec}		Cu	Fe
1	95	19	0.29	22.3	58.9	18.8	2.35	72.0	6.0
2	95	22	0.37	27.4	29.1	43.5	2.76	54.0	13.0
3	95	25	0.33	24.8	40.2	35.0	2.84	63.7	10.4
4	95	27	0.44	28.7	33.7	37.6	2.47	62.9	10.3
5	95	25	0.55	26.2	46.2	27.6	2.83	65.4	11.8
6	95	29	0.60	23.7	42.1	33.9	3.29	67.3	7.6
7	95	21	0.37	27.9	33.0	38.9	2.74	55.4	8.1
8	95	23	0.27	30.8	40.2	28.9	2.99	60.9	6.0
9	95	19	0.42	25.3	45.2	29.6	2.92	77.4	7.8
10	95	24	0.34	28.4	39.5	32.5	2.59	67.0	9.4
11	95	18	0.45	20.4	50.0	29.6	3.10	60.6	5.8
12	95	21	0.40	22.7	46.3	31.0	2.93	60.9	9.9
13	95	24	0.31	36.5	32.3	31.6	2.21	59.2	9.8
14	95	29	0.42	23.9	35.4	40.7	2.00	67.6	14.8
15	95	21	0.28	32.0	34.5	33.8	2.64	51.8	10.0
16	95	23	0.28	33.9	50.9	15.2	2.57	71.2	9.4
Average values		**23**	**0.38**	**27.1**	**41.1**	**31.8**	**2.70**	**63.6**	**9.4**

grained materials, which have a significant impact on copper extraction rate, may undergo agglomeration to improve solution permeability and enhance copper extraction rate.

6. Based on the pilot column leaching test results conducted on ores from the Erdenetiin Ovoo deposit, it is necessary to develop a mathematical model [22] that defines the relationships between factors affecting copper extraction rate. This model will be used to explore the possibility of achieving efficient copper extraction through heap leaching in a shorter time frame.

References

1. Purevdash M. Prospects for hydrometallurgical processing of oxidized copper ores and sulfide copper concentrates as an integral part of the new technology for complex processing of the Erdenetiin Ovoo deposit. *Zapiski Gornogo Instituta*. 2011;189:313—316. (In Russ.).
   Пурэвдаш М. Перспективы гидрометаллургической переработки окисленных медных руд и сульфидных медных концентратов как составная часть новой технологии комплексной переработки месторождения «Эрдэнэтийн Овоо». *Записки Горного института*. 2011;189:313—316.
2. Bartos P.J. SX-EW copper and the technology cycle. *Resources Policy*. 2002;28(3-4):85—94.
   https://doi.org/10.1016/S0301-4207(03)00025-4
3. Ansah E.O., Jyoti A., Black J.R., Haese R.R. The importance of reaction mechanisms and coupled dissolution with reprecipitation (CDR) reactions when modelling copper leaching in heap systems. *Minerals Engineering*. 2023;203:108357.
   https://doi.org/10.1016/j.mineng.2023.108357
4. Trujillo J.Y., Cisternas L.A., Galves E.D., Mellado M.E. Optimal design and planning of heap leaching process. Application to copper oxide leaching. *Chemical Engineering Research and Design*. 2014;92(2): 308—317.
   https://doi.org/10.1016/j.cherd.2013.07.027
5. Mortazavi A., Abbasloo Z., Ebrahimi L., Keshavars A., Masoomi A. Geotechnical investigation and design of leaching heap No. 2, Meydook copper mine, Iran. *Minerals Engineering*. 2015;79:185—195.
   https://doi.org/10.1016/j.mineng.2015.06.010
6. Robertson S.W., Staden P.J., Cherkaev A., Petersen J. Properties governing the flow of solution through crushed ore for heap leaching. *Hydrometallurgy*. 2022; 208:105811.
   https://doi.org/10.1016/j.hydromet.2021.105811
7. Lizama H.M. In-situ leaching of copper from spent heaps. *Hydrometallurgy*. 2023;215:105997.
   https://doi.org/10.1016/j.hydromet.2022.105997
8. Damdinzhav Zh., Sizyakov V.M., Brichkin V.P., Andreev E.E., Boduen A.Ya. Practice of heap leaching of refractory ores of the Erdenetiin Ovoo deposit. *Obogashchenie rud*. 2009;(5):3—5. (In Russ.).
   Дамдинжав Ж., Сизяков В.М., Бричкин В.П., Андреев Е.Е., Бодуэн А.Я. Практика применения кучного выщелачивания труднообогатимых руд месторождения «Эрдэнэтийн Овоо». *Обогащение руд*. 2009;(5):3—5.
9. Khalezov B.D. Heap leachingof copper-zinc ores. Ekaterinburg: Ural Branch of the RAS, 2013. 346 p. (In Russ.).
   Халезов Б.Д. Кучное выщелачивание медных и медно-цинковых руд. Екатеринбург: УрО РАН, 2013. 346 с.
10. Column Leaching Procedure. https://www.911metallurgist.com/hydrometallurgy-testing/ (accessed: 01.03.2024).
11. Staden P.J., Kolesnikov A.V., Petersen J. Comparative assessment of heap leach production data — 1. A procedure for deriving the batch leach curve. *Minerals Engineering*. 2017;101:47—57.
    https://doi.org/10.1016/j.mineng.2016.11.009
12. Robertson S.W. Development of an integrated heap leach solution flow and mineral leaching model. *Hydrometallurgy*. 2017;169:79—88.
    https://doi.org/10.1016/j.hydromet.2016.12.010
13. Wang L., Yin S., Wu A. Ore agglomeration behavior and its key controlling factors in heap leaching of low-grade copper minerals. *Journal of Cleaner Production*. 2021;279:123705.
    https://doi.org/10.1016/j.jclepro.2020.123705
14. Apua M.C., Mapilane S. Leaching kinetics and predictive models for elements extraction from copper oxide ore in sulphuric acid. *Journal of the Taiwan Institute of Chemical Engineers*. 2021;121:313—320.
    https://doi.org/10.1016/j.jtice.2021.04.005
15. Liu W., Hashemzadeh M. Solution flow behavior in response to key operating parameters in heap leaching. *Hydrometallurgy*. 2017;169:183—191.
    https://doi.org/10.1016/j.hydromet.2017.01.007
16. Kimball B.E., Rimstidt J.D., Brantley S.L., Chalcopyrite dissolution rate laws. *Applied Geochemistry*. 2010;25(7):972—983.
    https://doi.org/10.1016/j.apgeochem.2010.03.010
17. Cerqueira B., Covelo E.F., Rúa-Díaz S. Contrasting mobility of arsenic and copper in a mining soil: A comparative column leaching and pot testing approach. *Journal of Environmental Management*. 2022;318:115530.
    https://doi.org/10.1016/j.jenvman.2022.115530
18. Lizama H.M. How copper dump leaching works. *Minerals Engineering*. 2021;171:107075.
    https://doi.org/10.1016/j.mineng.2021.107075
19. Ansah E.O., Jyoti A., Black J.R., Haese R.R. The importance of reaction mechanisms and coupled dissolution with reprecipitation (CDR) reactions when modelling copper leaching in heap systems. *Minerals Engineering*. 2023;203:108357.
    https://doi.org/10.1016/j.mineng.2023/108357
20. Lichtner P.C. The quasi-stationary state approximation to coupled mass transport and fluid-rock interaction in a porous medium. *Geochimica et Cosmochimica Acta*. 1988;52:143—165.
    https://doi.org/10.1016/0016-7037(88)90063-4

21. Dzhartaeva I., Massakbayeva S. Investigation of factors affecting the process of heap leaching of copper ores. *Polish Journal of Science*. 2021;40:13—16.
22. Jamsa-Jounela S.L., Cziprian Z. Heap leaching simulation. In: *IFAC Symposium on Automation in Mining, Mineral and Metal Processing*. Cologne, Germany, 1998. P. 43—48.
https://doi.org/10.1016/S1474-6670(17)35854-8

Information about the authors

Sambuu Gantulga – Master of science in engineering, Senior Engineer of the Technological park project unit, SOE "Erdenet Enterprise".
E-mail: gantulga.s@erdenetmc.mn

Tserendagva Tsend-Ayush – Ph.D, Head of the Development Department, SOE "Erdenet Enterprise".
E-mail: ts.tsendayush@erdenetmc.mn

Byambasuren Altantuyaa – Ph.D, Professor, Lecturer of the Institute of geology and mining engineering, Mongolian University of Science and Technology.
https://orcid.org/0000-0002-8414-9114?lang=en
E-mail: altantuya@must.edu.mn

Sergey V. Mamyachenkov – Dr. Sci. (Eng.), Head of the Department of metallurgy of non-ferrous metals, Ural Federal University n.a. the First President of Russia B.N. Eltsin.
https://orcid.org/0000-0002-4458-3792
E-mail: svmamyachenkov@yandex.ru

Информация об авторах

Самбуу Гантулга – магистр технических наук, ведущий инженер Проектной единицы, Производственно-технологический парк, ПГС «Предприятие Эрдэнэт».
E-mail: gantulga.s@erdenetmc.mn

Цэрэндагва Цэнд-Аюуш – к.т.н, начальник отдела развития ПГС «Предприятие Эрдэнэт».
E-mail: ts.tsendayush@erdenetmc.mn

Бямбасурэн Алтантуяа – к.т.н., профессор, преподаватель кафедры геологии и горной промышленности, Монгольский университет науки и технологии.
https://orcid.org/0000-0002-8414-9114?lang=en
E-mail: altantuya@must.edu.mn

Сергей Владимирович Мамяченков – д.т.н., заведующий кафедрой металлургии цветных металлов Уральского федерального университета им. первого Президента России Б.Н. Ельцина.
https://orcid.org/0000-0002-4458-3792
E-mail: svmamyachenkov@yandex.ru

Contribution of the authors

S. Gantulga – conducted experiments, prepared initial samples, participated in the discussion of results, drafted the manuscript, and formulated the conclusions.

Ts. Tsend-Ayush – defined the research objectives and participated in the discussion of results.

B. Altantuyaa – participated in the discussion of results and contributed to writing the manuscript.

S.V. Mamyachenkov – processed the results and edited the manuscript.

Вклад авторов

С. Гантулга – проведение экспериментов, приготовление исходных образцов, участие в обсуждении результатов, подготовка текста, формулировка выводов.

Ц. Цэнд-Аюуш – определение цели работы, участие в обсуждении результатов.

Б. Алтантуяа – участие в обсуждении результатов, написание статьи.

С.В. Мамяченков – обработка результатов, редактирование текста статьи.

The article was submitted 26.02.2024, revised 28.08.2024, accepted for publication 20.11.2024

Статья поступила в редакцию 26.02.2024, доработана 28.08.2024, подписана в печать 20.11.2024