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Metallurgy

Development of Software for Hydrometallurgical Calculation of Metal Extraction

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ABSTRACT

Hydrometallurgy plays a critical role in the metallurgical industry by providing an efficient method for extracting metals from ores and secondary materials using aqueous solutions. This approach is particularly advantageous for processing low-grade and complex ores, as well as secondary resources that cannot be effectively processed by traditional pyrometallurgical methods. The objective of this study is to develop specialized software to automate and optimize the calculations necessary for metal extraction in hydrometallurgical processes. The software integrates a complete computational framework for automating the various stages of the hydrometallurgical process, including ore composition initialization, total element mass calculations, and the determination of metal concentrations in both metal products (matte) and by-products (slag). The methodology involves the design and implementation of a web-based application using Django for the user interface and MySQL for robust data storage. The computational module, written in Python, automates the mathematical operations required to simulate complex chemical reactions and metal extraction processes. This module supports real-time processing and ensures accurate calculations for each stage of metal extraction, including leaching, extraction, re-extraction, sorption, and electrolysis. The software also features detailed tables and dynamic graphs that allow users to analyze the distribution of valuable metals and assess the influence of key operational parameters on extraction efficiency. The results show that the developed software successfully manages large datasets, enhances the precision of hydrometallurgical calculations, and minimizes the risk of human error. The implementation of the software leads to significant improvements in the economic efficiency of production by optimizing metal recovery rates and reducing operational costs. Additionally, it supports comprehensive process control by providing actionable insights into each stage of extraction, thus improving the quality of the final metal product. Overall, the software represents a significant technological advancement in the field, offering a scalable solution for industries aiming to streamline hydrometallurgical processes.

Keywords: hydrometallurgy, calculation automation, metal extraction, mathematical modeling.

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Introduction

Hydrometallurgy is a vital field in the metallurgical industry, providing efficient extraction of metals from ores and secondary materials using aqueous solutions. This method plays a key role in the extraction of metals such as copper, gold, and rare earth elements due to its ability to process low-grade and complex ores, as well as secondary resources that cannot be effectively processed using traditional pyrometallurgical methods [[1], [2], [3]]. For example, in studies on the hydrometallurgical treatment of industrial waste from copper production at a copper smelter in Kazakhstan, the process of copper leaching from man-made mineral formations was investigated. Analysis showed that the copper content in the raw material was 0.481%, present in various mineral forms, including sulfates and sulfides [4]. The use of gravity concentration and flotation methods allowed for obtaining concentrates with copper contents of 9.35% and 46%, respectively, and sulfuric acid leaching in a mixing mode enabled copper extraction from the enriched raw material [5].

Research and development trends in hydrometallurgy have evolved significantly over the past several decades. Modern hydrometallurgy has been developing for more than 100 years, with a continuous accumulation of related articles. A bibliometric analysis of articles in "Hydrometallurgy", the most authoritative journal in this field, highlights several key trends from 1975 to 2019 [6]. For instance, in [7] an innovative hydrometallurgical process for selectively recovering base and precious metals from waste-printed circuit boards, showcasing the potential of hydrometallurgy was demonstrated. And as one of the principles of circular hydrometallurgy, which emphasizes designing energy-efficient and resource-efficient flowsheets that consume minimal reagents and produce minimal waste, the implementation of real-time analysis and digital process control is important [8].

Precise calculations in hydrometallurgy are crucial for optimizing the metal extraction process, contributing to reduced production costs, increased product yield, and minimized environmental impact. In industrial production conditions, errors in calculations can lead to significant financial losses and technological problems. Traditional calculation methods, based on manual data entry and basic tools like spreadsheets, are prone to human error and do not provide the necessary accuracy and promptness.

Hydrometallurgical processes include several key stages where accurate metal extraction calculations are important [9]. The first stage involves calculating the extraction of metal from the initial ore, where the solid material transitions into a liquid. This method is used to determine the efficiency of metal leaching from the ore using various agents and leaching conditions [10]. The second stage involves calculating metal extraction from the solution during the extraction and re-extraction processes, where the metal is transferred from the productive solution to the rich electrolyte, which is especially important in copper production. The third stage involves calculating metal extraction in the sorption and desorption processes, where metals are extracted from solutions onto solid sorbents and then desorbed for further use. The fourth stage involves calculating the extraction of the obtained metal on the cathode from the rich solution, which is important in electrolytic processes where metals are deposited on cathodes from rich electrolytes. Finally, the fifth stage includes a combined extraction scheme that covers several stages of the technological process, allowing for a comprehensive assessment of metal extraction efficiency from ore to the final product [11].

One of the central goals of hydrometallurgical process design is to determine what resources are required to produce the desired annual amount of product [12]. Flowsheet simulation is widely used in metallurgical design to provide data for equipment sizing, process strategies, and cost estimates. Simulations are crucial for predicting plant water balance and reagent usage during various study stages [13]. Many other works on the automation and simulation of hydrometallurgical processes have been conducted, mainly aimed at the development, optimization, and practical application of technologies for efficient metal extraction [[14], [15], [16], [17], [18], [19]]. For example, in [14], two processes for a small gold mining enterprise were modeled using PRO/II and Python, allowing for the analysis of the impact of uncertainties on extraction indicators and economic metrics. In [[15], [16]], a modular stationary simulator, PRISMA, was developed for modeling and simulating hydrometallurgical processes using object-oriented programming technology. In [17], the role of simulation software in the design and operation of metallurgical plants, considering mineral processing and hydrometallurgical installations for concentrate and pure metal production, is discussed. The use of JKSimMet software for the size-based design of mineral processing units and METSIM and IDEAS for developing energy and mass balances is highlighted. Modern technologies and software significantly simplify and speed up the calculation process, minimizing human errors and ensuring high accuracy and reproducibility of results. Also, recent research highlights the growing adoption of soft computing techniques, such as artificial neural networks and fuzzy algorithms, which are increasingly used to optimize and control complex, non-linear mineral

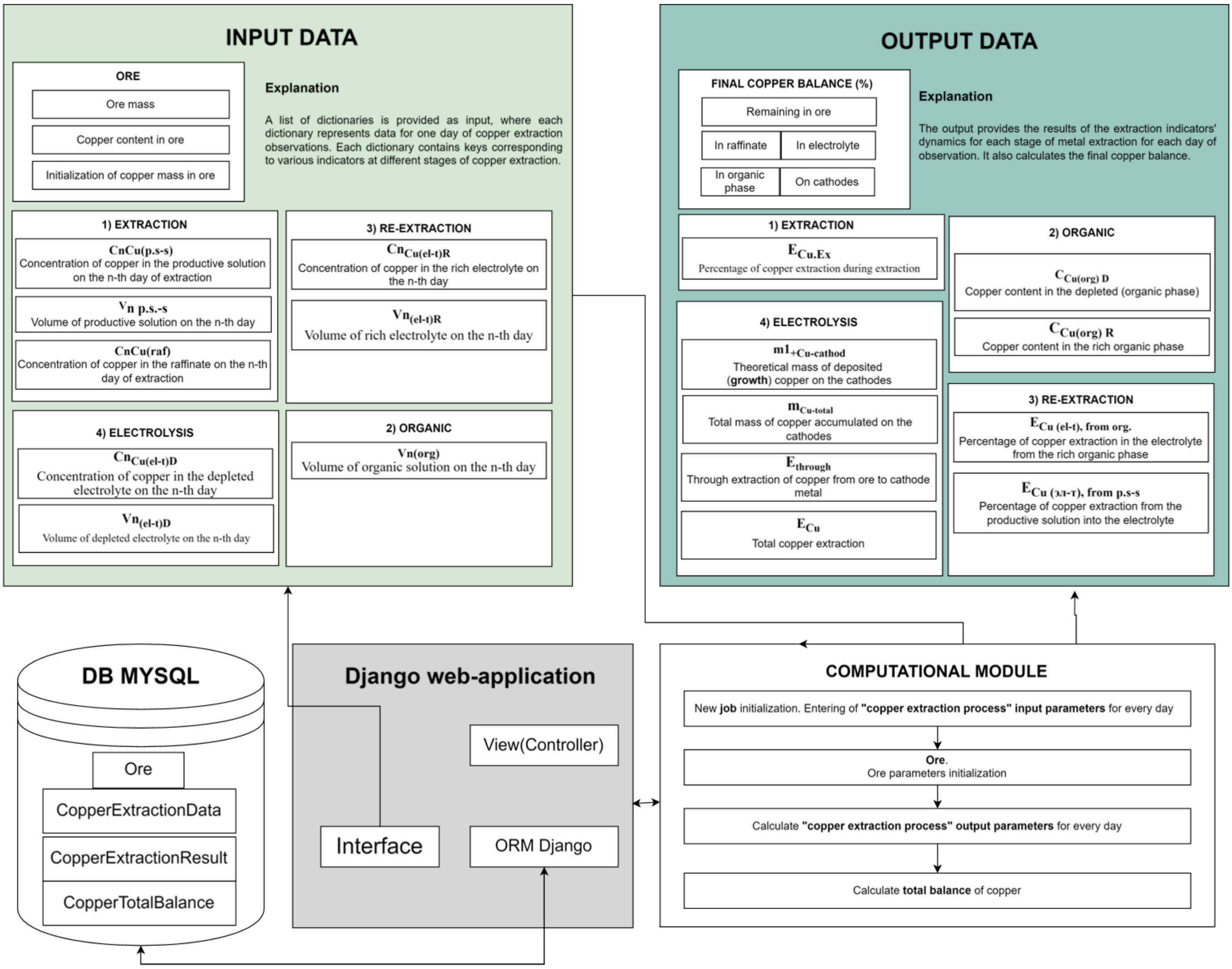

Figure 1 – General architecture of the system

processing stages, offering advanced alternatives to traditional methods [20].

To address the challenges of automating metal extraction calculations in hydrometallurgical processes, specialized software has been developed. This tool is a web application that automates the calculations of the full combined scheme of the hydrometallurgical metal extraction process, providing accuracy and ease of use.

The use of the developed software offers several advantages. Firstly, it increases the accuracy and reliability of calculations, eliminating human errors and enhancing precision through automation. Secondly, it significantly reduces the time required to perform calculations, allowing for faster production processes. Thirdly, the intuitive interface makes the software accessible to both researchers and production specialists. Thus, the development and implementation of software for automating hydrometallurgical calculations represent a significant step forward in optimizing metal extraction processes.

Experimental part

This experimental part describes the methods and computational processes used to model and calculate hydrometallurgical metal recovery processes. The focus is on the calculations and application of software that automates these processes

1. Architecture

The architecture of our system, shown in Figure 1, is designed to optimize the copper extraction process and includes a MySQL database, a Django web application, and a computational module. Input data is entered through the Django web application and stored in the MySQL database.

The computational module receives the input data, processes it using calculation algorithms, and stores the output data in the database.

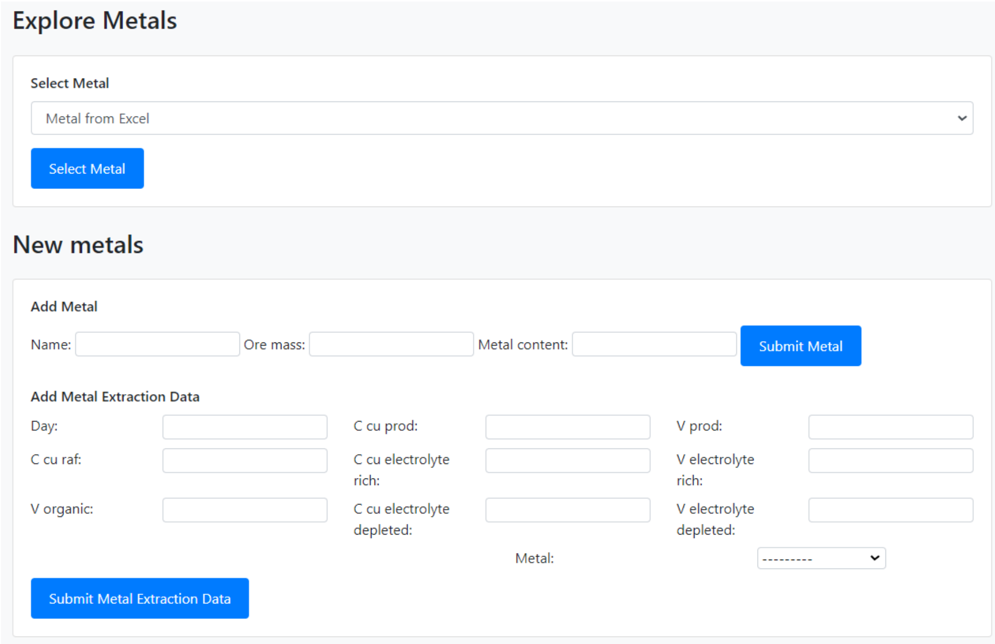

Figure 2 - Explore Metals

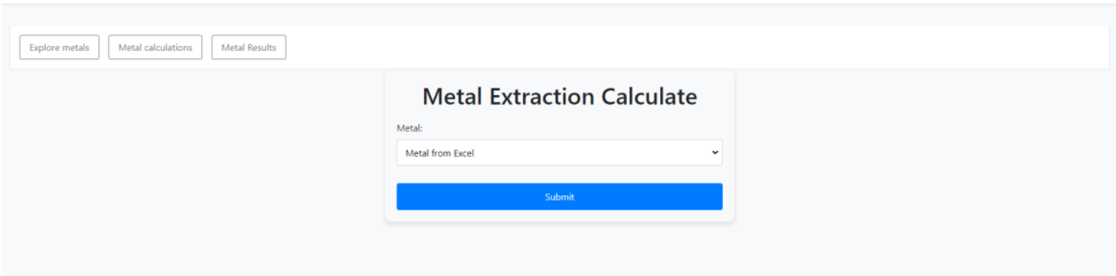

Figure 3 - Metal calculations

Job	in_raf_percent	in_electrolyte_percent	in_katods_percent	in_organics_percent	ore_remain_percent
Job2Task_7843	0.33	24.92	66.42	0.15	8.19

Figure 4 - Result of calculations (Total copper balance)

Day	Extraction efficiency	Copper concentration in lean organics	Copper concentration in rich organics	Organic re-extraction efficiency	Electrolyte re-extraction efficiency	Copper gain	Total mass of accumulated copper	Through copper recovery	Total final recovery
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.33
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.27
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.85
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.74
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.33
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.67
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.90
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.67
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.33
11	80.00	0.60	9.60	93.75	75.00	0.00	0.00	0.00	10.00
12	81.25	0.24	5.73	95.90	87.03	0.00	0.00	0.00	10.77
13	80.00	0.25	5.85	95.71	79.77	0.00	0.00	0.00	16.95
14	83.81	0.20	7.20	97.18	84.39	0.00	0.00	0.00	22.49

Figure 5 - Table of extraction rate dynamics

The system uses Python and Django for the web application, employing Django's ORM for database interaction and MySQL for data storage. The computational module, also written in Python, ensures reliable and efficient data processing.

2. Data

Various methods are necessary for the

successful calculation and analysis of metal extraction in hydrometallurgical processes. Here are the main ones:

1. Calculation of metal extraction from the original ore (solid → liquid):

This method is used to determine the amount of metal that can be extracted from the ore through leaching. The process starts with crushing the ore and immersing it in a solution that dissolves the metal. This method is important for assessing the economic feasibility of mining, as it allows understanding how much metal can be obtained from a specific volume of ore. It is used at various scales, from laboratory tests to industrial processes.

2. Calculation of metal extraction from the solution in the process of extraction/re-extraction (liquid → liquid):

The extraction process involves transferring the metal from the productive solution to the organic phase and then to the electrolyte. This method is used for the purification and concentration of metals, such as copper, before the electrolysis stage. The organic phase absorbs the metal from the aqueous solution, reducing its concentration, and then the metal is transferred to another solution for further processing.

3. Calculation of metal extraction from the

solution in the process of sorption (liquid → solid) and desorption (solid → liquid):

Metals from solutions are adsorbed on solid sorbents, such as activated carbon. After the sorbent is saturated with metal, desorption is performed, where the metal is returned to the solution for further processing.

This method is often used for precious metals, such as gold, due to its high efficiency and cost-effectiveness.

4. *Calculation of metal deposition on the cathode from the rich solution:*

At this stage, the metal, which has been concentrated in the electrolyte, is deposited on the cathodes during the electrolysis process. This method allows obtaining pure metal of high purity. The concentration of the metal in the solution must be maintained at a certain level to prevent crystallization and ensure optimal conditions for metal deposition.

5. Combined or complete extraction scheme (through extraction - from ore to cathode metal):

This method involves the sequential application of all the above processes for maximum metal extraction from the ore to the production of finished cathode metal. Using this scheme allows for achieving high efficiency and minimizing metal losses at each stage. The combined approach ensures the integration of various technological processes, leading to the optimization of the entire production cycle, cost reduction, and improvement in the quality of the final product.

In our work, we use the fifth method because it provides the maximum efficiency and completeness of metal extraction from the ore. This allows for minimizing losses and increasing the economic profitability of the process, ensuring full control at each stage of processing.

2.1. Input Data

The system receives a list of dictionaries as input, where each dictionary represents the data of

one day's observation of the copper extraction process. Each dictionary contains keys corresponding to various indicators at different stages of copper extraction. The input includes values such as:

For the Ore (Leaching) Stage:

- **Name**
- **Ore mass**
- **Metal content** – Concentration of the desired metal in the ore

- $\mathbf{C_{nCu(p.s\text{-}s)}}$ – Copper concentration in the productive solution on the n-th day of leaching
- $\mathbf{C_{nCu(raf)}}$ – Copper concentration in the raffinate on the n-th day of leaching
- $\mathbf{V_{n(p.s\text{-}s)}}$ – Volume of productive solution on the n-th day

For the Extraction and Re-Extraction Stages:

- $\mathbf{V_{n(org)}}$ – Volume of organic phase on the n-th day
- $\mathbf{C_{nCu(el\text{-}t)R}}$ – Copper concentration in the rich electrolyte on the n-th day
- $\mathbf{V_{n(el\text{-}t)R}}$ – Volume of rich electrolyte on the n-th day

For the Electrolysis Stage:

- $\mathbf{C_{nCu(el\text{-}t)}D}$ – Copper concentration in the depleted electrolyte on the n-th day
- $\mathbf{V_{n(el\text{-}t)}D}$ – Volume of depleted electrolyte on the n-th day

2.2. Output Data

The output provides the dynamics of indicators for each stage of extraction for each observation day. Additionally, the overall copper balance is calculated (Remaining in the ore, in the raffinate, in the organic phase, in the electrolyte and on the cathodes). With the start of each stage, new indicators for calculation are added (formulas for their calculation also change with the onset of a new stage, as explained in more detail in section 3):

For the Ore (Leaching) Stage:

- $E_{(Cu)}$ – Total copper extraction

For the Extraction and Re-Extraction Stages:

- $E_{(Cu.Exc)}$ – Copper extraction percentage during extraction
- $C_{Cu(org)}D$ – Copper content in the depleted (organic phase)
- $C_{Cu(org)}R$ – Copper content in the rich (organic phase)
- $E_{Cu(el\text{-}t),\ from\ org}$ – Copper extraction percentage into the electrolyte from rich organic
- $E_{Cu(el\text{-}t),\ from\ p.s\text{-}s}$ – Copper extraction percentage from the productive solution into the electrolyte

For the Electrolysis Stage:

- $m_{+Cu-cathode}$ – Theoretical mass of copper deposited (growth) on the cathodes
- $m_{Cu-total}$ – Total accumulated copper mass on the cathodes
- $E_{through}$ – Through copper extraction from ore to cathode metal

3. Computational Module

This module connects the input and output data by using the input data to perform mathematical operations and outputs the results of these operations as output data. The module's logic is entirely implemented in Python.

Since the days for the initiation of stages can be chosen independently, for the sake of simplicity, we used pre-selected intervals. This standardizes the process, making it more predictable and manageable. The extraction stage begins on the 12th day, and electrolysis starts on the 19th day. The entire process lasts a total of 30 days.

3.1. Stages and Formulas

As the formulas change with each new stage, it is better to explain them separately and show their changes.

Days 1–10: Leaching

Initially, the mass of the desired metal in the ore is calculated:

$$m_{Cu.init} = (\text{Ore Mass} * \text{Metal Content}) / 100 \quad (1)$$

Next, using the obtained mass, the total copper extraction (E_{Cu}) is calculated over the next 10 days:

$$E_{Cu} = (C_{Cu} \times V_{p.\,s\text{-}s}) / m_{Cu.init} \times 100\ \% \quad (2)$$

Days 11–18: Extraction and Re-Extraction

$E1_{Cu\ (el\text{-}t),\ from\ p.s.\text{-}s}$ (Copper extraction percentage from the productive solution into the electrolyte), **$E1_{Cu\ (el\text{-}t),\ from\ org}$** (Copper extraction percentage into the electrolyte from the rich organic phase), **$C_{Cu(org)}D$** (Copper content in the depleted organic phase), **$C_{Cu(org)}R$** (Copper content in the rich organic phase), **$E_{Cu.Exc}$** (Copper extraction percentage during extraction), and the formula for **E_{Cu}** are updated.

$$E_{Cu.Exc} = (C_{nCu(p.s\text{-}s)} - C_{nCu(raf)}) / (C_{nCu(p.s\text{-}s)}) \times 100\% \quad (3)$$

$$E1_{Cu\ (el\text{-}t),\ from\ p.\ s\text{-}s} = (C1_{Cu(el\text{-}t)} \times V1_{(el\text{-}t)} - C0_{Cu(el\text{-}t)} \times V0_{(el\text{-}t)}) / (C1_{Cu(p.s\text{-}s)} \times V1_{p.s\text{-}s}) \times 100\% \quad (4)$$

$$E1_{Cu\ (el\text{-}t),\ from\ org.} = (C1_{Cu(el\text{-}t)} \times V1_{(el\text{-}t)} - C0_{Cu(el\text{-}t)} \times V0_{(el\text{-}t)}) / (C1_{Cu\ (org.\ R)} \times V1_{org.}R) \times 100\% \quad (5)$$

$$C1_{Cu(org)}\ D = ((C1_{Cu(p.s\text{-}s)} \times V1_{p.s\text{-}s} - C1_{Cu\ raf} \times V1_{raf}) - (C1_{Cu(el\text{-}t)} \times V1_{(el\text{-}t)} - C0_{Cu(el\text{-}t)} \times V0_{(el\text{-}t)})) / V1_{org} + C0_{Cu(org)}\ D \quad (6)$$

$$C1_{Cu(org)}\ R = ((C1_{Cu(p.s\text{-}s)} \times V1_{p.s\text{-}s} - C1_{Cu\ raf} \times V1_{raf}) / V1_{opr} + C0_{Cu(org)}\ D \quad (7)$$

$$E_{Cu} = (C1_{Cu(p.s\text{-}s)} \times V1_{p.s\text{-}s} - C0_{Cu\ raf} \times V0_{raf} + C0_{Cu(el\text{-}t)} \times V0_{(el\text{-}t)}) / m_{Cu.init} \times 100\% \quad (8)$$

- 1 - indicators for the current day
- 0 - indicators for the previous day
- R-rich or saturated solution (electrolyte, organic phase)
- D - depleted, poor solution (electrolyte, organic phase)

Days 19–30: Electrolysis

m1+Cu-cathode (Theoretical mass of copper deposited (growth) on the cathodes), mCu - total (Total accumulated copper mass on the cathodes), Eskv. (Through copper extraction from ore to cathode metal). During electrolysis, the formulas for

CCu(org)O, ECu(el-t), from org, ECu(el-t), from p.r-ra, and ECu are updated.

$$m1_{+Cu\text{-}cathode} = (C1_{Cu(el\text{-}t)}R \times V1_{(el\text{-}t)}R - C1_{Cu(el\text{-}t)}D \times V1_{(el\text{-}t)}D) \quad (9)$$

$$m_{n(Cu\text{-}total)} = m_{1+Cu\text{-}cathode} + m_{2+Cu\text{-}cathode} + \ldots + m_{n+Cu\text{-}cathode} \quad (10)$$

$$E_{n(through)} = m_{n(Cu\text{-}total)} / m_{Cu.init} \times 100\ \% \quad (11)$$

$$C1_{Cu(org)}D = ((C1_{Cu(p.s\text{-}s)} \times V1_{p.s\text{-}sa} - C1_{Cu\ raf} \times V1_{raf}) - (C1_{Cu(el\text{-}t)} \times V1_{(el\text{-}t)} - C0_{Cu(el\text{-}t)} \times V0_{(el\text{-}t)}) - m0_{+Cu\text{-}cathode}) / V1_{org} + C0_{Cu(org)}D \quad (12)$$

$$E1_{Cu\ (el\text{-}t),\ from\ org.} = (C1_{Cu(el\text{-}t)} \times V1_{(el\text{-}t)} - C0_{Cu(el\text{-}t)} \times V0_{(el\text{-}t)} + m0_{+Cu\text{-}cathode}) / (C1_{Cu\ (org.\ R)} \times V1_{org.R}) \times 100\ \% \quad (13)$$

$$E1_{Cu\ (el\text{-}t),\ from\ p.s\text{-}s} = (C1_{Cu(el\text{-}t)} \times V1_{(el\text{-}t)} - C0_{Cu(el\text{-}t)} \times V0_{(el\text{-}t)} + m0_{+Cu\text{-}cathode}) / (C1_{Cu(p.s\text{-}s)} \times V1_{p.s\text{-}s}) \times 100\ \% \quad (14)$$

$$E_{Cu} = (C1_{Cu(p.s\text{-}s)} \times V1_{p.s\text{-}s} - C0_{Cu\ raf} \times V0_{raf} + C0_{Cu(el\text{-}t)} \times V0_{(el\text{-}t)} + m0_{Cu\text{-}total}) / m_{Cu.init} \times 100\% \quad (15)$$

Result: Copper Balance

The copper balance represents the percentage distribution of copper across various components of the technological process after completing all processing and extraction stages. It shows how much copper remains in each of the following categories:

1. Residual in the ore: Copper remaining in the original ore after extraction.

2. In raffinate: Copper remaining in the solution used for washing and purification.

3. In the electrolyte: Copper is present in the electrolyte after electrolysis.

4. In the organic phase: Copper is present in the organic phases (e.g., in extractants).

5. On the cathodes: Copper deposited on the cathodes during electrolysis.

This balance helps assess the efficiency of the copper extraction and processing processes and identify losses at various stages of the technological process.

Residual in the ore:

$$Cu_{ore} = 100\% - Cu_{raf} - Cu_{el\text{-}t} - Cu_{org} - Cu_{cathode} \quad (16)$$

Residual in the raffinate:

$$Cu_{raf} = (C_{Cu(raf)} \times V_{(p.s\text{-}s)}) / m_{Cu.init} \times 100\% \quad (17)$$

Residual in the electrolyte:

$$Cu_{el\text{-}t} = (C_{Cu(el\text{-}t)}O \times V_{(el\text{-}t)}O) / m_{Cu.init} \times 100\% \quad (18)$$

Residual in the organic:

$$Cu_{org} = (C_{Cu(org)}O \times V_{(org)}) / m_{Cu.init} \times 100\% \quad (19)$$

Residual on the cathode:

$$Cu_{cathode} = m_{Cu\text{-}total} / m_{Cu.init} \times 100\% \quad (20)$$

Results and Discussion

As a result of the conducted research, a specialized website was created to simplify the process of monitoring parameters during metal extraction.

Main functions of the website:

- Adding input data via the interface
- Calculating the dynamics of output parameters
- Displaying the calculation results in a table

Initially, the user is greeted with the "Explore Metals" page (Figure 2), where they can either select existing data or add their own metal and all input data (section 2.1).

Next, the user should navigate to the "Metal Calculations" page (Figure 3), where they need to confirm the start of the calculation process.

Finally, the user can go to the "Metal Results" section to view the results (Figures 4–5).

As shown in Figure 5, a table displays the daily dynamics of the extraction indicators. This table allows the user to track the progress of the process.

Conclusions

This research and the development of specialized software for hydrometallurgical copper extraction processes have yielded significant technological advancements. By leveraging a Django-based architecture with MySQL as the data storage backbone, the software ensures consistent and accurate data processing, enabling comprehensive monitoring and management of the extraction process. The inclusion of various stages, from leaching to electrolysis, in a single combined extraction method, has proven highly effective for optimizing metal recovery and minimizing operational inefficiencies.

The software's design allows users to input data seamlessly, calculate complex parameter dynamics in real time, and view detailed results through clear tables and graphs. This not only aids in tracking process parameters but also empowers users to perform deep analysis of each stage's efficiency, making the decision-making process more data-driven and precise. The system, thus, significantly enhances the overall productivity and profitability of the copper extraction process, improving the quality of the final product while reducing both time and costs.

Despite these successes, there is substantial room for future improvements. One promising direction is integrating artificial intelligence and machine learning algorithms into the software. This would enable predictive modeling, allowing the system to forecast outcomes under different conditions and optimize processes accordingly. Such capabilities could enhance the software's adaptability, especially when dealing with variable ore compositions and changing operational parameters.

Moreover, expanding the software to support multi-metal extraction processes and handle more complex ores will increase its applicability in diverse industrial settings. Future enhancements could also focus on improving the user interface and ensuring the scalability of the system to meet the demands of larger operations. Integration with cloud-based infrastructure for real-time global access and further automating the monitoring of environmental impact during the extraction process would also be valuable additions to the software's roadmap.

Conflict of interest. The corresponding author declares that there is no conflict of interest.

CRediT author statement

B. Kenzhaliyev: Conceptualization, Methodology, Metallurgical Analysis. **B. Amangeldy:** Software Development, Technological Implementation**. N. Azatbekuly:** Practical Testing, Application of Technologies**. A. Mukhanbet:** Process Optimization, Technical Validation. **A. Koizhanova:** Data Analysis, Metallurgical Assessment. **D. Magomedov:** Manuscript Drafting, Reviewing, Metallurgical Interpretation.

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Металл алуға арналған гидрометаллургиялық есептеулер үшін бағдарламаны әзірлеу

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ТҮЙІНДЕМЕ
Гидрометаллургия металлургия өнеркәсібінде сулы ерітінділерді пайдалана отырып, кендерден және қайталама материалдардан металдарды алудың тиімді әдісін қамтамасыз ету арқылы маңызды рөл атқарады. Бұл тәсіл әсіресе төмен сұрыпты және күрделі кендерді, сондай-ақ дәстүрлі пирометаллургиялық әдістермен тиімді өңдеуге келмейтін қайталама ресурстарды өңдеу үшін тиімді. Бұл зерттеудің мақсаты гидрометаллургиялық процестерде металды алу үшін қажетті есептеулерді автоматтандыру және оңтайландыру үшін арнайы бағдарламалық қамтамасыз етуді жасау болып табылады. Бағдарламалық қамтамасыз ету гидрометаллургиялық процестің әртүрлі кезеңдерін автоматтандыруға арналған толық есептеу жүйесін біріктіреді, оның ішінде руда құрамын инициализациялау, элементтердің жалпы массасын есептеу, металл өнімдеріндегі (штейндегі) және жанама өнімдердегі (шлак) металдардың концентрациясын анықтау. Әдістеме пайдаланушы интерфейсі үшін Django және сенімді деректерді сақтау үшін MySQL арқылы веб-негізделген қолданбаны жобалау мен енгізуді қамтиды. Python тілінде жазылған есептеу

модулі күрделі химиялық реакциялар мен металдарды алу процестерін модельдеу үшін қажетті математикалық операцияларды автоматтандырады. Бұл модуль нақты уақыт режимінде өңдеуді қолдайды және сілтілеу, экстракция, қайта экстракция, сорбция және электролизді қоса алғанда, металды алудың әрбір кезеңі үшін дәл есептеулерді қамтамасыз етеді. Бағдарламалық жасақтамада сонымен қатар пайдаланушыларға бағалы металдардың таралуын талдауға және негізгі операциялық параметрлердің өндіру тиімділігіне әсерін бағалауға мүмкіндік беретін егжей-тегжейлі кестелер мен динамикалық графиктер бар. Нәтижелер әзірленген бағдарламалық жасақтама үлкен деректер жиынын сәтті басқаратынын, гидрометаллургиялық есептеулердің дәлдігін арттыратынын және адам қателігінің қаупін барынша азайтатынын көрсетеді. Бағдарламалық қамтамасыз етуді енгізу металл алу көрсеткіштерін оңтайландыру және пайдалану шығындарын азайту арқылы өндірістің экономикалық тиімділігін айтарлықтай жақсартуға әкеледі. Бұған қоса, ол экстракцияның әрбір кезеңіне әсер ететін түсініктер беру арқылы процесті кешенді бақылауды қолдайды, осылайша соңғы металл өнімінің сапасын жақсартады. Тұтастай алғанда, бағдарламалық қамтамасыз ету гидрометаллургиялық процестерді оңтайландыруға бағытталған салалар үшін ауқымды шешім ұсынатын бұл саладағы маңызды технологиялық прогресс болып табылады.

Түйін сөздер: гидрометаллургия, есептеулерді автоматтандыру, металл алу, математикалық модельдеу.

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Разработка комплексного программного обеспечения для гидрометаллургического расчета извлечения металлов

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АННОТАЦИЯ

Гидрометаллургия играет ключевую роль в металлургической промышленности, предоставляя эффективный метод извлечения металлов из руд и вторичных материалов с использованием водных растворов. Этот подход особенно полезен для переработки низкосортных и сложных руд, а также вторичных ресурсов, которые не могут быть эффективно обработаны традиционными пирометаллургическими методами. Целью данного исследования является разработка специализированного программного обеспечения для автоматизации и оптимизации расчетов, необходимых для извлечения металлов в гидрометаллургических процессах. Программное обеспечение включает в себя полную вычислительную структуру для автоматизации различных этапов гидрометаллургического процесса, таких как инициализация состава руд, расчеты общей массы элементов и определение концентраций металлов в продуктах (штейн) и побочных продуктах (шлак). Методология включает разработку и внедрение веб-приложения на базе

Django для интерфейса пользователя и MySQL для надежного хранения данных. Вычислительный модуль, написанный на языке Python, автоматизирует математические операции, необходимые для моделирования сложных химических реакций и процессов извлечения металлов. Этот модуль поддерживает обработку данных в режиме реального времени и обеспечивает точные расчеты на каждом этапе извлечения металлов, включая выщелачивание, экстракцию, реэкстракцию, сорбцию и электролиз. Программное обеспечение также включает подробные таблицы и динамические графики, позволяющие пользователям анализировать распределение ценных металлов и оценивать влияние ключевых операционных параметров на эффективность извлечения. Результаты показывают, что разработанное программное обеспечение успешно справляется с обработкой больших объемов данных, повышает точность гидрометаллургических расчетов и минимизирует риск человеческих ошибок. Внедрение этого ПО приводит к значительному улучшению экономической эффективности производства за счет оптимизации показателей извлечения металлов и снижения эксплуатационных расходов. Кроме того, оно поддерживает комплексное управление процессом, предоставляя практические данные для каждого этапа извлечения, что улучшает качество конечного металлического продукта. В целом, программное обеспечение представляет собой значительное технологическое достижение в данной области, предлагая масштабируемое решение для предприятий, стремящихся оптимизировать гидрометаллургические процессы и повысить эффективность извлечения металлов.

Ключевые слова: гидрометаллургия, автоматизация расчетов, извлечение металлов, математическое моделирование.

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