Engineering Journal of Satbayev University
Volume 148 (2026), Issue 3, 16-23

https://doi.org/10.51301/ejsu.2026.i3.03

Application Practice of L-SX-EW in the Processing of Copper Ores from Kazakhstan Deposits

N. Yakushev*
VNIItsvetmet, a branch of the RSE «NC CPMRM RK», Oskemen, Kazakhstan
**Corresponding author:* *nikita.yakushev2112@mail.ru*

Abstract. The article provides an analytical review of the current state and development prospects of Leach-Solvent Extraction-Electrowinning (L-SX-EW) technology within the global and domestic copper industries. The study analyzes the mineral resource base of the Republic of Kazakhstan, including major copper deposits in the East and Central regions. Attention is given to solvent extraction flowsheets, the impact of mineralogical composition, and key technological challenges in processing oxidized and mixed copper ores. The paper highlights the historical role of «VNIItsvetmet» in the development of regional hydrometallurgical technologies and research approaches. The work systematizes data on modern technological schemes and principal efficiency factors of the L-SX-EW process, confirming its vital role in maintaining the long-term competitiveness of Kazakhstan's copper sector.

Keywords: *copper, heap leaching, solvent extraction, electrowinning, Kazakhstan mineral resources, oxidized copper ores*.

Received: 05 March 2026
Received in revised form: 08 June 2026
Accepted: 15 June 2026
Available online: 30 June 2026

1. Introduction

The global increase in copper consumption, including high-purity cathode grades and concentrates, together with the gradual depletion of high-grade sulfide ore reserves and the transition towards the development of off-balance resources and refractory oxidized and mixed ore, necessitates modernization and the development of more efficient ore processing technologies and enhanced recovery of valuable components. Under these conditions, heap leaching followed by solvent extraction and electrowinning (L-SX-EW), which enables the production of high-purity copper, has become one of the key technological solutions. According to the International Copper Study Group (ICSG), hydrometallurgical processes currently account for approximately 20-25% of total mine copper production worldwide [1].

The Republic of Kazakhstan possesses significant copper ore reserves – approximately 36 million tonnes of identified resources. The mineral resource base of copper in Kazakhstan is primarily represented by deposits of copper sandstones (Zhezkazgan), complex copper-pyrite and pyrite-polymetallic ores (Zyryanovskoye, Artemyevskoye, and others in the Rudny Altai, Eastern Kazakhstan), copper porphyry deposits (Aktogay and Aidarly, Bozshakol, Koksay, etc.), and copper skarn deposits (Sayak). Mine copper production in 2021 amounted to 520 thousand tonnes. The country accounts for approximately 2.5% of global mine production and refined copper output (second place within the CIS) [2]. The successful implementation of projects such as Aktogay, Kounrad, and Almaly has demonstrated the effectiveness of L-SX-EW technology. However, the involvement of ores with complex mineralogical compositions, as well as mixed ores, in hydrometallurgical processing presents a number of technological challenges.

The main issues encountered at operating plants include high concentrations of impurities (iron, silica, manganese, chlorides, etc.) in pregnant leach solutions (PLS), which complicate copper extraction by solvent extraction, as well as the formation of insoluble interfacial emulsions (crud). Optimization of the solvent extraction process is a critical stage for ensuring stable plant operation [3].

This article provides an overview of L-SX-EW technology, ranging from global trends to the specific operational features of domestic deposits. The paper examines the current state of the technology in international practice, technological flowsheets and key stages of heap leaching, as well as the factors affecting process efficiency. Particular attention is given to the industrial implementation of L-SX-EW in the processing of copper ores in Kazakhstan and to the historical role of VNIItsvetmet in the development of hydrometallurgical technologies in the region.

2. Research methodology

Over the past decade, SX-EW technology has demonstrated steady growth. According to analytical reports, total global copper mine production increased from 18.4 million tonnes in 2014 to approximately 22.4 million tonnes in 2023. Copper production by the L-SX-EW method also rose by about 17% over the same period. From 2026 onward, further

nikita.yakushev2112@mail.ru
Engineering Journal of Satbayev University. eISSN 2959-2348. Published by Satbayev University

growth of hydrometallurgical production is forecast at an average annual rate of about 2%, driven by the development of green technologies [4]:

– Renewable energy sources (RES): the construction of wind turbines and solar panels requires copper consumption volumes that are 3-4 times higher than those of conventional power plants;

– Transport sector: the production of electric vehicles requires 2-4 times more copper than the manufacture of conventional internal combustion engine vehicles;

– Urbanization: large-scale global investments in infrastructure development provide additional stimulus to the copper market;

– Copper produced by electrowinning (EW) consistently meets international LME Grade A standards (99.99% purity), enabling producers to market the product directly to end users without intermediate processing stages.

In several regions (for example, in Africa, including the Democratic Republic of the Congo), hydrometallurgical operations have demonstrated significant production growth, particularly against the backdrop of new project commissioning and capacity expansions [1, 5].

The key advantages of SX-EW technology include relatively low capital and operating costs, simplicity of process flowsheets and equipment design, and the possibility of reprocessing waste dumps previously considered uneconomic. However, the technology also has significant drawbacks: it is characterized by long metal recovery cycles that may extend over months or even years, as well as strong dependence on climatic conditions and the permeability of the ore heap [6, 7].

Global copper production is concentrated in several key regions [8]:

1). Chile – the undisputed world leader in both reserves and copper production. In 2023, the country's output amounted to approximately 5 million tonnes.

2). Peru – ranks second globally, with production of 2.6 million tonnes.

3). China – produces about 1.7 million tonnes of copper. It should be noted that China is not only a major producer but also the world's largest consumer.

4). United States – the U.S. mining sector produces approximately 1.1 million tonnes of copper annually. A significant share originates from operations in Arizona, where SX-EW technology has historically been widely applied for the processing of oxidized ores.

5). Russian Federation – consistently ranks among the top five global refined copper producers. Russian enterprises account for approximately 4.8% of total world output, highlighting the region's importance in maintaining global supply balance.

6). Democratic Republic of the Congo (DRC) – the fastest-growing region. The DRC reached second place globally in copper mine production (3.3 million tonnes in 2024). The principal contribution comes from the large-scale Kamoa-Kakula and Tenke Fungurume projects.

3. Results and discussion

3.1. Process flowsheets and key stages of heap leaching

Solvent extraction (SX) in copper hydrometallurgy is the process of recovering metal ions from pregnant leach solutions (PLS) generated during leaching and concentrating them into an electrolyte suitable for subsequent electrowinning (EW). The essence of the method lies in a reversible chemical reaction between the aqueous phase and an organic reagent (extractant) dissolved in a diluent. The process proceeds in two main stages:

Extraction. Contact between the pregnant leach solution (PLS) and the organic phase, during which copper ions transfer into the organic phase, replacing hydrogen ions of the extractant.

Stripping (re-extraction). Contact of the loaded organic phase with a strong sulfuric acid solution, resulting in the transfer of copper back into the aqueous phase, thereby producing a purified and concentrated electrolyte suitable for cathode production.

The overall L–SX–EW process chain, including leaching, solvent extraction, stripping, and electrowinning, is shown in Figure 1. The extraction–stripping reaction can be expressed as follows:

$$CuSO_4(\text{aqueous}) + 2RH(\text{org.}) \rightleftharpoons CuR_2(\text{org.}) + H_2SO_4 \tag{1}$$

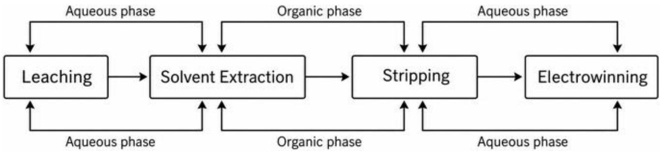

Figure 1. Process flowsheet of the L–SX–EW process chain

The selection of the process and equipment configuration for solvent extraction is determined by the copper concentration in the initial pregnant leach solution (PLS) and the required degree of recovery. During the life of a deposit and throughout the heap leaching process, the composition of the pregnant solution inevitably changes. At the initial stages, the solution typically contains higher concentrations of readily leachable components. As the reserves are depleted, however, the chemical composition of the minerals within the heap changes. As a result, the concentration of recoverable components in solution gradually decreases, and undesirable or secondary components may begin to appear. Changes in the composition of the pregnant solution represent one of the key factors influencing the dynamics of metal recovery from ores and the overall efficiency of the heap leaching process. Considering the combined impact of these factors, modification of the process flowsheet may become necessary [9, 10].

In modern practice, several basic solvent extraction configurations are used, each offering specific operational advantages. Series extraction configuration (2E – 1S) (Figure 2).

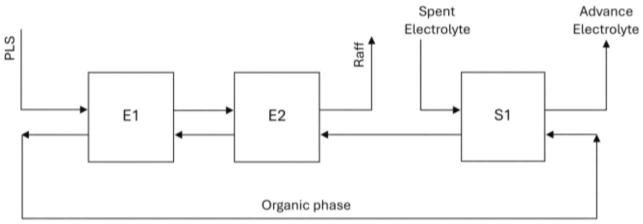

Figure 2. Sequential extraction circuit

Pregnant leach solution (PLS) sequentially passes through several extraction stages (E1 and E2), contacting the organic phase, generally in a counter-current arrangement. One of the key features of this configuration is ensuring the maximum possible copper recovery from the Pregnant leach solution (PLS) (approximately 90%) through deeper depletion of the aqueous phase at the second extraction stage. The efficiency of copper transfer can be enhanced by adding extraction and stripping stages to the circuit, increasing the extractant concentration, or modifying the relative flow rates of the organic and aqueous phases (O/A ratio). Depending on PLS characteristics (pH, copper concentration, impurities), up to three extraction stages and two stripping stages may be applied.

To increase copper production capacity, the standard sequential extraction circuit may be replaced with a parallel or combined configuration (Figures 3 and 4).

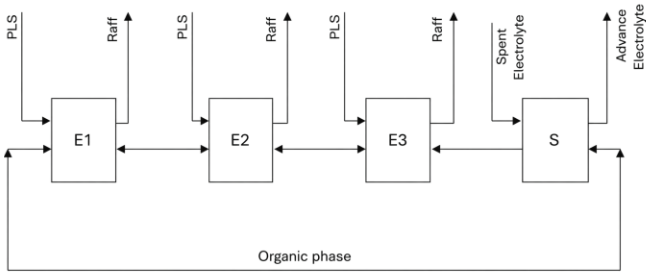

Figure 3. Parallel extraction circuit

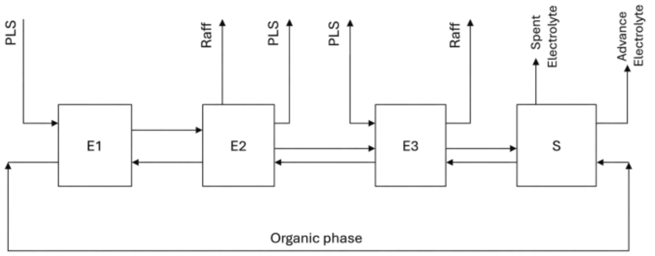

Figure 4. Sequential-parallel extraction circuit

In this example, the Pregnant leach solution (PLS) is fed in parallel to the mixers of both extraction stages, while the organic phase flow remains the same as in the sequential scheme. This arrangement allows the same circuit to process twice the PLS flow rate, provided that the extractant concentration can be increased to transfer the additional copper. As a result, the overall rate of copper transfer from the PLS to the electrowinning circuit can be increased. Implementing parallel flow in the circuit is a cost-effective way to enhance the productivity of an existing sequential-type plant. Plants are often converted from sequential to parallel or sequential-parallel configurations toward the end of the mine life [11].

Washing of the organic phase with water is an auxiliary operation in the solvent extraction process, positioned between the extraction and stripping stages. The primary purpose of this stage is to remove entrained aqueous phase and associated impurities that are carried by the organic phase from the pregnant leach solution (PLS) obtained by heap leaching.Under copper SX–EW conditions, the organic phase after extraction typically contains mechanically entrained PLS, including iron and manganese ions, chlorides, and other undesirable components that may adversely affect subsequent process stages and the quality of the electrolyte for electrowinning.

The organic phase washing is carried out by contacting it with a weak aqueous solution in a separate mixer-settler unit or a dedicated wash cell. As a result of this contact, both the mechanically entrained aqueous phase and a portion of impurities loosely held in the organic phase are removed. This significantly reduces the transfer of undesirable components to the stripping stage and subsequently to the EW electrolyte [12].

The selection of a specific extraction circuit is a compromise between the depth of metal recovery and the plant throughput in terms of solution flow rates. For a clear comparison of the advantages and disadvantages of sequential, parallel, and hybrid configurations, a summary table has been prepared (Table 1), reflecting the specifics of their application under various operating conditions.

Table 1. Brief characteristics of extraction circuits

Criterion	Sequential extraction circuit	Parallel extraction circuit	Sequential-parallel extraction circuit
Operating principle	Aqueous and organic phases move in full counter-current flow through all stages.	The PLS stream is split and fed simultaneously to different extraction stages.	Combination scheme: part of the PLS passes through one stage, while another part passes through two extraction stages.
Recovery	Maximum, as it enables ~90% copper recovery from the pregnant leach solution (PLS) due to deep depletion at the second stage.	Lower. The solution contacts the organic phase only once, resulting in higher copper content in the raffinate.	Adjustable. Provides a balance between recovery depth and processing volume.
PLS flow rate capacity	Limited. The entire solution volume must pass through each stage.	Maximum. Allow processing of up to twice the PLS volume.	High. Optimal for plants increasing throughput while copper grades decline.
Copper concentration in PLS	Suitable for medium concentrations (2–5 g/L Cu in pregnant leach solutions).	Effective for very low-grade solutions when maintaining high flow rates is required.	Optimal when copper concentration in ore decreases over time.
Examples of application	Zaldívar Mine (Chilie)	Used as a temporary measure for capacity expansion.	Morenci Mine (USA); Aktogay (Kazakhstan); Kansanshi Mine (Zambia)

3.2. Factors affecting process efficiency

The efficiency of the hydrometallurgical «leaching – solvent extraction – electrowinning» (L–SX–EW) technology is determined by a combination of physicochemical and process parameters. Primary importance is attributed to the mineralogical composition of the feed ore, which dictates the leaching regime selection and predetermines the kinetics of valuable metal transfer into the pregnant leach solution (PLS). However, as noted by researchers, an equally critical factor is the accumulation of impurity elements in circulating solutions, such as iron, manganese, chloride, and silica [13].

The presence of these components not only reduces extraction selectivity but also accelerates degradation of the organic phase, leading to increased operating costs and reduced cathode metal purity. The mineral composition of the primary raw material establishes the foundation for the entire process chain. Minerals determine which copper-bearing phases are available for leaching, how readily they dissolve, which by-products will enter the PLS, and the overall chemical environment of the solution. Different minerals exhibit varying solubility in sulfuric acid. For example, copper carbonates such as Malachite and Azurite dissolve readily, whereas minerals such as Chrysocolla, Cuprite, and Tenorite require higher sulfuric acid concentrations. Secondary sulfides may be leached in the presence of strong oxidants such as ferric sulfate (Fe^{3+}), while Chalcopyrite is the most refractory among common copper minerals [14, 15]. Gangue minerals also exert a significant influence. For instance, high contents of Calcite and Dolomite (typical of mixed ores in the Republic of Kazakhstan) lead to excessive sulfuric acid consumption.

The pregnant leach solution (PLS) derived from heap or tank leaching and fed to the solvent extraction stage represents a multicomponent system. In addition to copper ions (Cu^{2+}), the solution almost invariably contains impurities capable of significantly affecting extraction selectivity, organic phase stability, and electrolyte quality in the electrowinning (EW) stage. The most common impurities in PLS include iron (Fe^{2+}/Fe^{3+}), manganese (Mn^{2+}), aluminum (Al^{3+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), chlorides, silicic acid, and colloidal particles. Their presence may result in both direct losses in SX efficiency and indirect operational issues related to organic degradation and electrolyte contamination [16].

The presence of ferric iron (Fe^{3+}) reduces current efficiency during electrowinning, as it is continuously reduced at the cathode and oxidized at the anode. Although modern oxime extractants exhibit high selectivity toward copper, Fe^{3+} may be partially co-extracted or interact with the organic phase, impairing phase separation and increasing the tendency for interfacial crud formation [17].

Manganese is typically present in solution as Mn^{2+} and is scarcely extracted into the organic phase. However, during electrowinning (EW), it may be oxidized to Mn^{3+} or Mn^{4+} species, which are strong oxidants. These compounds can accelerate degradation of both the extractant and the diluent, shortening organic phase life and increasing reagent losses.

The presence of chloride ions in PLS, and especially in the EW electrolyte, is considered a critical factor limiting process stability. Chlorides accelerate equipment corrosion, promote the formation of undesirable gaseous by-products during electrolysis, and impair cathode copper quality.

Colloidal particles of silicic acid, clay minerals, and metal hydrolysis products play a particular role in impairing SX circuit performance. They are capable of stabilizing emulsions. The accumulation of such impurities leads to increased phase separation time, higher organic phase losses, and overall plant instability [18].

3.3. Industrial implementation of L–SX–EW processes in the processing of copper ores in kazakhstan

The transition to industrial implementation of L–SX–EW technology marked a turning point for the copper industry of Kazakhstan, enabling the development of off-balance and refractory oxidized ore reserves. To date, the successful operation of hydrometallurgical complexes at the country's largest deposits confirms not only the technical reliability of the flowsheet but also its strategic importance in maintaining national competitiveness in the global cathode copper market.

3.3.1. Aktogay

The Aktogay deposit is the largest hydrometallurgical processing site for oxidized copper ores in the Republic of Kazakhstan and one of the most large-scale examples of industrial heap leaching implementation. Aktogay is a major porphyry copper deposit, where SX–EW technology was first introduced to process the oxidized «cap» overlying the primary sulfide ore body.

The first cathode copper from oxidized ore was produced in December 2015. The design capacity of the SX–EW facility is approximately 25,000 tonnes of copper per year from the oxide zone. This SX–EW complex became an essential component of the overall production strategy, as it enabled the integration of hydrometallurgy for processing low-grade oxidized ores that are inefficiently treated by conventional concentration methods [19].

At Aktogay, a multi-line extraction system is employed. Given the enormous volumes of circulating pregnant leach solution (PLS), the plant operates under a flexible configuration combining sequential and parallel extraction circuits (Figure 4). This approach ensures high productivity even under seasonal fluctuations in copper concentration in the PLS [20].

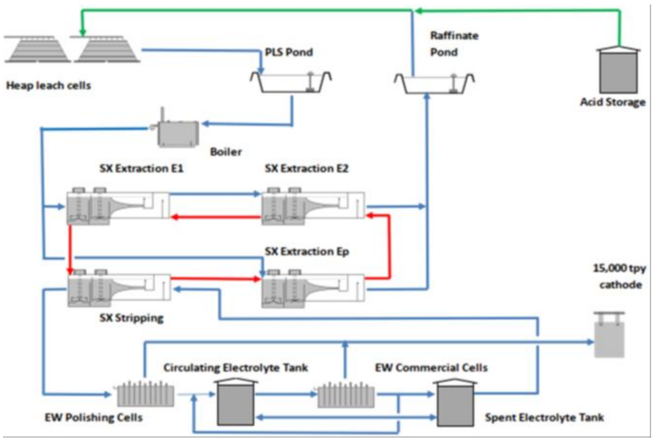

Figure 4. SX–EW Flowsheet of the Aktogay Mining and Processing Plant

By 2026, the depletion of oxidized ore reserves posed a significant threat to the continued operation of the oxide plant at Aktogay, implying a potential full shutdown of the production cycle – from heap leaching on active pads to cathode copper production. In order to extend the operational life of the facility, management initiated the search for innovative approaches to processing alternative feed materials, including off-balance ores and technogenic waste.

Conventional intensification methods, such as the use of percolation columns or agitated tank leaching, were rejected due to the enormous volumes of already stacked material. Underground leaching technology was also considered impractical given the open-pit mining configuration of the deposit.

The most promising development pathway identified was bioleaching, based on the activity of specialized microorganisms. This technology enables efficient recovery of valuable components from low-grade and mixed ores directly within existing heaps, minimizing capital expenditures for plant retrofitting. The implementation of bacterial leaching is regarded as a strategic solution capable not only of revitalizing the oxide plant's production capacity but also of significantly improving the overall resource efficiency of the Aktogay deposit in the long term [21].

3.3.2. Kounrad

The Kounrad project is unique not only for Kazakhstan but also in global practice. It represents one of the few successful and highly profitable examples of reprocessing historic technogenic dumps accumulated over decades (since the 1930s) of operation at the Kounrad copper mine. Historically, the Kounrad copper deposit was developed in the early 20th century, resulting in the formation of substantial waste rock dumps with relatively low copper grades (0.3% Cu).

The project was launched during 2010-2012, with the first cathode copper produced in April 2012. The initial SX–EW plant capacity was about 10 thousand tonnes of cathode copper per year. In subsequent years, production capacity was expanded: by 2015, additional extraction and electrowinning circuits were commissioned, increasing annual output to approximately 14 thousand tonnes of copper. The final product is M00K-grade cathode copper with a purity of at least 99.99% Cu, supplied both to the domestic market and for export [22].

The Kounrad project has earned a strong reputation for economic efficiency, as dump reprocessing requires relatively low capital and operating costs compared to conventional mining and concentrator complexes. As of the mid-2020s, cumulative cathode copper production since commissioning amounts to hundreds of thousands of tonnes, and the project is expected to remain in operation at least until 2034, processing significant volumes of copper-bearing material remaining from historical mining.

The dump material consists of oxidized copper ore with the following composition (%): 1.46 Fe; 0.17 S; 76.32 SiO_2; 11.86 Al_2O_3; 0.17 CaO; 0.13 MgO; 0.002 Zn; 0.001 Pb. Copper minerals are represented by approximately 76% oxide compounds, 13% secondary sulfides, 10.6% primary sulfides, and 0.4% sulfates. The maximum lump size in the dumps ranges from 0.6 to 1 m.

By 2025, the Kounrad dumps remain an economically viable source of copper. The company estimates remaining resources sufficient to sustain production at least until 2034. Copper recovery from the Eastern Dumps is estimated at approximately 45-50%, while recovery from the Western Dumps ranges from about 35-42% of the theoretical metal content [23, 24]. The Kounrad project became the first full-scale industrial SX–EW operation in Kazakhstan based on hydrometallurgical copper recovery from dump bodies, demonstrating the technological and economic viability of the flowsheet for low-grade copper resources.

3.3.3. Almaly

The Almaly deposit represents one of the most interesting and technically challenging cases for hydrometallurgy in Kazakhstan. Unlike Aktogay, where processes are already scaled up and well established, Almaly is frequently referenced in scientific studies as a site characterized by «complex» ores requiring non-standard approaches to solution purification.

The Almaly copper deposit is located in the Shetsky District of the Karaganda Region, approximately 150 km from the regional center. The resource potential is significant, amounting to about 30 million m^3 of ore. Since the end of 2018, a hydrometallurgical complex operated by Sary-Arka Copper Processing has been in operation at the site. The enterprise specializes in cathode copper production via heap leaching, producing up to 10 thousand tonnes of high-grade copper annually, primarily for export markets [25].

The technological scheme at Almaly is as follows: after heap leaching, copper is transferred into the pregnant leach solution (PLS), from which it is subsequently recovered by solvent extraction (SX) using organic extractants. The selection of the optimal extractant composition and operating conditions is a key task for this project.

Research has shown that from Almaly PLS (with Cu concentrations of approximately 0.26-2.35 g/dm^3), the most effective extractant for selective copper recovery under laboratory conditions was Acorga 5640 at a concentration of about 5%, providing copper recovery of up to ~94%. Other extractants, such as LIX 984N and Acorga 5910 / Acorga 5747, also demonstrated high selectivity; however, under the given conditions, Acorga 5640 proved to be optimal. This finding is important for designing efficient industrial SX–EW flowsheets tailored to the specific composition of Almaly PLS [26].

Recent publications indicate that, based on the current ore base, approximately 4.43 million tonnes of ore per year are planned to be processed to produce around 9 thousand tonnes of cathode copper annually, with potential for further capacity increases as infrastructure and technology develop [27].

At this deposit, a range of technological challenges has been identified, primarily associated with impurity components such as iron (Fe) and silica (SiO_2). These impurities may impair phase separation, promote crud formation, and negatively affect the quality of produced copper. Addressing these issues requires integrated technological solutions and strict control of SX–EW operating parameters [28].

3.3.4. Ayak-Kodjan

The Ayak-Kodjan deposit is located in the Ekibastuz District of the Pavlodar Region of the Republic of Kazakhstan, forming part of the regional copper belt. The project was developed by Eurasia Copper Operating with the objective of exploiting oxidized and low-beneficiation-grade ore bodies. These ores are traditionally difficult to process by flotation but are well suited for hydrometallurgical copper recovery [29].

At Ayak-Kodjan, a full production cycle of Grade A cathode copper was implemented based on the L–SX–EW flowsheet, with a production capacity of approximately 2.5 thousand tonnes of cathode copper per year (as of June 2014). However, according to the latest available information, production at the site is currently suspended.

3.3.5. Borly

The Borly deposit is located in the Aktogay District of the Karaganda Region of the Republic of Kazakhstan, approximately 30 km from the city of Balkhash and near the Balkhash–Kounrad railway line. It belongs to the copper–molybdenum (Cu–Mo) ore type, with the presence of both copper sulfide and oxide minerals. Historically, Borly has been recognized in geological exploration sources as a perspective copper (and molybdenum) deposit with moderate metal grades [30].

In the 2020s, a hydrometallurgical plant for the production of cathode copper using the SX–EW process was constructed and officially commissioned at the Borly deposit with the participation of Irkaz Metal Corporation. According to an official press release of the Government of the Republic of Kazakhstan, the enterprise in the Karaganda Region has a design capacity of 5 thousand tonnes of cathode copper per year and is expected to create approximately 140 jobs.

Production is carried out using a modern hydrometallurgical SX–EW cycle – from acid leaching to electrolytic deposition of high-purity M00k-grade cathode copper [31].

The annual ore consumption amounts to approximately 2.5 million cubic meters, equivalent to about 4.575 million tonnes. This volume ensures the stability and continuity of the production process, enabling the plant to achieve its planned output targets. The enterprise operates around the clock in two 12-hour shifts, using a rotational work schedule with 15-day shifts [32].

3.3.6. Berkarinskoye

The Berkarinskoye deposit is located in the East Kazakhstan Region of the Republic of Kazakhstan, approximately 350 km east of the city of Karaganda and in proximity to Semey. It represents an industrially significant copper ore project where an integrated mining and processing scheme based on the L–SX–EW flowsheet is being implemented.

The project has been developed by Arx Minerals through its subsidiary Nouvelle Mining. The mineral reserves have been registered on the state balance of Kazakhstan in accordance with the JORC Code classification (2012 edition).

The estimated annual production parameters include mining of approximately 600 thousand tonnes of ore and production of about 5 thousand tonnes of cathode copper per year. The projected mine life is 8-9 years, with potential extension subject to reserve expansion.

The nearest settlements are the villages of Algabas (approximately 9.5 km north of the site) and Kaynar (approximately 40 km east). The region is characterized by a sharply continental climate, with short hot summers and long severe winters, which significantly influences logistics and the technological organization of production, particularly heap leaching operations and solution management [33].

As of the end of 2024, public hearings were also conducted regarding environmental aspects of operations at the «North Berkara» site, which forms part of the Berkarinskoye deposit. This process is a mandatory stage for obtaining an Environmental Impact Permit (EIP/ERV). The hearings addressed geological boundaries, ore body characteristics, and planned exploration activities, including drilling and chemical-analytical studies [34].

3.4. The role of VNIItsvetmet in the development of hydrometallurgical technologies for processing oxidized and mixed copper ores in Kazakhstan

The establishment of a scientific and methodological framework for applying solvent extraction technologies to the processing of Kazakhstan's mineral resources began at VNIItsvetmet in 1997. Research activities were carried out under long-term programs aimed at introducing environmentally safe hydrometallurgical solutions for oxidized and mixed non-ferrous metal ores.

A significant milestone was international scientific and technical cooperation between the Republic of Kazakhstan and Japan, through which the institute obtained an automated pilot-scale plant. This facility enabled large-scale testing of beneficiation and hydrometallurgical processes under conditions close to industrial operation.

In subsequent years, comprehensive studies were conducted on more than twenty copper deposits across Kazakhstan, including Aktogay, Kounrad, Benkala, Zhezkazganskoye, Borly, Ayak-Kodjan, Ai, Vavilonskoye, Karchiga, Almaly, and Berkarinskoye Deposits. These deposits are characterized by diverse geological, mineralogical, and technological parameters.

The research results formed the basis for the development of design regulations for approximately fifteen industrial facilities. As a result, a practice-oriented model was established for adapting the L–SX–EW technology to raw materials with low to moderate copper grades and varying gangue mineral compositions.

One of the earliest examples of industrial validation was the processing of tailings from the Kounrad mine. Despite the extremely low copper content in the feed material (0.1-0.2%), the favorable mineralogical composition (predominantly quartz) resulted in relatively low sulfuric acid consumption and limited impurity accumulation in pregnant leach solutions. Based on these studies, a technological regulation was developed, leading to the commissioning in 2008 of the country's first solvent extraction facility operating on technogenic raw materials.

Based on research conducted at VNIItsvetmet, recommendations were also developed for implementing the L–SX–EW technology at the Benkala deposit. The proposed flowsheet was subsequently successfully introduced into industrial operation.

A new stage in technological development was associated with the exploitation of oxidized ores at the Aktogay deposit. This site is characterized by significant variability in material composition (volcanogenic formations, porphyry and granodiorite varieties) with an average copper grade of approximately 0.3%. Research findings from 2007-2013 were used in developing industrial process solutions by KAZ Minerals PLC (formerly Kazakhmys PLC) for heap leaching followed by solvent extraction and electrowinning. The commissioning of the plant in 2015 and achievement of a design capacity of about 25 thousand tonnes of cathode copper per year confirmed the technological feasibility and economic efficiency of the selected solutions.

In 2016-2017, VNIItsvetmet conducted research on heap leaching of oxidized copper ores from the Almaly deposit in the Karaganda Region. The studies demonstrated the necessity of a more complex technological configuration due to low copper grades and specific mineralogical characteristics. The developed process procedure included three-stage crushing, increased sulfuric acid consumption (up to 12 kg/t), and an extended leaching period combined with parallel solvent extraction of solutions. Implementation of these solutions at Sary-Arka Copper Processing enabled the launch of cathode copper production with a capacity of up to 10 thousand tonnes per year. The plant was commissioned in 2018.

Further expansion of L–SX–EW application in Kazakhstan is associated with the commissioning in 2022 of a hydrometallurgical facility operated by KAZ Metal Corporation for processing ores from the Borly deposit (Karaganda region). The design capacity of the facility is up to 5 thousand tonnes of cathode copper per year. Between 2017 and 2022, a comprehensive research program was completed for processing oxidized and mixed ores from the Berkarinskoye Deposit (East Kazakhstan), culminating in the development of a technological regulation and subsequent industrial implementation of the project by Arx Minerals in 2023 [35].

4. Conclusions

The conducted review has demonstrated that heap leaching followed by selective solvent extraction and electrowinning of copper (L–SX–EW) represents one of the most efficient and economically justified approaches for processing oxidized and mixed copper ores in the Republic of Kazakhstan. The widespread industrial implementation of this technology is driven by the substantial resources of low-grade copper ores, the specific features of their mineralogical composition, and the possibility of incorporating technogenic formations and previously uneconomic reserves into production.

Analysis of mineralogical factors and pregnant leach solution composition indicates that the efficiency of L–SX–EW processes is largely determined by ore material composition, the nature of copper-bearing minerals, the ratio of gangue phases, and the presence of impurity components. Mineralogical differences between oxidized and mixed ores, as well as variability in iron, aluminum, manganese, silicon, and other element contents, significantly influence leaching kinetics, reagent consumption, organic phase stability, and copper extraction selectivity.

Industrial practice in Kazakhstan at deposits such as Aktogay, Kounrad, Almaly, Borly, and Berkarinskoye Deposit confirms that even with low copper grades in the feed material, acceptable recovery rates and high-purity cathode copper production can be achieved, provided that appropriate technological schemes, crushing parameters, leaching regimes, and extraction conditions are selected. A key factor in successful project implementation is the adaptation of technological solutions to the specific geological and mineralogical conditions of each deposit.

A special role in the development of hydrometallurgical copper processing technologies in Kazakhstan belongs to VNIItsvetmet, which for several decades has carried out comprehensive research and pilot-scale studies in heap leaching and solvent extraction.

Overall, the results of this review indicate that further development of the L–SX–EW technology in Kazakhstan is associated not only with expansion of the resource base through the inclusion of new deposits and technogenic materials, but also with improvement of solution quality control methods, reduction of organic phase losses, enhancement of extraction selectivity, and increased stability of operating regimes.

Author contributions

The author confirms that they are the sole contributor to this work.

Funding

This research received no external funding.

Acknowledgements

The author gratefully acknowledges the editor and reviewers for their helpful comments and suggestions.

Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

References

[1] International Copper Study Group. (2024). *World Copper Factbook 2025*. https://icsg.org/copper-factbook/

[2] Chernykh, A.I., Girfanov, M.M., Istomin, V.A., Fedorov, D.T., Pashkov, V.S., & Svatkov, A.S. (2023). Mineral resource base of the CIS countries of the Central Asian region: Status and directions of interaction and development. *Ores and Minerals*, (3), 6-36. https://doi.org/10.47765/0869-5997-2023-10011

[3] Ritcey, G.M. (1980). Crud in solvent extraction processing: A review of causes and treatment. *Hydrometallurgy*, *5*, 97-107. https://doi.org/10.1016/0304-386X(80)90031-6

[4] Dong, D., van Oers, L., Tukker, A., & van der Voet, E. (2020). Assessing the future environmental impacts of copper production in China: Implications of the energy transition. *Journal of Cleaner Production*, *274*, 122825. https://doi.org/10.1016/j.jclepro.2020.122825

[5] PW Consulting Chemical & Energy Research Center. (2025). Global copper solvent extraction reagent market size, share & trends analysis 2026–2032. *Available at:* https://pmarketresearch.com/chemi/copper-solvent-extraction-reagent-market/

[6] Khalezov, B.D. (2013). *Heap leaching of copper and copper-zinc ores (domestic experience)*. Yekaterinburg.

[7] Masloboev, V.A., Makarov, D.V., Svetlov, A.V., Fokina, N.V., Yanishevskaya, E.S., & Goryachev, A.A. (2018). Problems and prospects of hydrometallurgical processing of low-grade sulfide ores and technogenic waste in northern regions. *Proceedings of the Kola Science Centre of the Russian Academy of Sciences*, *9*(1), 58-64. https://doi.org/10.25702/KSC.2307-5252.2018.9.1.58-64

[8] Wood Mackenzie. (2024). *Global copper market outlook: Supply, demand, and price trends* (Metals & Mining Report). *Retrieved from:* https://www.woodmac.com/

[9] Dudley, K.A., Readett, D.J., Crane, P.A., & Mackenzie, J.M.W. (2002). *Copper hydrometallurgy process evolution: Changing operating parameters and philosophies throughout the life of Girilambone Copper Company's solvent extraction circuit.* ISEC 2002, Cape Town, South Africa.

[10] Miller, G. (2011). Methods of managing manganese effects on copper solvent extraction plant operations. *Solvent Extraction and Ion Exchange*, 29(5-6), 837-853. https://doi.org/10.1080/07366299.2011.595647

[11] Readett, D.J., Hanlon, M., Dudley, K.A., Crane, P.A., & Mackenzie, J.M.W. (2002). *Evolution of a copper solvent extraction circuit: Management of operating parameters under varying leach solution conditions*. International Solvent Extraction Conference (ISEC 2002), Cape Town, South Africa.

[12] Schlesinger, M.E., King, M.J., Sole, K.C., & Davenport, W.G. (2011). *Extractive metallurgy of copper* (5th ed.). Elsevier.

[13] Kordosky, G.A. (2002). Copper recovery using leach/solvent extraction/electrowinning technology: Forty years of innovation. *Journal of the Southern African Institute of Mining and Metallurgy*, *102*(8), 445-450.

[14] Solís Marcial, O.J., Nájera-Bastida, A., Soriano-Vargas, O., Ruelas Leyva, J.P., Talavera-López, A., Inchaurregui, H., & Zárate Gutiérrez, R. (2025). Recovery of copper from pregnant leach solutions of copper concentrate using aluminum shavings. *Minerals*, *15*(10), 1048. https://doi.org/10.3390/min15101048

[15] Naboychenko, S.S., & Smirnov, V.I. (1974). *Hydrometallurgy of copper*. Metallurgiya Publishing House.

[16] Wang, C.Y. (2005). *Crud formation and its control in solvent extraction*. International Solvent Extraction Conference 2005, Beijing, China.

[17] Ritcey, G.M. (2006). Equipment in solvent extraction processing. *Solvent extraction: Principles and applications to process metallurgy*, *2*, 253-419.

[18] Crane, F. (2004). Extraction in copper hydrometallurgy: Development and current status. *Complex Use of Mineral Resources*, (2), 36-55.

[19] Kazakhstan Today. (2015). KAZ Minerals produced first cathode copper at the Aktogay deposit. *Available at:* https://www.kt.kz/rus/ekonomika/kaz_minerals_proizvela_pervuju_katodnuju_medj_na_mestorozhdenii_aktogaj_1153613338.html

[20] KAZ Minerals. (2024). *Aktogay SX/EW flowsheet*.Technical drawing. https://www.kazminerals.com/media/17040/aktogay-sxew-flowsheet.pdf

[21] Kozhek, M., Mamezhanov, B., & Amarzayaa, U. (2025). Study of copper recovery from oxidized and low-grade ores of the Aktogay Mining and Processing Plant using heap and bacterial leaching and implementation of the "Heap Bioleaching at AGOK" project. *World Science*, *99*(6). https://doi.org/10.5281/zenodo.16792897

[22] Kursiv. (2024). Kazakhmys temporarily suspends one of its oldest copper mines. *Available at:* https://kz.kursiv.media/2024-07-04/zhnb-kazakhmyskounradconserv/

[23] Central Asia Metals PLC. (2025). *Annual report and accounts 2024*. https://www.centralasiametals.com/operations/kounrad/

[24] Discovery Alert. (2026). *Copper mining operations: Market dynamics 2026*. https://discoveryalert.com.au/copper-mining-operations-market-dynamics-2026/

[25] Chepushtanova, T.A., Yesirkegenov, M.I., Mamyrbayeva, K.K., Merkibayev, E.S., & Nikoloski, A. (2023). Testing of the opti-

mum extractant for solvent extraction of Almaly deposit copper. *Complex Use of Mineral Resources*, *324*(1), 43-49. https://doi.org/10.31643/2023/6445.06

[26] Mamyshev, Z. (2024). *Copper company reconstructs a mine in the Karaganda Region.* Kursiv. https://kz.kursiv.media/2024-07-16/zhnb-coppercompanyreconst/

[27] Mamyshev, Z. (2024). *Copper company reconstructs a mine in the Karaganda Region.* Kursiv. https://kz.kursiv.media/2024-07-16/zhnb-coppercompanyreconst/

[28] Chepushtanova, T.A., Yesirkegenov, M.I., Mamyrbayeva, K.K., & Merkibayev, E.S. (2023). Investigations of copper extraction and crud formation components of productive solution of the Almaly deposit. *Non-Ferrous Metals*, *54*(1), 11-19. https://doi.org/10.17580/nfm.2023.01.02

[29] Mining and Metallurgical Industry. (2014). Copper using SX–EW technology. *MMP*, (8), 11.

[30] National Geological Service. (n.d.). Teasers for 42 deposits of Kazakhstan. Investment overview. *Available at:* www.geology.kz

[31] Ministry of Industry and Construction of the Republic of Kazakhstan. (2022). Launch of a cathode copper production plant in the Karaganda Region. *Available at:* www.gov.kz

[32] Paletsky, V.A. (2025). Design of an aspiration system to reduce emissions at a hydrometallurgical complex of a mining deposit Bachelor's thesis, Satbayev University.

[33] Arx Minerals. (n.d.). Projects: Berkara Deposit. *Available at:* https://www.arxminerals.kz/

[34] Department of Natural Resources and Environmental Management of the Abai Region. (2024, December 4). Announcement of public hearings (North Berkara). *Available at:* www.gov.kz

[35] Sizikova, N.V., & Kushakova, L.B. (2023). Participation of VNIItsvetmet in the development of hydrometallurgical technology for processing oxidized and mixed copper ores of Kazakhstan deposits. *Innovations and integrated processing of mineral raw materials as key components of economic diversification: Proceedings of the international scientific and practical conference*, *1*, 42-44.

Қазақстан кен орындарының мыс кендерін өңдеу кезінде L-SX-EW қолдану тәжірибесі

Н. Якушев*

«ҚР МШКҚӨ ҰО» РМК «ВНИИцветмет» филиалы, Өскемен, Қазақстан

**Корреспонденция үшін автор:* nikita.yakushev2112@mail.ru

Аңдатпа. Мақалада әлемдік және отандық мыс өнеркәсібі контекстіндегі үймеде шаймалау, сұйық экстракция және электролиз (L-SX-EW) технологиясының қазіргі жағдайына аналитикалық шолу берілген. Шығыс және Орталық Қазақстанның ірі кен орындарын қоса алғанда, Қазақстан Республикасының минералдық-шикізат базасы талданған. Экстракция сызбаларына, минералогиялық құрамның әсеріне, сондай-ақ тотыққан және аралас мыс кендерін өңдеудегі технологиялық қиындықтарға назар аударылды. «ВНИИцветмет» институтының өңірдің гидрометаллургиясын қалыптастырудағы тарихи рөлі баяндалды. Жұмыс Қазақстанның мыс саласының бәсекеге қабілеттілігін қолдау үшін оның маңыздылығын растай отырып, L-SX-EW процесінің ағымдағы технологиялық сызбалары мен тиімділік факторлары туралы деректерді жүйелейді.

Негізгі сөздер: *мыс, үймеде шаймалау, сұйық экстракция), электролиз, Қазақстанның минералдық-шикізат базасы, тотыққан мыс кендері.*

Практика применения L-SX-EW при переработке медных руд месторождений Казахстана

Н. Якушев*

Филиал РГП «НЦ КПМС РК» «ВНИИцветмет», Усть-Каменогорск, Казахстан

**Автор для корреспонденции:* nikita.yakushev2112@mail.ru

Аннотация. В статье представлен аналитический обзор современного состояния технологии кучного выщелачивания, жидкостной экстракции и электролиза (L-SX-EW) в контексте мировой и отечественной медной промышленности. Проанализирована минерально-сырьевая база Республики Казахстан, включая крупные месторождения Восточного и Центрального Казахстана. Уделено внимание схемам экстракции, влиянию минералогического состава, а также технологическим вызовам при переработке окисленных и смешанных медных руд. Освещена историческая роль института «ВНИИцветмет» в становлении гидрометаллургии региона. Работа систематизирует данные о текущих технологических схемах и факторах эффективности процесса L-SX-EW, подтверждая его значимость для поддержания конкурентоспособности медной отрасли Казахстана.

Ключевые слова: *медь, кучное выщелачивание, жидкостная экстракция, электролиз, минерально-сырьевая база Казахстана, окисленные медные руды.*

Publisher's note