Extraction of Valuable Elements from Industrial Waste in the Kyrgyz Republic Based on the Process of Electrophysical Ionization

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Abstract: The relevance of this study is due to the need to find effective and environmentally safe extraction technologies, which is especially important for the Kyrgyz Republic, where industrial waste contains significant amounts of valuable components. The objective of this article is to investigate the applicability and effectiveness of the electrophysical ionization process for extracting valuable elements from industrial waste in the Kyrgyz Republic. The study analyses the mass concentrations of extracted elements after their treatment using electrophysical ionization. The results showed that the electrophysical ionization process is effective for extracting copper with a concentration of more than 1000 ppm, while the concentrations of uranium and tantalum were significantly lower, indicated the need for further optimization of the methodology. Additionally, moderate concentrations of phosphorus, strontium and barium were established which may be promising for their joint extraction. Theoretically, they enrich the knowledge of ionization processes in the context of waste recycling; practically, they pave the way for improving the efficiency of element extraction from waste. The results of the study provide a basis for engineering design, planning and optimization of recycling processes which can contribute to the sustainable development of the regional economy and improvement of the environmental situation.

Keywords: copper sulphate; electric field; spectroscopic analysis; waste recycling

1. Introduction

The study of new approaches to the recirculation of industrial waste has gained significance in the context of the global environmental crisis and the depletion of natural resources. As in many other countries, in the Kyrgyz Republic, the issue of waste disposal is particularly acute because of the insufficient development of modern waste processing technologies. However, industrial waste contains significant quantities of valuable elements which can be extracted and returned to the economic cycle[1-3].

There are four main states of matter: gas, liquid, solid, and plasma. However, there are other less common states that possess unique physical properties. An example of such a state is the Bose-Einstein condensate (BEC), in which atoms move in a coordinated manner to form a single quantum mechanical wave[1]. This state, in which all atoms are in one quantum state, behaves as a single macroscopic quantum wave. BEC was first experimentally achieved in 1995 in rubidium and sodium atoms using optical magnetic traps[2]. Since then, technologies have been improved, and condensates have been obtained in optical traps, lattices, and on atom chips, as well as molecular and photonic condensates being developed[4-6].

Currently, the BEC, representing an ensemble of bosons (including the Higgs boson) cooled to extremely low temperatures (0 K, -273.15°C), allows the observation of quantum effects on a macroscopic level[9]. The use of such

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states of matter, such as the BEC, in quantum informatics-for example, as qubits for quantum computers-as well as in other areas requiring high system coherence, such as superconductivity and superfluidity, opens up new possibilities for creating materials with revolutionary properties. This macroscopic-level coherence emerging in the quantum world enables materials to acquire new qualities that are capable of radically changing existing technologies[10), 11)]. It is noteworthy that a significant portion of recent Nobel Prizes in Physics have been awarded for research related to coherent phenomena, such as laser emission, the behaviour of cold atoms, the properties of liquid helium, and superconductors. This underscores the importance of studying and applying coherent quantum interactions to physical systems.

Consequently, it can be concluded that coherence in collective quantum interactions within a physical system can initiate the emergence of new physical properties in substances and materials. These properties can be used to develop products for various purposes and scales in industry.

The hypothesis of this study is that modern methods of electrophysical ionization and quantum mechanics, such as the use of the BEC state, can be adapted for efficient extraction and recirculation of valuable elements from industrial waste. This not only promotes the sustainable use of resources, but also represents a new approach to managing industrial waste, capable of minimizing environmental damage and enhancing the economic efficiency of production processes. Main objectives:

i. Develop a new method for extracting valuable elements from industrial waste using the principles of quantum mechanics and the BEC.
ii. Assess the economic and environmental effectiveness of the proposed recycling methods in the context of sustainable development in the Kyrgyz Republic.

Specific tasks:

a) Study the physical properties of the BEC and its potential applications in extraction processes.
b) Develop and test a prototype installation for electrophysical ionization using the quantum states of matter to extract valuable elements from waste.
c) The chemical composition of industrial waste in the Kyrgyz Republic was analysed to determine the content of valuable elements.
d) Model the interaction processes in quantum systems as applied to recycling technologies.

These tasks aim to confirm the hypothesis regarding the feasibility of using quantum technologies in the recycling of industrial waste and to demonstrate their advantages over standard methods in terms of sustainability and economic efficiency.

2. Literature Review

The recycling of industrial waste has garnered heightened interest in recent years, motivated by environmental issues and economic prospects. Research has emphasised the necessity of advancing technologies for the effective extraction of valuable elements from waste, thereby alleviating resource scarcity and minimising environmental pollution. This literature review analyses significant advancements in waste recycling techniques, specifically emphasising the electrophysical ionization process and its utility in extracting valuable elements.

The initial technique for element extraction from industrial waste was chemical leaching, which utilises chemical solvents to dissolve specific elements from solid waste. This method, while effective, presents environmental hazards due to the utilisation of hazardous chemicals and the possibility of toxic by-products [6]. In light of these challenges, electrochemical techniques, such as electrophysical ionization, have surfaced as viable alternatives owing to their eco-friendly characteristics and efficacy[12)].

Electrophysical ionization, employing electric fields to extract ions from waste solutions, has been thoroughly investigated in recent years. F. Akhter et al[13)]. demonstrated the effectiveness of this method in extracting heavy metals from industrial wastewater, resulting in substantial decreases in environmental contamination. A study by L. Chen et al[14)]. similarly indicated elevated recovery rates of metals, including copper and lead, through electrophysical ionization, thereby reinforcing the method's viability for industrial waste recycling.

Theoretical advancements in quantum mechanics, especially the utilisation of Bose-Einstein condensates (BEC), have facilitated the emergence of innovative methods for material extraction. According to M.H. Anderson et al[15)]., Bose-Einstein Condensate (BEC) facilitates the observation of quantum phenomena at a macroscopic level, presenting novel opportunities for improving the efficiency of industrial processes, such as element extraction. Research conducted by T. Vibel et al[16)]. investigated the application of BEC in ionization processes, revealing enhancements in energy efficiency and element recovery.

Notwithstanding these advancements, the extraction of specific elements, including uranium and tantalum, continues to pose difficulties. Conventional techniques, such as flotation and chemical precipitation, frequently result in inadequate recovery rates for these elements owing to their minimal concentrations in waste[17)]. S. Gulliani et al[18)]. have examined the amalgamation of electrophysical ionization with techniques like ultrasonication and magnetic separation to enhance the recovery of rare and dispersed elements. This study indicates that optimising process parameters, such as electric field strength and electrode materials, can substantially improve the extraction of elements like uranium and tantalum.

In the Kyrgyz Republic, there is an increasing demand for efficient waste recycling technologies to tackle the region's industrial waste issues. Research conducted by N. Totubaeva et al[19]. and T.I. Turdiev and A.G. Nizamiev[20] has underscored the economic viability of extracting copper, phosphorus, and other valuable elements from regional industrial waste. Nonetheless, these studies underscore the necessity for technological advancements to enhance the efficiency and sustainability of recycling processes.

The literature on waste recycling technologies highlights electrophysical ionization as an efficient and eco-friendly technique for extracting valuable elements from industrial waste. Nevertheless, obstacles persist, especially concerning the extraction of low-concentration elements. Additional research is required to refine process parameters and incorporate quantum mechanical principles, such as Bose-Einstein Condensation, to improve the efficiency and scalability of these technologies. This study expands on previous research by examining the feasibility of electrophysical ionization for extracting elements from industrial waste in the Kyrgyz Republic, emphasising the enhancement of valuable component recovery and the reduction of environmental impact.

3. Materials and Methods

This research was conducted in the laboratories of Osh State University and Osh Technological University in Osh, Kyrgyz Republic. The samples used included industrial waste from the Kansk Industrial Complex of the Kyrgyz Republic, which contained valuable elements. A total of 100 kg of waste was selected for the study, which was pre-analysed for the content of valuable elements such as copper (Cu), uranium (U) and tantalum (Ta), phosphorus (P), strontium (Sr), antimony (Sb), yttrium (Y), lanthanum (La), and scandium (Sc), barium (Ba) and strontium (Sr), from a vast area of waste to ensure the representativeness of the results.

Industrial waste samples were gathered from multiple places within the Kansk Industrial Complex to guarantee a broad and representative sample collection. The garbage was initially categorised and classed according to its physical characteristics and visual attributes. Thereafter, the samples were pulverised into a fine powder with a mechanical grinder to enhance the surface area and aid the extraction process. The soil samples were subsequently dissolved in specific solvents to generate working solutions. The solvents were selected for their capacity to dissolve the target elements while reducing interference from other constituents in the trash.

The principal technique for element extraction is electrophysical ionization. This procedure entails the conduction of electric current via an aqueous solution containing metal ions. This approach was selected due to its superior efficiency in extracting components from intricate mixes and its capacity for real-time process control.

The electrophysical ionization apparatus comprised a plexiglass chamber with cathode and anode electrodes linked to a direct current power source. The anode chamber housed a copper electrode secured within a stiff framework and protected from the surrounding aqueous solution by a filter cloth to maintain the separation of the anode sludge. The cathode chamber housed a stainless-steel electrode. The surface area of both the anode and cathode measured 120 cm². The anode current density, defined as the current per unit area of the anode electrode, was 0.6 A/cm². The investigation lasted 120 min, beginning with an anode electrode mass of 42.65 g. Samples of the anode sludge were obtained bi-hourly. After the experiment concluded, the masses of the anode and sludge were quantified.

The developed setup consisted of a plexiglass cell with cathode and anode electrodes connected to a direct current power supply (Figure 1). This design simplifies the process of copper sulphate production, reduces its cost, and potentially enhances the competitiveness of the product.

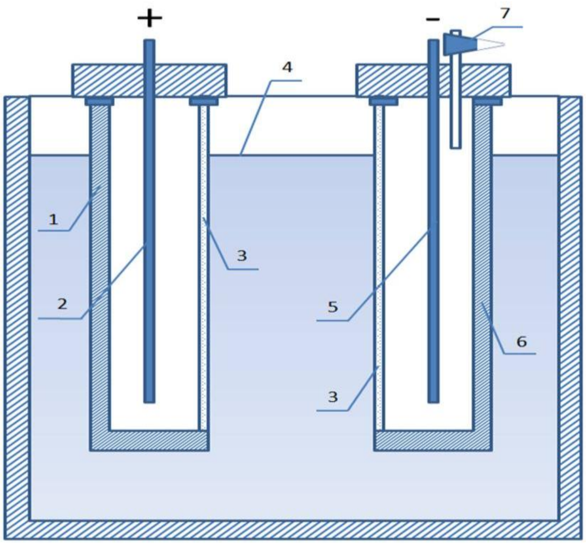

Fig. 1: Device for electrophysical ionization.
Note: 1 – anode chamber; 2 – copper electrode; 3 – membrane (filter fabric); 4 – water level; 5 – stainless steel electrode; 6 – cathode chamber; 7 – tap for cathodic gas
Source: compiled by the authors.

The granular sludge's chemical composition was analysed using spectrometric techniques. This approach facilitated the accurate quantification of Cu and other metals in the precipitate. An evaluation was performed following each experiment to determine the efficacy of the electrophysical ionization technique. The spectroscopic examination utilised an atomic absorption spectrometer (AAS) and an inductively coupled plasma mass spectrometer (ICP-MS). The AAS was utilised for the quantitative analysis of copper, whereas the ICP-MS was employed to identify and quantify additional trace elements in the precipitates. The materials were prepared for examination by dissolving them in suitable acids and diluting them to acceptable quantities.

The influence of the electric field on the solution is described by an equation representing the work done on the system and is expressed as follows (1):

$$dA = TdS - dU \ (1)$$

where, dA – work differential; T – temperature; dS – change in entropy; dU – change in the internal energy of the system.

The effect of an electric field on a solution is described by equation (1), which relates the work done by the system to heat, entropy change, and internal energy change. In this equation, the first term (TdS) represents the work that depends on the change in entropy, and the second term (dU) represents the change in internal energy of the system. Changes in these quantities determine how the electric field interacts with the molecules of the solution, affecting its thermodynamic state.

Equation (2) expresses the rate of change of work per unit of time, in particular through the rate of change of entropy and internal energy. This allows us to estimate the dynamic effect of the electric field on the system. The lower the activation energy of a system, the more work it performs during an isothermal process under the influence of an electric field:

$$\frac{dA}{dt} = \frac{TdS}{dt} - \frac{dU}{dt}, (2)$$

The dynamics of the energy change in the condensed phase (solution) over time interval dt can be represented by the following equation (3):

$$\frac{dU}{dt} = \frac{Qdm}{dt} = Q\frac{mkT}{\hbar}exp\left[-\frac{E_a}{kT}\right], (3)$$

where, Q – energy capacity of the solution; m – the mass of the system under consideration; E_a is the activation energy; $\hbar$ – reduced Planck's constant, a quantum mechanical constant.; k – Boltzmann constant, a fundamental physical constant that relates the average kinetic energy of particles in a system to the temperature.

The Hamiltonian operator is an essential concept in quantum mechanics that represents the entire energy of a system. It encompasses both kinetic energy (the mobility of particles) and potential energy (energy stored inside the system owing to position or contact forces). The Hamiltonian is employed in the Schrödinger equation to ascertain the temporal evolution of the system and to identify its potential energy levels. If the Hamiltonian operator of this system is denoted as $\hat{H}$, then the stationary states ψ_k and the corresponding energy levels E_k of these states are determined from the solution of the Schrödinger equation (4):

$$\hat{H}\psi_k = E_k\psi_k, (4)$$

where, $\hat{H}$ – Hamiltonian operator, which represents the total energy (kinetic + potential) of the system in quantum mechanics; ψ_k – the stationary states of the system, which represent the allowed quantum states that the system can occupy; E_k – energy levels corresponding to the stationary states ψ_k, representing the quantized energy values of the system.

According to the principles of quantum mechanics, a system can exist in a linear superposition of stationary states (5):

$$\psi_{int} = \sum c_k\psi_{fin} \ (5)$$

where, ψ_{int} – initial state of the liquid-phase condensed system; ψ_{fin} – final state of the system; c_k – coefficient representing the contribution of each stationary state ψ_k to the final state of the system.

The acquired data was analysed with statistical data processing tools. Statistical tools, including regression analysis and principal component analysis, facilitate the evaluation of relationships between process factors and the efficacy of element extraction. Regression analysis was utilised to determine the correlation between the applied voltage, electric field strength, and the mass of the precipitate. Principal component analysis was employed to ascertain the primary parameters affecting extraction effectiveness and to diminish the dimensionality of the data set. This statistical method facilitated the comprehension of the intricate connections among the diverse process factors and their influence on the extraction of valuable materials. This work utilised a systematic methodology encompassing sample preparation, electrophysical ionization, spectroscopic analysis, and data analysis, yielding a thorough comprehension of the extraction process for valuable components from industrial waste. Statistical approaches facilitated the identification of critical elements affecting extraction efficiency and the optimisation of process parameters.

4. Results

The production of copper sulphate from industrial waste is a labour-intensive and economically costly technological process. Therefore, the development of equipment that optimizes the technological processes is important. To address this issue, a setup for electrophysical ionization was developed and designed to obtain copper sulphate from industrial waste.

According to global practice, anodic scrap or copper granules are traditionally used to neutralize circulating electrolytes. However, the use of copper granules is expensive, which increases the cost of copper sulphate and reduces its competitiveness in the global market.

For the analysis of the sediment morphology, the collected sample was dried in an oven at a temperature of 110±5°C until a constant mass was achieved. The powder structure was assessed using microscopy, as shown in Figure 2. The image depicts a microscopic photograph of the crystalline formation of the anodic sediment obtained as a result of electrophysical ionization. The crystals exhibit irregular shapes with distinct facets and angles, and are coloured blue, which may be due to image colour processing or specific characteristics of the chemical composition of the substance.

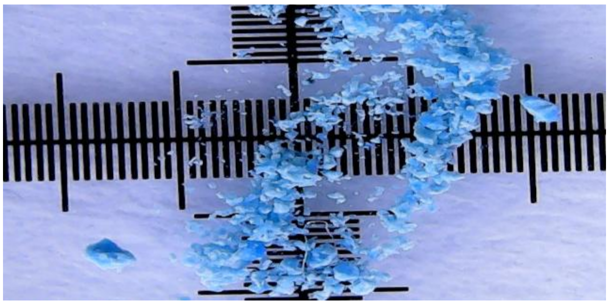

Fig. 2: Structure of the powdered anodic deposit.
Source: compiled by the authors

The measurement scale present in the image allows for the estimation of the particle sizes. It is evident that the sediment sizes vary, with both larger and smaller crystals observed. It can also be noted that the crystals were unevenly distributed, forming clusters and voids. This may indicate heterogeneity in the deposition process or dynamics of the movement of the solution during the process.

The effect of an electric field on a solution is described by an equation that expresses the work done by the system, as shown in equation (1). In this context, the change in work over a time interval *dt* can be expressed through equation (2). The first part of equation is responsible for the change in the internal energy of the liquid solution, which is not converted into work, while the second part describes the energy spent on activating the system under the influence of an electric field. The dynamics of energy change in the condensed phase (solution) over time *dt* is represented by equation (3). From equation, it can be concluded that the lower the activation energy of the solution under given electrical conditions (ECS), the more work is performed by the system in an isothermal process.

Consequently, the efficiency of the transition process from a nonequilibrium state to an equilibrium state can be regulated by manipulating the activation energy of the condensed phase in the ECS. The activation of molecules in liquid-phase solutions can occur via the transition of atoms into excited dynamic states (EDS), initiated by electron excitation. Such macroscopic activation of the system can be induced by the absorption of electromagnetic energy, which can be achieved through various agents including electrical discharge, electric and magnetic fields, and ultrasound. Consider the influence of the electric field on the atoms of the solution in EDS as well as on the atoms of the surface layer of the electrode. The interaction of the electric field with the atomic spins of the solution transitions them from an equilibrium state to a nonequilibrium state. It can be assumed that during the reaction process, as the system moves along the reaction coordinate, it passes through the superposition of states ψ_{int} and ψ_{fin}. This implies that quantum coherence plays an important role in the elementary interactions.

The mathematical models in the study aim to describe the thermodynamic and energetic behavior of the system under the electric field's influence, represented by equations (1), (2), and (3). These equations provide a theoretical framework for understanding work, internal energy, and entropy changes, assuming ideal, reversible processes without significant energy losses. They enable a quantitative analysis of key variables such as activation energy and work output, offering foundational insights into the ionization process.

These theoretical models do not account for real-world irreversibilities such as energy losses due to resistance, non-ideal electrode behavior, and heat dissipation during electrophysical ionization. To reconcile the models with experimental data, corrections for these irreversibilities are necessary. Discrepancies can be attributed to factors like electrode polarization and solution conductivity changes. By comparing experimental results, such as mass deposition and electric field strength, with theoretical predictions, the models can be refined to incorporate empirical corrections.

Irreversibilities, such as incomplete ionization and energy dissipation, lower the efficiency of energy conversion and cause the actual work to deviate from ideal predictions. Including factors like entropy generation and Joule heating helps adjust the theoretical models, improving their applicability to real-world processes.

Thus, interactions at the quantum level, driven by the influence of an electric field, are crucial for the activation and progression of chemical reactions in liquid-phase systems. In the process of electrophysical ionization occurring at the anode within the DEL, an oxidative transition of copper from a zero valence (Cu^0) to a divalent state (Cu^2+) is observed. In this same context, electrolytic decomposition of water occurs, leading to the formation of oxygen (O_2) and protons (4H^+) at the anode and hydrogen (H_2) at the cathode.

In the process of electrophysical ionization aimed at the extraction of valuable metals from industrial waste, the efficiency of extraction of the main elements, in particular copper, silver, zinc and lead, was evaluated. Since the extraction efficiency depends on various factors, such as the initial concentration of elements in the waste, the experimental conditions and the properties of the solution, a detailed analysis of the results allows us to assess the real possibilities of this method for practical application in industrial conditions. For other elements, such as zinc and lead, the extraction efficiency was also evaluated. The initial mass of zinc in the industrial waste was 200 g, of which 4.0 g of zinc was recovered, giving a recovery efficiency of 2%. For lead, where the initial mass was 150 g, 1.2 g of lead was recovered after the experiment, which is 0.8% recovery efficiency.

These data indicate that the extraction efficiency depends on a number of factors, including the type of element, its concentration in the initial solution, and electrophysical conditions such as the magnitude of the electric field and the duration of the experiment. It should be borne in mind that given the low extraction efficiency, further studies will need to optimize the process parameters, including the choice of electrodes, electric voltage, and other factors that can increase the metal extraction rate.

The accompanying change in element concentrations during the experiment indicated the accumulation of copper near the anode, forming a dense "sheath". The concentration of copper in the resulting powder ranges from 0.4 to 2.0 grams per litter. This process illustrates significant changes in the distribution of metals when applying electrophysical treatment methods, which is key to understanding the mechanisms of industrial wastewater processing and purification.

Table 1 displays the results of the experimental measurements related to the electrophysical ionization. The values recorded in the table include the voltage (V, in volts), electric field (E, in volts per centimetre), and mass (m, in grams) of the resulting solution.

Table 1: Variation of electric field intensity and relative mass during the process of electrophysical ionization depending on the applied voltage

V, volts	5.1	10.1	15.1	20.1	25.1	29.3	29.3	29.3
E, Volts/cm	2.7	5.34	7.99	10.63	13.28	15.5	21.08	32.2
m, gr	0.09	0.16	0.26	0.4	0.46	0.55	0.55	0.68

Source: compiled by the authors.

The data analysis indicated that as the applied voltage increases from 5.1 to 29.3 volts, the electric field strength rises from 2.7 to 32.2 V/cm. This corresponds to the expected increase in the electric field strength with increasing applied voltage, considering the constant distance between the electrodes.

Additionally, the mass of the solution also increases from 0.09 to 0.68 grams, which may indicate the accumulation of deposited substances, such as copper, forming a "sheath" around the anode electrode, as previously described. Such metal accumulation could result from an effective electrodeposition process, which intensifies with increasing voltage and electric field strength.

The data suggest that the experimental conditions promoted a gradual and predictable increase in the mass of the precipitate depending on the voltage, highlighting the quantitative relationship between the applied electric field and ionization process. This correlation can be used to control the degree of electrophysical ionization for both analytical and industrial purposes.

Figure 3 shows the dependence of the precipitate mass mmm on the electric field strength *E*, expressed in volts per centimetre (V/cm). A monotonic increase in the precipitate mass with increasing field strength was observed, suggesting a direct correlation between the electric field intensity and the number of deposited elements during the electrophysical ionization process.

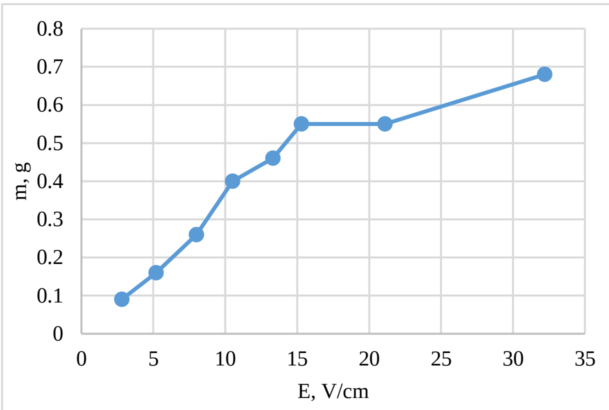

Fig. 3: Graph of the dependence of the sediment mass in the anode electrode on the electric field strength between the electrodes

Source: compiled by the authors.

Figure 4 illustrates the inverse dependence of the precipitate mass on the distance between electrodes *d*, measured in centimetres. It is evident that as the distance increases, the precipitate mass decreases, which can be attributed to the reduced efficiency of the electrodeposition process owing to the increased volume of the solution between the electrodes.

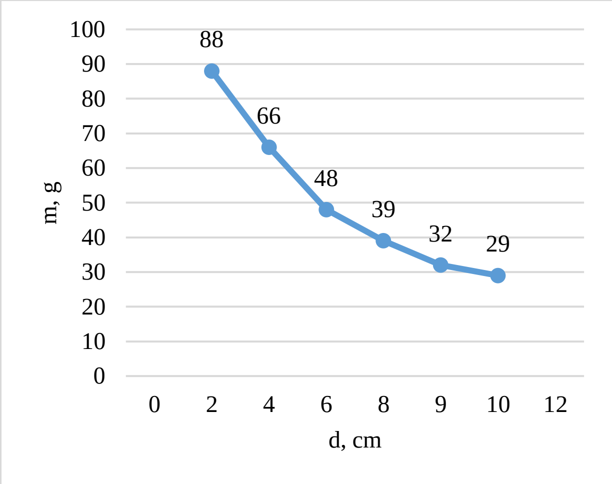

Fig. 4: Graph of the dependence of the mass of the sediment in the anode electrode on the electric field intensity between the electrodes

Source: compiled by the authors.

Figure 5 presents the dependence of current III, expressed in milliamperes (mA), on the precipitate mass, mmm, measured in grams. An exponential increase in current with increasing precipitate mass was observed, indicating that ionization and metal deposition processes led to an increase in the electrical conductivity of the solution.

These data collectively emphasize the complex nature of the processes occurring in the system during electrophysical ionization. Changes in precipitate mass as a function of field strength, electrode distance, and current are critically important for optimizing metal extraction processes and wastewater treatment in industrial practice. Figures 3, 4, and 5 show the experimental data obtained during the study.

The graph shows that as the field intensity increases, the mass of the precipitate also increases, and the dependence is represented by a curve that is close to linear in the initial section and shows saturation at higher values of field intensity. Such a curve may indicate a process that initially follows linear dynamics but slows as it approaches a certain saturation point. In the context of electrophysical ionization, this may mean that at low intensities, the efficiency of ionization and deposition of the element is high, but with increasing field strength and the accumulation of the element near the electrode, the availability of active sites for ionization may decrease or the diffusion rate of ions in the solution may slow, leading to a reduction in the growth rate of the precipitate mass.

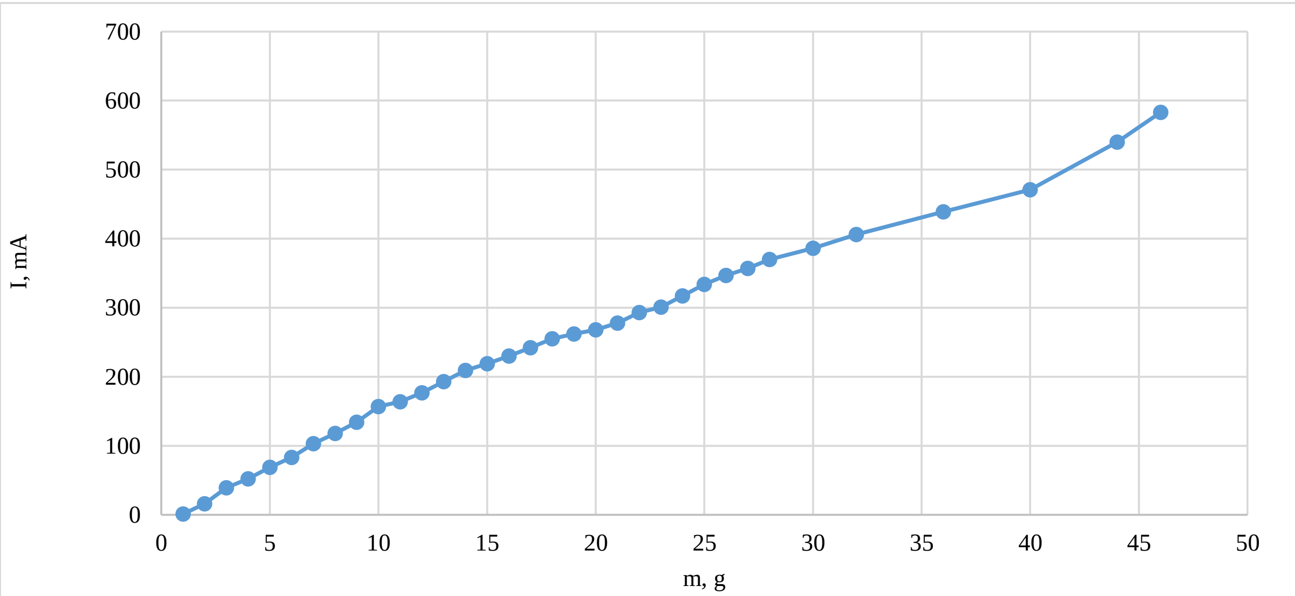

Fig. 5: Dependence of current magnitude on the concentration of industrial waste powders

Source: compiled by the authors

Studying this dependence is crucial for determining the optimal conditions for the electrodeposition of elements, which can be used to develop effective technologies for the treatment and recycling of industrial waste.

The graph shows that, as the distance between the electrodes increased from 2 to 10 cm, the mass of the deposit decreased from 88 to 29 g. This relationship can be explained by several factors, including changes in the electrodeposition efficiency due to the increased volume of solution between the electrodes, which consequently lowers the concentration of copper ions available for deposition. Additionally, it is possible that the increase in distance reduces the electric field strength, leading to a decrease in the migration rate of ions towards the electrodes and, as a result, a reduction in their deposition rate.

This result highlights the importance of optimizing the distance between the electrodes in electrochemical purification or refining processes, as it affects the rate and efficiency of valuable element extraction. Therefore, to maximize the yield of an element, it is necessary to consider this relationship when designing and optimizing industrial electrolysers and other electrodeposition equipment.

The graph shows that the initial increase in the current was slow and linear within the range of small masses. Subsequently, the growth became more pronounced and exhibited an exponential character. This may indicate that at low concentrations of powder in the solution, there is a linear relationship between the increase in precipitate mass and the current, which is typical for systems where the reaction is limited by the availability of reagents. As the mass of the powder increases, and consequently, the concentration of ions, the current intensifies owing to the increased number of charge carriers, leading to an enhanced conductivity of the solution. With further increases in the powder mass, the curve smoothens, possibly due to reaching the solubility limit or the limited capacity of the electrolyte to conduct large currents.

Analysing such data is essential for developing and optimizing electrochemical treatment processes for industrial waste, where precise adjustment of electrical parameters and precipitate concentration ensures operational efficiency and safety. This also helps to determine the optimal conditions for electrodeposition, which is crucial for regulating the process of valuable element recovery.

The collective data highlight the complex nature of the processes that occur in the system during electrophysical ionization. Changes in precipitate mass depending on field intensity, distance between electrodes, and current are critically important for optimizing the processes of element extraction and wastewater treatment in industrial practice. The chemical composition of the anodic copper sulphate was determined using spectroscopic analysis, and the results are presented in Table 2.

Table 2: Mass concentration of chemical elements extracted from industrial waste

No.	Cu 10^{-3}	U, 10^{-1}	Ta, 10^{-1}	P, 10^{-2}	Sb, 10^{-2}	Y, 10^{-3}	La, 10^{-2}	Sr, 10^{-2}	Ba, 10^{-2}	Sc, 10^{-1}
1	>1000	<0.5	<1.2	<2	<0.5	<0.3	<1.2	3	<2	<2

Source: compiled by the authors.

The analysis of the table with the weight concentrations of chemical elements extracted from industrial waste using the process of electrophysical ionization allows for the following scientific conclusions:

Predominance of Copper (Cu). A value of more than 1000 ppm (parts per million) for copper indicates that the electrophysical ionization process is particularly effective in extracting copper from industrial waste. This makes Cu the primary element for recovery, considering its economic value and wide application in various industries.

Low Concentration of Uranium (U) and Tantalum (Ta). Values of less than 0.5 ppm for uranium and less than 1.2 ppm for tantalum indicate their low concentrations in the sample after ionization. This may suggest a low initial concentration in industrial waste or limited efficiency of the method for these elements.

Moderate Concentrations of Phosphorus (P) and Strontium (Sr). Concentrations below 2 ppm for phosphorus and 3 ppm for strontium may be economically significant if these elements are present in forms amenable to further processing. However, their low concentration requires more sensitive extraction methods.

Very Low Levels of Antimony (Sb), Yttrium (Y), Lanthanum (La), and Scandium (Sc). With concentrations of less than 0.5 ppm, these elements are minor components in the sample. Their extraction and use may be limited to specific industrial applications where their properties are valuable despite their low concentrations.

Barium (Ba) and Strontium (Sr). The concentrations of these elements are also below 2 ppm, necessitating additional analysis to assess the potential economic value of their extraction in the context of additional costs and technological requirements.

The proposed electrophysical ionisation approach offers considerable environmental advantages over traditional extraction and waste recycling methods. Conventional chemical leaching techniques sometimes depend on powerful acids or toxic solvents, producing hazardous by-products that need expensive treatment and disposal. Conversely, electrophysical ionisation reduces the reliance on harmful chemicals by employing an electric field to recover useful components from industrial waste, thereby mitigating the danger of secondary contamination. The circular economy is improved by this method because it recovers valuable metals like copper (>1000 ppm), phosphorus, and strontium from waste streams. These elements are then used again in industry instead of ending up in landfills or polluting water sources. The procedure markedly diminishes the environmental impact of waste management, especially in areas such as the Kyrgyz Republic, where industrial waste treatment facilities are few.

Moreover, the energy efficiency of electrophysical ionisation improves its ecological sustainability. This approach functions at comparatively low temperatures and excludes combustion, hence minimising greenhouse gas emissions, in contrast to energy-intensive smelting or pyrometallurgical processes. Optimisation of electrical characteristics is essential to minimise energy losses and avert excessive power usage, which may undermine its environmental benefits. A vital component of environmental efficacy is the reduction of harmful element dissemination. The investigation demonstrated that copper was extracted successfully, although uranium and tantalum were found in far lower amounts. This indicates that electrophysical ionisation may be less efficacious at eliminating radioactive or highly distributed materials, necessitating further purification methods to avert environmental contamination. The electrophysical ionization process appears promising for the extraction of copper from industrial waste, although the efficiency of extracting other elements may vary. High concentrations of Cu may determine the primary economic value of the recovered elements, whereas the presence of other elements requires further analysis in the context of their potential use and extraction cost.

The industrial scalability of the electrophysical ionisation apparatus outlined in the article presents both prospects and obstacles for large-scale manufacturing. The approach has shown significant efficacy in copper extraction (>1000 ppm), but it requires additional optimisation for elements such as uranium and tantalum. To make this configuration work for industrial purposes, the electrode surface area would need to be increased, the electric field parameters would need to be tweaked, and the solvent selection would need to be improved so that elements dissolve better. Energy consumption must be evaluated for cost-effectiveness, especially with the power demands for sustaining the electric field throughout prolonged processing durations. Existing problems, like the fact that some elements aren't extracted efficiently enough and that energy can be lost due to resistance and changes in solution conductivity, mean that new electrode materials and hybrid extraction methods need to be used. This method, through appropriate technical enhancements and automation, has the potential for sustainable waste processing on an industrial scale, minimising environmental impact, and facilitating resource recovery.

5. Discussion

The results of this study demonstrate the potential of electrophysical ionization as an effective method for extracting valuable elements, particularly copper, from industrial waste in the Kyrgyz Republic. The concentration of copper extracted exceeded 1000 ppm, confirming that this method is highly efficient for recovering copper from complex waste materials. S. Krishnan et al[6). observed analogous results, examining contemporary technologies for metal recovery and emphasising the efficacy of electrochemical methods for copper extraction. Their research highlights that these methods provide both economic and environmental advantages, especially in minimising waste and reclaiming valuable materials from industrial processes.

The diminished recovery rates for uranium (<0.5 ppm) and tantalum (<1.2 ppm) in this study highlight the difficulties inherent in extracting elements found in low concentrations. Y. Mubula et al[9)]. highlighted the necessity of optimising electrophysical ionization techniques for the recovery of rare elements in their review on the application of external electric fields. They propose that modifying parameters such as electric field intensity and electrode composition could markedly improve the extraction efficiency for elements such as uranium and tantalum, a direction warranting investigation in subsequent research.

Furthermore, moderate levels of phosphorus (<2 ppm) and strontium (3 ppm) were detected in this study. The findings align with those presented by Y. Tashpolotov et al[21)]., who examined the use of electrophysical ionization for element extraction from industrial waste in Central Asia. It was determined that, although phosphorus and strontium were present in moderate concentrations, the economic feasibility of extracting these elements is primarily contingent upon the advancement of more sensitive and cost-efficient extraction techniques. In areas such as the Kyrgyz Republic, where modern waste processing technology is scarce, enhancing techniques for the extraction of phosphorus and strontium could foster the growth of industries like agriculture, which require these elements[22-24)].

Electrophysical ionization presents numerous advantages when juxtaposed with conventional techniques like slag leaching, as articulated by J. Abeywickrama et al[7)]. Although slag leaching can be effective in specific instances, it frequently entails the utilisation of chemicals that may present environmental hazards. Electrophysical ionization, in contrast, minimises the utilisation of hazardous chemicals and is more ecologically sustainable, rendering it a superior choice for sustainable waste recycling methodologies[25-27)]. This study's results indicate the potential for integrating electrophysical ionization with sophisticated ion exchange methods to enhance recovery rates for low-concentration elements. Their research underscores the significance of creating hybrid systems that amalgamate various extraction techniques to enhance recovery processes[28), 29)].

This study theoretically explores the potential of quantum mechanical principles, specifically BEC, to improve the ionization process. This study's theoretical framework is based on the research conducted by C.C. Chen et al.[10)], which investigated the ongoing generation of BEC and its implications in material science. This study did not directly implement BEC technology; however, future research may explore its application in industrial waste recycling, specifically to enhance the extraction efficiency of low-concentration elements. The macroscopic quantum coherence identified in Bose-Einstein condensate systems may provide a novel avenue for enhancing process efficiency, as proposed by V.I. Yukalov and E.P. Yukalova[30)], who simulated superfluid states to improve material interactions.

The concentration of copper extracted in this study is particularly significant when juxtaposed with other research focused on copper recovery from solid waste. Y. Zhang et al[8]. performed a life cycle assessment of copper extraction from pyrometallurgical waste, revealing that contemporary electrochemical methods, including electrophysical ionization, improve copper recovery rates and diminish the environmental impact of waste treatment processes. The elevated copper concentration observed in this study corroborates the findings of Y. Zhang et al[8]., suggesting that electrophysical ionization may significantly contribute to sustainable waste management and resource recovery, especially in areas such as the Kyrgyz Republic, where industrial waste management infrastructure is lacking.

This study demonstrates that electrophysical ionization is an effective technique for extracting valuable elements from industrial waste, notably copper, which was recovered in substantial concentrations. Electrophysical ionization presents considerable environmental benefits over conventional chemical extraction methods by decreasing the reliance on hazardous substances and lessening toxic by-products[31-33]. The elevated recovery rate of copper validates the efficacy of this process for metals found in substantial concentrations within waste materials.

The recovery of lower-concentration elements, such as uranium and tantalum, was less effective, corroborating findings from other studies that emphasise the difficulties in recovering rare or dispersed elements using this method[34), 35]. The suboptimal efficiency of the process for these elements indicates that further optimisation of parameters, including electric field strength, electrode materials, and ionization duration, is essential to enhance extraction rates[36-38]. The moderate levels of phosphorus and strontium suggest that these elements may also be recoverable if extraction techniques are improved. In comparison to alternative methods like chemical leaching or ion exchange, electrophysical ionization exhibits significant potential for sustainability and cost-efficiency, especially for high-concentration elements[39), 40]. The limitations identified for low-concentration elements indicate the necessity for additional development and hybridisation with complementary technologies.

A limitation of this study is its relatively narrow focus on a specific set of industrial waste samples, potentially constraining the generalisability of the findings to other waste types or regions. The recovery efficiency for elements such as uranium and tantalum were below expectations, indicating that the method may not be universally applicable to all elements, especially those found in low concentrations. The study also failed to directly incorporate advanced quantum mechanical principles, such as Bose-Einstein condensates, thereby constraining the investigation of their practical influence on the ionization process.

Subsequent research should concentrate on refining the parameters of the electrophysical ionization process to improve the extraction of trace elements, including uranium and tantalum. Investigating the integration of this method with alternative extraction techniques, such as ion exchange or ultrasonication, may enhance the overall efficiency and economic feasibility of the process. Additional research is required to evaluate the practical implementation of quantum mechanical phenomena, such as Bose-Einstein condensates, in industrial waste recycling, as this may result in substantial technological progress in the domain. Broadening the spectrum of waste samples examined would enhance the assessment of this method's wider applicability across various industries and geographical areas.

6. Conclusions

The central task of this study was to investigate the possibility of extracting valuable elements from industrial waste in the Kyrgyz Republic using an electrophysical ionization process. Quantitative data on the concentrations of various elements after the ionization procedure were obtained, which allowed for the assessment of the efficiency of the method and its potential for industrial application:

High Concentration of Copper (Cu). The results showed that copper is extracted with high efficiency (>1000 ppm), confirming the hypothesis about the suitability of electrophysical ionization for extracting copper from waste.

Low concentrations of uranium (U) and tantalum (Ta). The low concentrations of uranium (<0.5 ppm) and tantalum (<1.2 ppm) indicated the need for process refinement to improve the yield of these elements, which was highlighted in the research objectives.

Moderate concentrations of other elements. The concentrations of phosphorus, strontium, and barium, ranging from <2 to 3 ppm, suggest the possibility of their combined extraction and utilization, aligning with the objective of optimizing the extraction of valuable components.

Assessment of Environmental and Economic Feasibility. The low levels of toxic elements, such as uranium and the potential for extracting economically valuable elements confirm the environmental and economic feasibility of applying electrophysical ionization on an industrial scale.

Effectiveness of Electrophysical Ionization. Experiments confirmed the high efficiency of electrophysical ionization in extracting copper from industrial waste. This method demonstrated significant advantages over traditional methods owing to its ability to increase the extraction rate of valuable elements at low energy costs.

This study confirmed the effectiveness of electrophysical ionization for extracting valuable elements and identified pathways for further process improvement, including the need to increase the yield of certain elements. The proposed method provides a basis for developing economically efficient and environmentally safe waste processing technologies, which are important for the sustainable development of the Kyrgyz Republic industry. Future research should focus on improving the ionization processes to increase the yield of these elements, as well as developing cost-effective methods for further purification and utilization.

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