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# Research of the Interacting Process of Copper-Base Alloys with Leaching Solutions under the Action of Different Physicochemical Factors

Bagdaulet Kenzalyevich Kenzhaliyev,  
Ainur Nurkalyevna Berkinbayeva and Rustam Hasanovich Sharipov

Kazakh-British Technical University, Almaty, Republic of Kazakhstan

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Corresponding Author:  
Bagdaulet Kenzalyevich  
Kenzhaliyev  
Kazakh-British Technical  
University, Almaty,  
Republic of Kazakhstan  
Email: kenzhaliyevkz@gmail.com

**Abstract:** Analysis of the current scientific and technical data shows the increased difficulty in innovative solutions development for metal extraction from different kinds of mineral raw materials, due to fundamental change in mineral resources base of metallurgy. Apart from polymetallic ores, complex in chemistry and intractable, the basis for the current mineral resources base is formed by technogenic production waste, so-called recovered materials. The source for nonferrous metals is not only mineral but also recovered materials. The possibility of copper and zinc extraction from recovered materials, particularly from latten, widely-used in technology, has been examined. The article studies influence of different physicochemical factors on the process of dissolution of copper-base alloys by cathode and anode polarization of a sulfur-graphite electrode. It is specified that copper and zinc extraction by cathode polarization is 25 and 30% respectively. During the solution process, copper is oxidized and sulfurized and complex zinc sulfates are formed, which prevent metals from further dissolution. Electrolyte concentration, current density and temperature contribute to metal solubility increase. It is shown that the difference in leach process of metal alloys and polymetallic minerals is connected both with metal alloys' structure and mechanism of metals' solution in nonorganic aqua solution. The results of the phase analysis prove that sulfide and copper oxides and hydrated zinc sulfate, i.e., zinc dissolution is made via formation of sulfates.

**Keywords:** Alloys, Electrochemical Leaching, Microstructure of Electrolytes, Nonferrous Metals, Sulfur-Graphite Electrode

## Introduction

Finding ways of sustainable use of non-renewable mineral resources and environmental protection (that are closely related) continues to be vitally essential. Combination of solutions to these two problems is determined by canons in natural science subjects and the condition of metallurgical science. At international research and practice conferences of last few years it has been argued that the objective reason for defaults in usage of mineral resources is a poor scientific research of both primary technologies and waste recovery processes in metallurgy due to absence of rational recycling methods. It was emphasized that technology refinement of mineral processing is made on the basis

of obsolete scientific notions, used in scientific and technical reasons of metallurgical processes.

In international scientific practice innovative technical solutions in metallurgy are also based on traditional physicochemical notions, particularly, about microstructure of nonorganic aqua solutions. Research of process patterns in different nonorganic aqua solutions and electrolyte systems up until today remains a topical problem for description of solutions' origins during their concentration and environmental parameters change. International fundamental science sees an urgent need for creation of theory of solution, applicable for description and predicting of used liquid systems' behavior in the course of technological processes.

Research of hydrometallurgical processes made with the use of electric energy is becoming one of the current research areas.

Importance of fundamental scientific research development in the sphere of hydrometallurgical processes will increase with complication of mineral resources base, growth of technogenic waste and recovered metal materials.

Research arose not only from the necessity to define particularities of dissolution of metal mixtures (for example, alloys) in the process of electrochemical machining, but also to check for the change of physico-chemical parameters, received during dissolution of liquid systems, as there was a possibility to define solutions' microstructure by infrared spectroscopy method.

## Literature Review

Analysis of scientific-technical and patent literature shows that the research is directed to problem-solving connected with certain types of materials and special reactant treatments of technological processes. It is obvious that during study of extraction technology of nonferrous metals (Ahmed *et al.*, 2012; Vafaeian *et al.*, 2011), noble metals (Celep *et al.*, 2011; Zhang *et al.*, 2004) in leach (Alonso-Gómez and Lapidus, 2009) and electrolytic processes (Kenzhaliev, 2014; Silva *et al.*, 1994) from sulfide, oxidized, mixed mineral products and concentrates (Feng and Van Deventer, 2006; Hashemzadehfini *et al.*, 2011; Senanayake, 2007), recovered and technogenic materials (Jessop and Turner, 2011), mineralogical particularity of mining aspects is neglected, as a rule, especially in regard to same-name materials, which can vary in their chemical activity in reference to chemical agents and can show physical properties leading to their incomplete usage in technological process. Insufficient attention is paid to interconnection, interdependence in multicomponent systems both in solid state during thin interpenetration of different minerals and during leach, sorption and electrolytic processes (Jeffrey *et al.*, 2005). Versatile approach to problem-solving in reprocessing of modern mineral, technogenic and recovered materials in mining production has not been created yet, due to the absence of package approach during analysis of thermodynamics, kinetics and reaction mechanism in complex systems.

Scientific and technical literature specifies large-scale and fast extension of systems range, characteristic for modern metallurgic and chemical technologies, having practical application (for example, use of multicomponent solutions (Ficeriova *et al.*, 2002; Ficeriová *et al.*, 2005; Lampinen *et al.*, 2015), complex electrolytes, nanostructured electrodes, composite electrodes etc.). It is noted that technology of extreme parameters is being developed, allowing to increase drastically the efficiency of innovative technical solutions.

Relevance of the conducted research is defined by the necessity of technology intensification based on the usage of experimental data about structure of solutions and transport properties in the system solid-liquid.

Electrochemical dissolution and metal reduction processes have found application in hydrometallurgical technologies long ago. They are largely used recently for manufacturing of articles with purposeful formation of physical and technical properties. Equipment is created that allows implementing technologies with high efficiency and lowest loss of valuable components of materials, let alone reducing of power consumption. However, application problem of electrochemical technologies for efficient reprocessing of complex and refractory mineral raw materials stays up-to-date and attracts increased attention of researchers (Breuer and Jeffrey, 2002; Kenzhaliyev *et al.*, 2014).

As a base for an innovative technology of metal extraction from metal-containing materials we took concurrent process of formation of a leaching agent and reaction of dissolution of metals from primary products in a volume of one reactor. We have not found research in this field in literature accessible to us. In a general-theoretical view multiple literature sources on the study of coupled chemical reactions in metal corrosion research may be considered analogues to the present research. In our case sulfur undergoes a reaction of thiocompound formation, reacting in metal dissolution from solid phase. Meanwhile sulfur ensures intermediate compounds' formation, gathering considerably the rate of metal dissolution reaction. It is evident that reaction of chemical induction forms the basis for chemical processes. Chemical kinetics classifies chemical reactions in accordance with what particles (molecules, ions, atoms and free radicals) take part in an elementary act of reaction. Three types of main types of reactions are distinguished: (1) molecular or simple (interfluent with saturated molecules), (2) chain or radical (with intermediate formation of free radicals or atoms), (3) ionized (involving ions). We can suppose with high percent of confidence that all types of reactions determined by present-day ideas take place in the analyzed electrochemical systems that also complicates the task of our research. Sulfur capacity to form complex structures, for example, thiosulfates of different chemical compositions, adds to complication of the studied reactions. This circumstance specifies the necessity to monitor possible formation of amphiphilic molecules in a solution, which are capable for an easy change under environmental changing.

Literature (Lizama *et al.*, 2002; Wakeman *et al.*, 2008) stipulates that recovery mechanism of mineral resources by dissolution, for example, with the help of bacterial leaching, particularly to nonferrous metals' extraction from materials as polymetallic ores, refractory ores, concentrates, mill tailings, recovered materials and other similar materials.

Method (Sun *et al.*, 2015) of processing of polymetallic ores, concentrates, recovered materials includes activation of starting material by electric action, in this case starting material is fed into an activation chamber, electric action is made by electrodes placed in the chamber and voltage impulses are applied to electrodes. This work allows increasing extraction degree of metals in the leach process and rate of leaching of nonferrous metals from containing materials.

Literature (Gericke *et al.*, 2010) studied mechanism of chemical durability violation of basic sulfide minerals of copper-zinc ores under conditions of exposure to electrochemically processed underspoil waters, on the basis of study of dissolution kinetics of minerals, their chemical composition and structure of their surface, specific surface of minerals, study of their solution products and of further crystallization (newly formed phases) from product solutions.

There has been recently a considerable increase of publications, which shows that there is a pressing necessity of intensification of leach processes of nonferrous metals due to complicating of refinable raw materials. Electrodes (Friedrich and Snell, 2004) and nonorganic and organic solutions (Leaist *et al.*, 1989; Polcaro *et al.*, 1999; Tangirala *et al.*, 2010) are used to accelerate dissolution of nonferrous metals.

## Materials and Methods

The source for nonferrous metals is not only mineral but also recovered materials. Possibility of copper and zinc extraction from recovered materials has been studied, particularly from latten, widely used in technology. Figure 1 shows typical kinetic transition curves of copper from latten by cathode and anode polarization.

Chemical composition of latten %: Cu-58.65, Zn-39.79, Pb-1.34, Cr-0.06, Ni-0.05. Chemical analysis makes clear that composition of latten is quite complex that may influence transition of main metals into solution, particularly, during constant change of leaching solution microstructure.

Methods of work are based on new scientific notations about nonorganic aqua solutions' microstructure, which is formed by molecular principle and on innovative method of usage of a composite sulfur-graphite electrode, which is a source of obtaining of a leaching agent and simultaneously ensures electrochemical reactions in the system electrode-solution mineral raw materials.

Dissolution of latten was made at different concentrations of feed solution, different temperatures, current densities, in these conditions latten was used as anode and cathode, sulfur-graphite electrode was used as counter electrode in both cases.

Figure 1a shows specific rates of copper dissolution versus dissolution time at initial alkali concentration of 0.1, 0.2, 0.5 and 1.0 M. Figure 1b shows specific rates of

zinc dissolution for the same concentrations. Other conditions of experiments: Current density  $i-100\text{A/m}^2$ , cathode-sulfur-graphite electrode, anode-latten.

## Results

According to data from Fig. 1, increase of alkali concentration in the feed solution ambiguously results in a specific rate of copper and zinc dissolution. During increase of alkali concentration from 0.1-1.0 M specific rate of dissolution increases considerably.

It is specified that increase of alkali concentration in the feed solution ambiguously results in a specific rate of copper and zinc dissolution during electrochemical dissolution of latten. During increase of alkali concentration from 0.1-0.2 M specific rate of dissolution increases considerably. During increase of concentration from 0.2-0.5 M and 1.0 M specific dissolution rate decreases, achieving minimal value at 1.0 M. Specific dissolution rates at 0.1-0.2 M for zinc are identical. Specific dissolution rates of zinc for 0.5 and 1.0 M are minimal in this case. Difference in the leach processes of metal alloys and polymetallic minerals is connected both with metal alloys' structure and metal dissolution mechanism in a nonorganic aqua solution.

Results shown on the curves of the interaction of brass according to the different concentrations of sodium hydroxide (0.1-1.0 M) showed that with increasing concentration of sodium hydroxide of 0.1-1.0 M specific dissolution rate of copper increases, respectively, from  $4.78 \cdot 10^{-12} \text{ mol/m} \cdot \text{s}$  to  $16 \cdot 10^{-12} \text{ mol/m}^2 \cdot \text{s}$  (Fig. 1).

The results of the dissolution rate of zinc (Fig. 2) during the process of the leaching of brass, show that in the initial stages leach has a maximum value, a further increase in time (up to 25,200) of the leaching reduces the specific rate: For a concentration of 0.1 M dissolution rate of zinc from  $6.69 \cdot 10^{-11} \text{ mol/m}^2 \cdot \text{s}$  to  $0.5 \cdot 10^{-11} \text{ mol/m}^2 \cdot \text{s}$ ; with the concentration of 0.2 M specific rate from  $25.6 \cdot 10^{-11} \text{ mol/m}^2 \cdot \text{s}$  to  $0.8 \cdot 10^{-11} \text{ mol/m}^2 \cdot \text{s}$ ; having concentration of 0.5 M specific rate of dissolution of zinc decreases from  $38.74 \cdot 10^{-11} \text{ mol/m}^2 \cdot \text{s}$  to  $2.4 \cdot 10^{-11} \text{ mol/m}^2 \cdot \text{s}$ ; with concentration of 1.0 M specific dissolution rate of the zinc drops from  $40.63 \cdot 10^{-11} \text{ mol/m}^2 \cdot \text{s}$  to  $4.8 \cdot 10^{-11} \text{ mol/m}^2 \cdot \text{s}$ .

In this case specific rate decreases slower (Fig. 2), there are inflections, showing the change of dissolution mechanism. It is obvious, that this is connected with formation of hardly soluble zinc entities-ZnO (MeS). Results of X-ray phase analysis prove this fact.

Figure 3 shows infra-red spectrum of a solution, received during leaching of latten by solution  $C_{\text{NaOH}}-0.5 \text{ M}$ , at current density  $i-150\text{A/m}^2$ . In the spectrum (Fig. 3) of a solution, received after latten leaching, adsorption bands of stretch  $\nu(\text{OH})-3418 \text{ cm}^{-1}$ , deformation  $\delta\text{HOH}-1651 \text{ cm}^{-1}$  and librational  $\nu_{\text{L}}\text{H}_2\text{O}-680 \text{ cm}^{-1}$  vibrations of molecular water were detected. Group  $[\text{S}_2\text{O}_3]^{2-}-1118, 997 \text{ cm}^{-1}$ . Group  $[\text{CO}_3]^{2-}-1419 \text{ cm}^{-1}$  (Nakamoto, 2009).

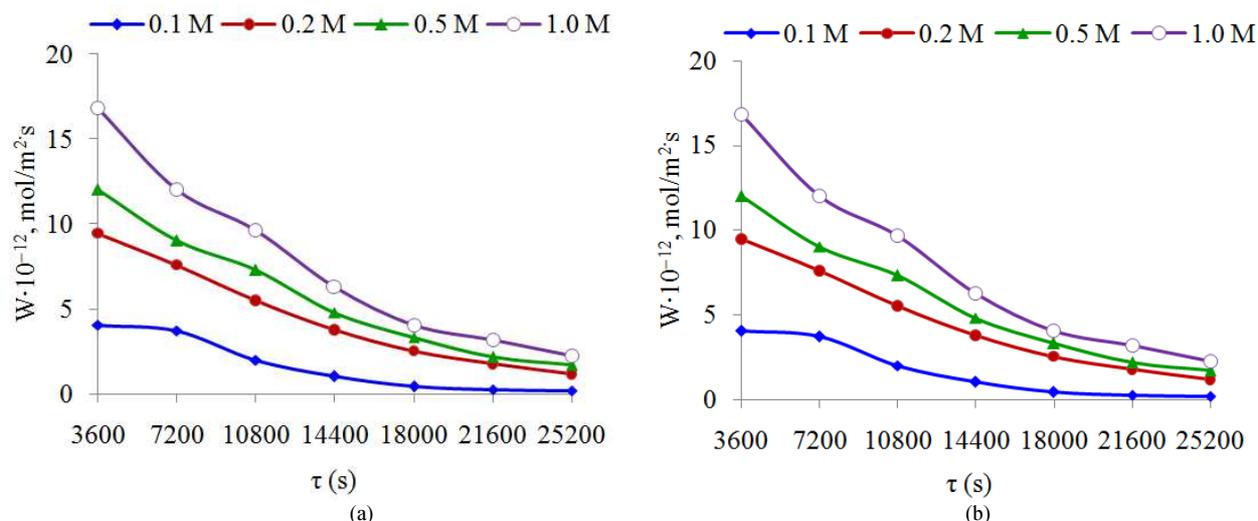


Fig. 1. Specific rate of copper dissolution during latten electro leaching in dependence to sodium hydroxide concentration, (a) i-150 A/m<sup>2</sup>, anode-latten, cathode-sulfur-graphite electrode, (b) i-150 A/m<sup>2</sup>, anode-sulfur-graphite electrode, cathode-latten

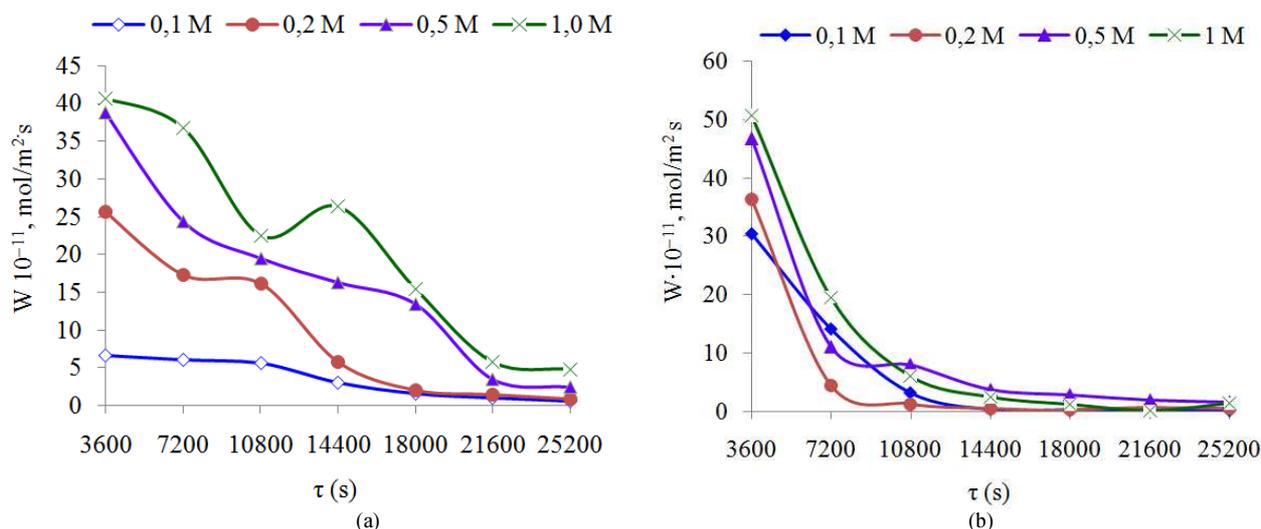


Fig. 2. Specific rate of zinc dissolution during latten electroleaching in dependence to sodium hydroxide concentration, (a) i-150 A/m<sup>2</sup>, anode-latten, cathode-sulfur-graphite electrode, i-150 A/m<sup>2</sup>, anode-sulfur-graphite electrode, cathode-latten

Optical density was measured at a maximum of absorption bands, characterizing vibrations  $\nu$  OH,  $\delta$  HOH,  $\nu_L$ H<sub>2</sub>O,  $\nu_4$ (E) thiosulfate ion,  $\nu_1$ (A<sub>1</sub>) thiosulfate ion,  $\nu_3$  group [CO<sub>3</sub>]<sup>2-</sup> (Fig. 3). Optical density at maximums of absorption bands, corresponding to: Stretch vibrations of water  $\nu$  OH is 1.488; deformation vibrations of water  $\delta$  HOH-0.882; librational vibrations of water  $\nu_L$ H<sub>2</sub>O – 0.855. At a maximum of an absorption band, characterizing vibration  $\nu_4$ (E) of a thiosulfate ion, at wave number 1118 cm<sup>-1</sup> optical density is 0.457. Optical density at a maximum of an absorption band at wave number 997 cm<sup>-1</sup>, characterizing vibration  $\nu_1$ (A<sub>1</sub>) of thiosulfate ion is 0.498. Optical density at a maximum of an absorption

band of vibration of  $\nu_3$  of group [CO<sub>3</sub>]<sup>2-</sup> at wave number 1419 cm<sup>-1</sup> is 0.4204.

Semi-quantitative X-ray phase analysis of latten was made before and after electrochemical leaching. The shooting was made on D8 Advance (Bruker) machine,  $\alpha$ -Cu, voltage across the tube 40 kV, current 40 ma. Received data of diffraction patterns was processed and interplanar spacing was measured in software EVA. Interpretation of samples and phase search were made in Search/match program using base of powdery diffractometric data PDF-2 (ICDD). Error of semi-quantitative analysis amounts to  $\pm 20\%$  (relative).

Phase composition of the feed and the sample received after leaching is shown in Table 1-2.

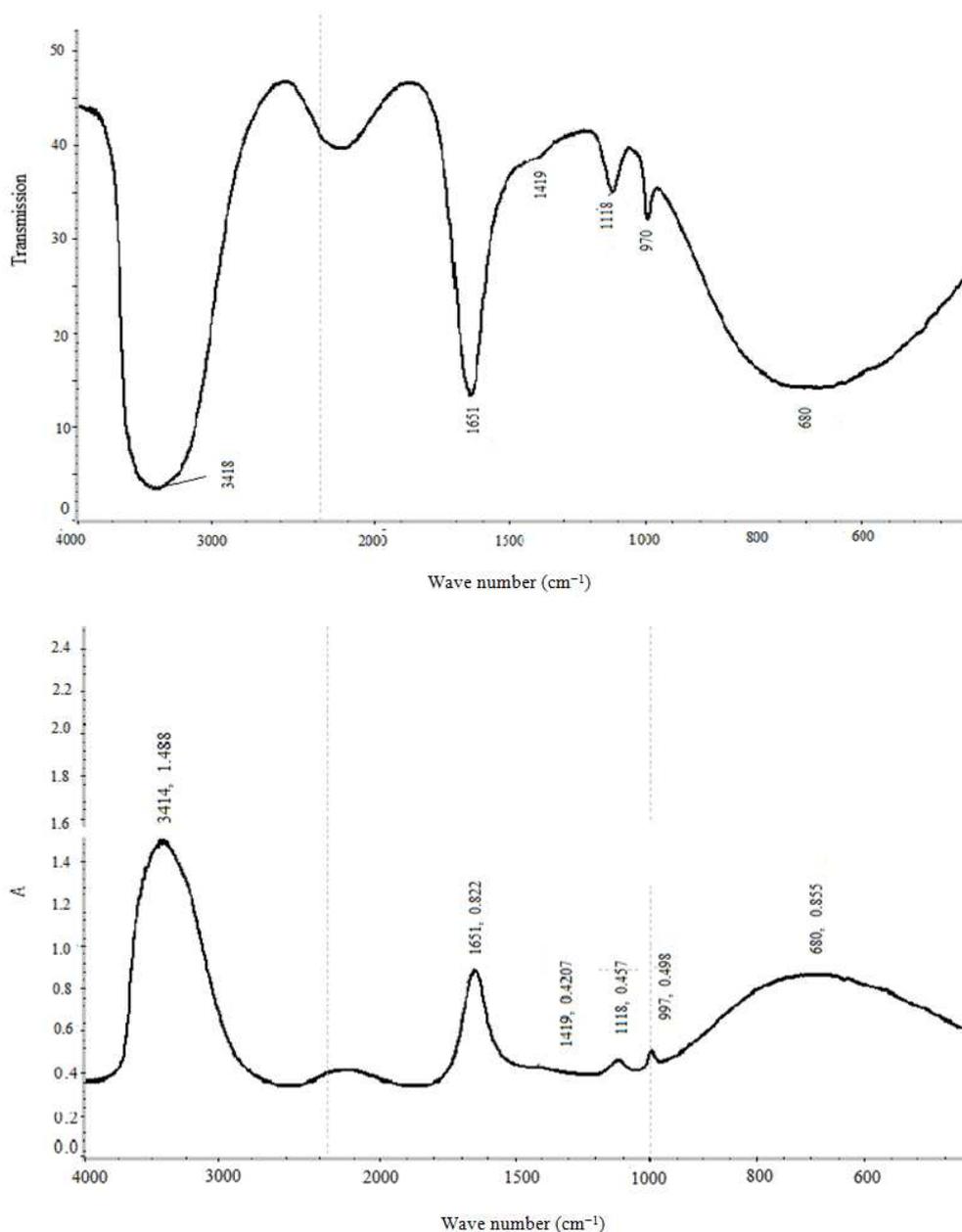


Fig. 3. Infra-red spectrum of latten solution

Table 1. Results of X-ray phase analysis of latten before leach process

Component name	Formula	Semi-quantitative composition
Copper Zinc	Cu 0.64 Zn 0.36	62.9
Zhanghengite, syn	CuZn	27.1
Lead Oxide	Pb <sub>2</sub> O	4.3
Zinkosite, syn	Zn(SO <sub>4</sub> )	5.7

It is specified that after leaching of latten by 0.5 M solution of NaOH at current density  $i = 150 \text{ A/m}^2$  copper oxide, copper sulfide and zinc sulfate are found in solid products of leaching.

Table 2. Results of X-ray phase analysis of latten after leaching by 0.5 M solution of NaOH at current density  $i = 150 \text{ A/m}^2$

Component name	Formula	Semi-quantitative composition
Covellite	CuS	20.9
Zinc sulfate hydroxide hydrate	Zn <sub>4</sub> SO <sub>4</sub> (OH) <sub>6</sub> ·4H <sub>2</sub> O	15.7
Zinc sulfate hydroxide hydrate	Zn <sub>4</sub> SO <sub>4</sub> (OH) <sub>6</sub> ·3H <sub>2</sub> O	16.8
Sulfur	S	23.4
Copper Oxide	Cu <sub>2</sub> O	3.9
Graphite	C	19.3

Metals (Cu, Zn) are often present in the form of oxides in mineral and recovered materials. Therefore we studied the influence of physicochemical factors on leaching of copper and zinc oxides using sulfur-graphite electrode.

Figure 4 shows that with increase of sodium hydroxide concentration in the first hour specific rate increases, then it decreases, thereafter it scarcely changes, pH is decreasing. Solution products of sulfur-graphite electrode are likely to oxidize and form sulfite and sulfate anions, which scarcely interact with copper oxides. X-ray analysis of solid residue after the leach process showed that when interacting with solution zinc oxides transform into hydroxide, which partially dissolves in electrolyte.

In the case of CuO copper dissolution most likely comes from cuprous oxide ( $\text{Cu}_2\text{O}$ ).

The Table 3 shows conditions and results of the experiments on electro leaching of copper and zinc oxides. It is shown that with an increase in time of the leaching duration, a decrease is observed in specific rate. A decline is observed in the quantity of dissolved oxygen, pH and conductivity.

It was found that with increasing concentration of sodium hydroxide in the first hour, an increase and then a decrease in specific rate is observed. A decrease is observed in the quantity of dissolved oxygen, pH and conductivity.

The results of the experiment show that by increasing the current density and temperature, an increase is observed in specific rate of dissolution of metals, quantity of oxygen, pH and conductivity.

Solution products of sulfur-graphite electrode are likely to oxidize and form sulfite and sulfate anions,

which scarcely interact with copper oxides. X-ray analysis of solid residue after the leach process showed that when interacting with solution zinc oxides transform into hydroxide, which partially dissolves into electrolyte. In the case of CuO copper dissolution most likely comes from cuprous oxide ( $\text{Cu}_2\text{O}$ ), according to literature data.

Figure 5 shows infra-red spectrum of solution received after leaching of  $\text{Cu}_2\text{O}$ . In the spectrum (Fig. 5) of the solution absorption bands of stretch  $\nu(\text{OH})$ -3400  $\text{cm}^{-1}$ , deformation  $\delta\text{HOH}$ -1651  $\text{cm}^{-1}$  and librational  $\nu_{\text{L}}\text{H}_2\text{O}$ -674  $\text{cm}^{-1}$  vibrations of molecular water were found. Group  $[\text{S}_2\text{O}_3]^{2-}$  -1119, 997  $\text{cm}^{-1}$ . Group  $[\text{CO}_3]^{2-}$  -1395  $\text{cm}^{-1}$  (Nakamoto, 2009)

Optical density was measured at a maximum of absorption bands, characterizing vibrations  $\nu \text{OH}$ ,  $\delta \text{HOH}$ ,  $\nu_{\text{L}}\text{H}_2\text{O}$ ,  $\nu_4(\text{E})$  thiosulfate ion,  $\nu_1(\text{A}_1)$  thiosulfate ion,  $\nu_3$  group  $[\text{CO}_3]^{2-}$  (Fig. 5). Optical density at maximums of absorption bands, corresponding to: Stretch vibrations of water  $\nu \text{OH}$  is 1.538; deformation vibrations of water  $\delta \text{HOH}$ -0.872; librational vibrations of water  $\nu_{\text{L}}\text{H}_2\text{O}$ -0.828. At a maximum of an absorption band, characterizing vibration  $\nu_4(\text{E})$  of a thiosulfate ion, at wave number 1119  $\text{cm}^{-1}$  optical density is 0.438. Optical density at a maximum of an absorption band at wave number 997  $\text{cm}^{-1}$ , characterizing vibration  $\nu_1(\text{A}_1)$  of a thiosulfate ion is 0.486. Optical density at a maximum of an absorption band of vibration of  $\nu_3$  of group  $[\text{CO}_3]^{2-}$  at wave number 1395  $\text{cm}^{-1}$  is 0.4051.

Identical results were received after study of physicochemical characteristics of solutions during zinc oxide leaching by electrochemical method.

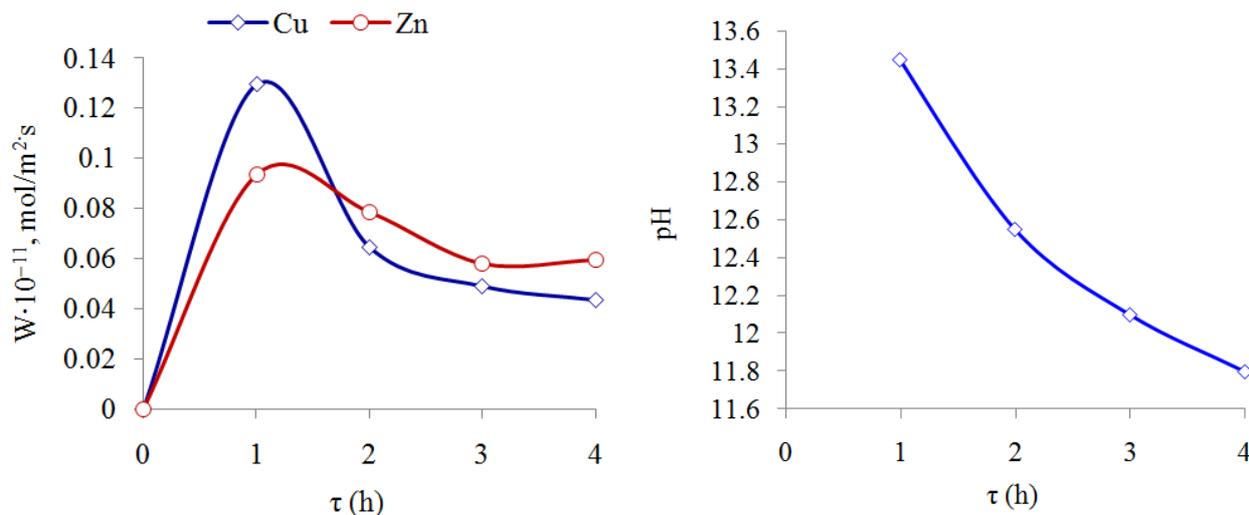


Fig. 4. Specific rate changing of copper and zinc pH in the leach process

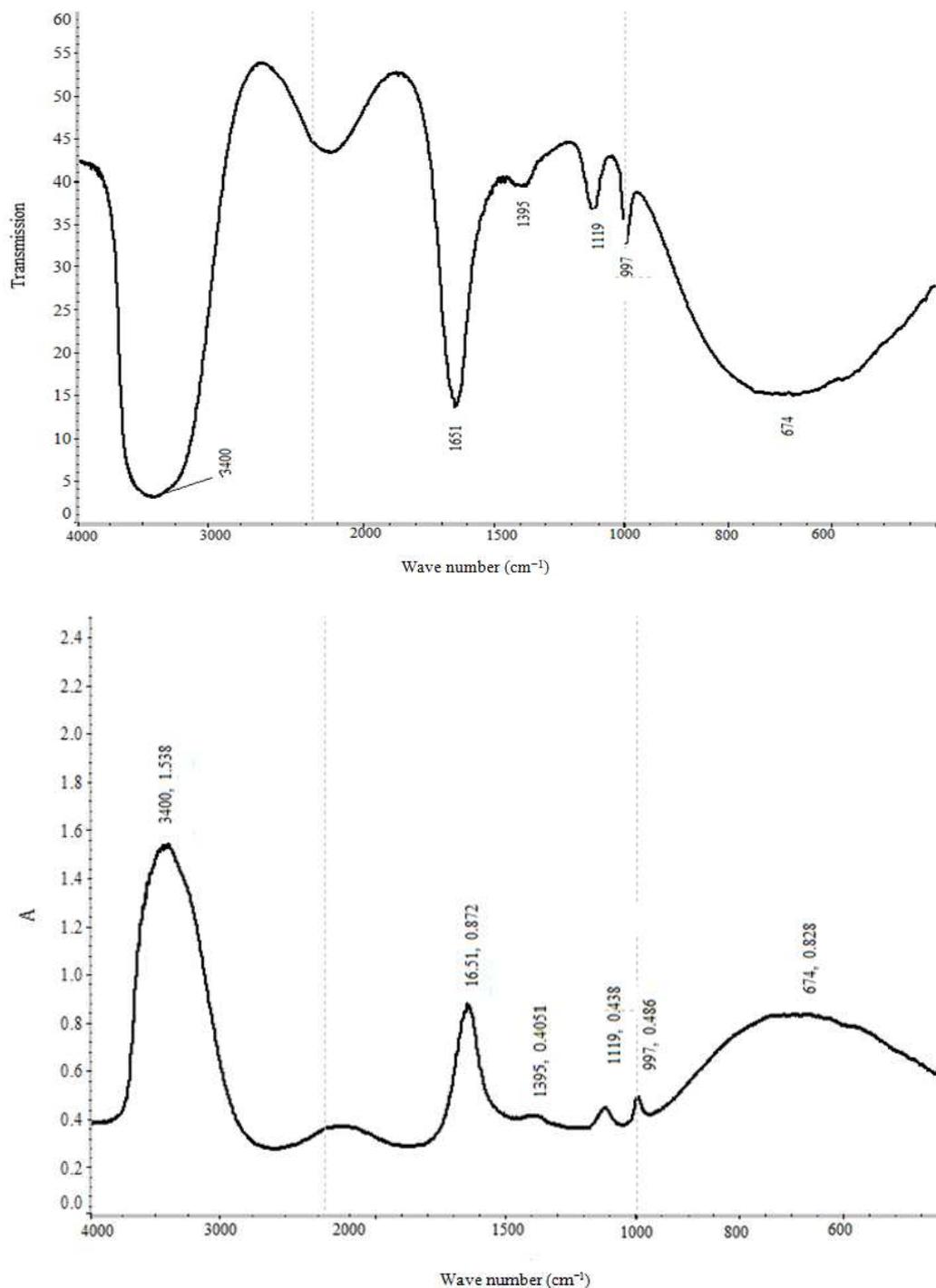


Fig. 5. Infra-red spectrum of solution received after leaching of  $\text{Cu}_2\text{O}$

In the spectrum of solution received after leaching of  $\text{ZnO}$  (Fig. 6) absorption bands of stretch  $\nu(\text{OH})$ -3431  $\text{cm}^{-1}$ , deformation  $\delta\text{HOH}$ -1651  $\text{cm}^{-1}$  and librational  $\nu_1\text{H}_2\text{O}$ -685  $\text{cm}^{-1}$  vibrations of molecular water were found. Group  $[\text{S}_2\text{O}_3]^{2-}$ -1119, 997  $\text{cm}^{-1}$ . Group  $[\text{HCO}_3]^-$ -1369  $\text{cm}^{-1}$  (Nakamoto, 2009). Optical density was

measured at a maximum of absorption bands, characterizing vibrations  $\nu \text{OH}$ ,  $\delta \text{HOH}$ ,  $\nu_1\text{H}_2\text{O}$ ,  $\nu_4(\text{E})$  thiosulfate ion,  $\nu_1(\text{A}_1)$  thiosulfate ion and stretch vibration of group  $[\text{HCO}_3]^-$  (Fig. 6). Optical density at maximums of absorption bands, corresponding to: Stretch vibrations of water  $\nu \text{OH}$  is 1.517; deformation

vibrations of water  $\delta$  HOH-0.872; librational vibrations of water  $\nu_L$ H<sub>2</sub>O-0.834. At a maximum of an absorption band, characterizing vibration  $\nu_4$ (E) of a thiosulfate ion, at wave number 1119  $\text{cm}^{-1}$  optical density is 0.493. Optical density at a maximum of an

absorption band at wave number 997  $\text{cm}^{-1}$ , characterizing vibration  $\nu_1$ (A<sub>1</sub>) of a thiosulfate ion is 0.533. Optical density at a maximum of an absorption band of stretch vibration of group [HCO<sub>3</sub>]<sup>-</sup> at wave number 1369  $\text{cm}^{-1}$  is 0.433.

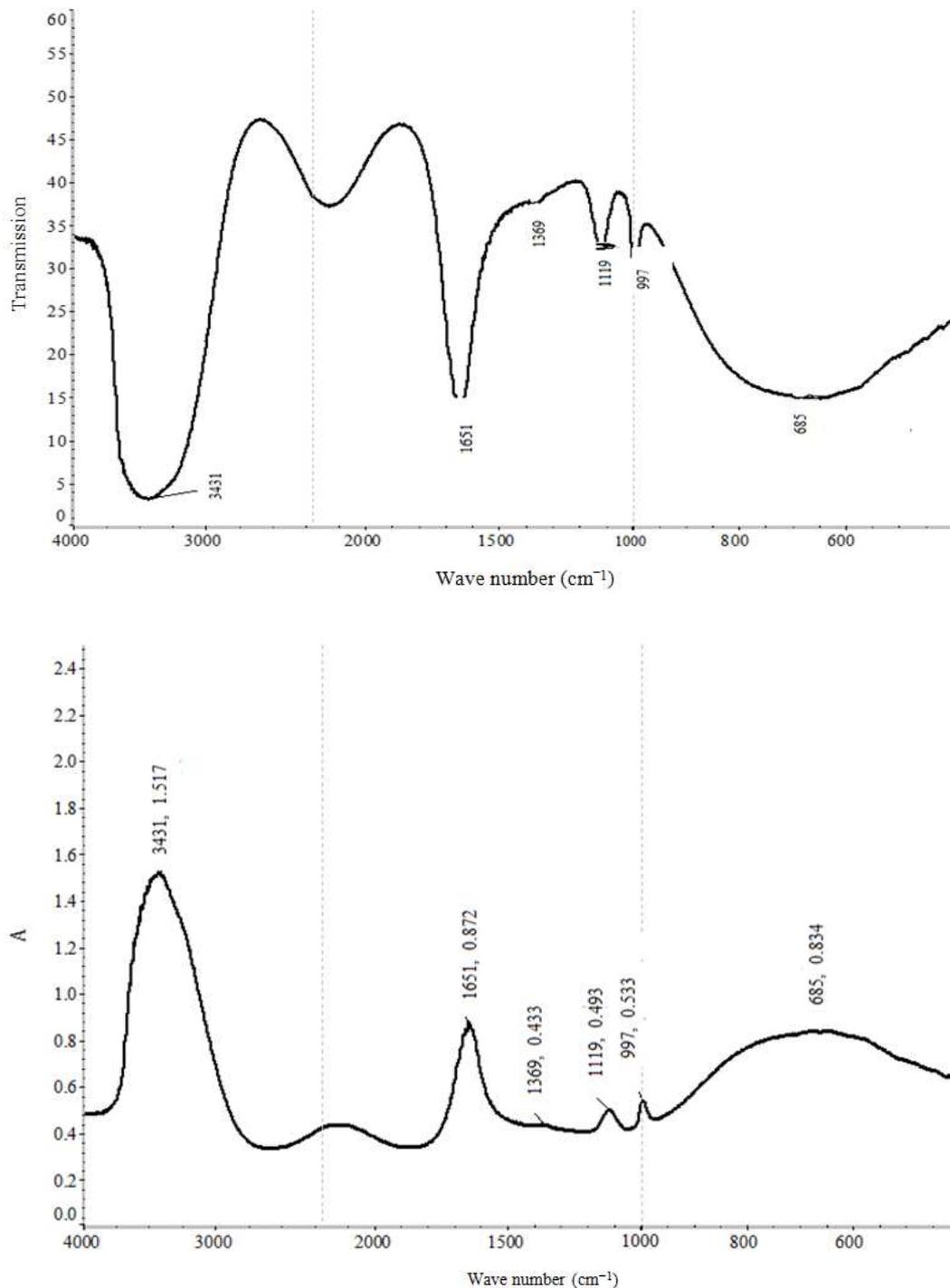


Fig. 6. Infra-red spectrum of solution received after leaching of ZnO

Table 3. Conditions and results of experiments during copper and zinc oxides leaching

$\tau$ , hour	S, M	i, A/m <sup>2</sup>	t, °C	$\omega$ , rpm
<b>Conditions</b>				
Duration influence				
1	0.5	100	25	480
2	0.5	100	25	480
3	0.5	100	25	480
4	0.5	100	25	480
Solvent concentration influence				
1	0.1	100	25	480
1	0.2	100	25	480
1	0.5	100	25	480
1	1	100	25	480
Current density influence				
1	0.5	50	25	480
1	0.5	100	25	480
1	0.5	150	25	480
Temperature influence				
1	0.5	100	25	480
1	0.5	100	40	480
1	0.5	100	50	480
1	0.5	100	60	480
<b>Results</b>				
pH	DO, mg/L	Eh, mmho/cm	W(Cu), mole/m <sup>2</sup> ·s	W(Zn), mole/m <sup>2</sup> ·s
Duration influence				
13.45	5.50	65.30	0.1296	0.0937
12.55	4.70	74.10	0.0648	0.0784
12.1	4.20	52.80	0.0491	0.0581
11.8	3.60	47.60	0.0435	0.0597
Solvent concentration influence				
11.3	3.95	24.35	0.0876	0.0804
12.75	4.47	45.30	0.1352	0.1027
13.45	5.50	65.30	0.1463	0.1296
13.66	7.46	95.70	0.1548	0.1474
Current density influence				
13.43	5.48	64.50	0.1117	0.0882
13.45	5.50	65.30	0.1296	0.0937
13.45	5.51	66.40	0.1430	0.1343
Temperature influence				
13.45	5.50	65.30	0.1296	0.0937
13.43	6.30	72.30	0.1475	0.1423
13.44	6.40	85.70	0.1653	0.1542
13.43	6.20	91.50	0.1742	0.1637

## Discussion

Results of latten interacting process in dependence to different sodium hydroxide concentrations (0.1-1.0 M) shown on curves revealed that with the increase of sodium hydroxide concentration from 0.1-1.0 M specific rate of copper dissolution is increasing, respectively, from  $40.78 \cdot 10^{-11}$  mole/m<sup>2</sup>·s up to  $160 \cdot 10^{-11}$  mole/m<sup>2</sup>·s (Fig. 1).

It is determined that specific rates of metal dissolution are higher by cathode polarization of a sulfur-graphite electrode. Specific rates are decreasing in time in both cases that can be related to alloy passivation, i.e., CuO, CuS formation. During cathode polarization of a sulfur-graphite electrode the rate noticeably depends on electrolyte concentration in first

4 h (and increase of concentration noticeably affects during anode polarization of a sulfur-graphite electrode).

It is established that specific rates of dissolution of zinc is higher than of copper. During cathode polarization the effect of NaOH concentration on the zinc output is stronger that during anode polarization. In this case specific rate decreases slower, there are inflections, showing the change of dissolution mechanism. It is obvious, that this is connected with formation of hardly soluble zinc entities-ZnO (MeS). Results of X-ray phase analysis prove this fact.

## Conclusion

The article studied influence of different physicochemical factors on the process of dissolution of

copper-base alloys by cathode and anode polarization of a sulfur-graphite electrode. It is shown that copper and zinc extraction by cathode polarization is 25 and 30% respectively. During the solution process, copper is oxidized and sulfurized and complex zinc sulfates are formed, which prevent metals from further solution. Electrolyte concentration, current density and temperature contribute to metal solubility increase.

The article analyzed the influence of different physicochemical factors on the process of dissolution of nonferrous metals from oxides using sulfur-graphite electrode. It is specified that dissolution rates of metals from oxides are not high. Therefore, it is shown that metal dissolution primarily depends on the nature of the feed material, its metal speciation, leachates and nature of dissolvent, according to our study of leaching. Microstructure of leaching solutions was studied by the method of infrared spectroscopy. The conclusion that almost all physicochemical factors influence the microstructure of nonorganic aqua solutions and that microstructure of nonorganic aqua solutions has a molecular-based nature, has been proven.

It is recommended in the leaching technology to obtain sodium sulfide compounds electrochemically directly in an alkali solution from sulfur-containing solid materials, in order to combine processes of receiving of reagents and extraction of noble and nonferrous metals from ores.

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## Author's Contributions

**Bagdaulet Kenzalyevich Kenzhaliyev:** Organized the study, data collection of the study sample, analysis and writing of the manuscript.

**Ainur Nurkalyevna Berkinbayeva:** Designed the research plan, participated in the results analysis.

**Rustam Hasanovich Sharipov:** Contributed to the reviewing of the article critically.

## Ethics

The authors have no conflicts of interest in the development of the research and publication of this article.

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