Texnologik jarayonlar va yuklamalarni boshqarish uchun intellektual tizimlardan foydalanish

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Dolzarbligi: sanoat korxonalarida energiya iste'molini avtomatlashtirish va raqamlashtirish nafaqat energiya samaradorligini oshirish, balki resurslarni tejash, texnologik jarayonni monitoring qilishga xizmat qiladi. Xususan, bugungi kunda texnologiyalar va yuklamalarni boshqarishda intelektual tizimlardan foydalanish energiya sarfini monitoring qilish, iste'molni tahlil qilish hamda uning turli bosqichlarida avtomatik ravishda boshqarish imkonini yaratib, ishlab chiqarish jarayonlarini yanada samarali, ishonchli va optimal amalga oshirishda muhim ahamiyat kasb etadi. Shu bilan birga, raqamlashtirish va avtomatlashtirish orqali energiya resurslaridan to'g'ri foydalanish, ularni to'g'ri taqsimlash va barqaror rivojlanish imkonini beradi.

Maqsad: ushbu tadqiqotning maqsadi texnologik jarayonlar va yuklamalarni boshqarishda intellektual va avtomatlashtirilgan tizimlarni ishlab chiqish va ulardan qo'llashdan olinadigan samaralar muhokama qilingan. Shu bilan birgalikda misni boyitish fabrikasi misolida, yuklamalarni boshqarish masalasi tahlil qilinadi va real vaqt rejimida energiya iste'molini kuzatish hamda boshqarish uchun aqlli texnologiyalar integratsiya qilish masalalari ko'rib chiqiladi.

Usullari: ma'lumotlarni yig'ish va tahlil qilish, energiyani monitoring qilish usullari, statistik va matematik tahlil, modellashtirish va simulyatsiya, eksperimental tadqiqotlar, tahliliy sharh va tavsiyalar ishlab chiqish.

Natijalar: Olmaliq kon-metallurgiya kombinati (OKMK) misni boyitish fabrikasida energiya iste'molining umumiy tuzilmasi o'rganilib, ishlab chiqarish texnologik jarayonida eng ko'p elektr energiyasi sarflanadigan texnologik bo'limlar aniqlangan. Tahlil natijalariga ko'ra, mis va molibden boyitish jarayonining siljish bo'limida energiya iste'moli eng yuqori bo'lib, umumiy iste'molning 87,48% ini tashkil etdi. Energiya samaradorligini oshirish maqsadida, mavjud raqamli monitoring va nazorat tizimlarini optimallashtirish, texnologik jarayonlar va yuklamalarni boshqarish bo'yicha takliflar ishlab chiqildi.

Kalit so'zlari: raqamli avtomatlashtirish, energiya iste'molini boshqarish, sanoat jarayonlari, energiya samaradorligi, energiya balansini monitoring qilish, elektr energiyasi tahlili, mis va molibden boyitish, texnologik jarayon optimallashtirish, avtomatlashtirilgan boshqaruv tizimlari, ekologik samaradorlik.

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Использование интеллектуальных систем для управления технологическими процессами и электрическими нагрузками

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Актуальность: автоматизация и цифровизация энергопотребления промышленными предприятиями позволяют не только повышать эффективность энергопотребления, т.е. экономить ресурсы, но и мониторить технологические процессы. В частности, использование интеллектуальных систем делает возможным управление технологическими режимами и электрическими нагрузками на различных производственных этапах. Это способствует более эффективному, надежному и оптимальному выполнению производственных процессов. Кроме того, цифровизация и автоматизация обеспечивают правильное использование и распределение энергетических ресурсов, повышение конкурентоспособности производимой продукции на внутреннем и внешнем рынках.

Цель: цель данного исследования заключается в разработке интеллектуальных и автоматизированных систем управления технологическими процессами и нагрузками, оценке в режиме реального времени их эффективности на примере фабрики по обогащению меди, а также разработка рекомендаций.

Методы: аналитический обзор и анализ имеющихся в литературе данных, применение современных методов мониторинга энергии, статистического и математического анализа, моделирования и симуляци, а также экспериментальные исследования.

Результаты: на медеобогатительной фабрике Алмалыкского горно-металлургического комбината (АГМК) изучена общая структура энергопотребления, выявлены технологические отделы с наибольшим потреблением электроэнергии в производственном процессе. Наибольшее энергопотребление было зафиксировано в отделении флотации меди и молибдена, где оно составило 87,48% от общего объема электропотребления. В целях повышения энергоэффективности предложена оптимизация существующих систем цифрового мониторинга и контроля, а также разработаны рекомендации по управлению технологическими процессами и нагрузками.

Ключевые слова: цифровизация, управление энергопотреблением, промышленные процессы, энергоэффективность, мониторинг энергетического баланса, анализ потребления электроэнергии, обогащение меди и молибдена, оптимизация технологических процессов, автоматизированные системы управления, экологическая эффективность.

Utilization of intelligent systems for managing technological processes and loads

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Relevance: automating and digitizing energy consumption in industrial enterprises not only improves energy efficiency but also aids in resource conservation and monitoring of technological processes. Specifically, using intelligent systems in technology and load management enables real-time monitoring of energy consumption, analyzing consumption patterns, and automatically managing consumption at various stages. This significantly enhances the efficiency, reliability, and optimization of production processes. Additionally, digitalization and automation facilitate the correct utilization and distribution of energy resources, supporting sustainable development.

Aim: The goal of this study is to develop intelligent and automated systems for managing technological processes and loads, as well as to discuss the benefits of their application. Additionally, using the example of a copper enrichment plant, the study examines load management and the integration of smart technologies to monitor and control energy consumption in real-time.

Methods: data collection and analysis, energy monitoring methods, statistical and mathematical analysis, modeling and simulation, experimental research, analytical review, and development of recommendations.

Results: at the copper enrichment plant of the Almalyk Mining and Metallurgical Complex (AMMC), the overall structure of energy consumption was analyzed, identifying the technological departments with the highest electricity consumption in the production process. Analysis results showed that the flotation department for copper and molybdenum had the highest energy consumption, accounting for 87.48% of total consumption. To improve energy efficiency, suggestions were made to optimize existing digital monitoring and control systems, as well as recommendations for managing technological processes and loads.

Key words: digital automation, energy consumption management, industrial processes, energy efficiency, energy balance monitoring, electricity consumption analysis, copper and molybdenum beneficiation, process optimiza-

tion, automated control systems, ecological efficiency.

1. Introduction

The global industrial sector has been experiencing significant advancements in automation and digitalization, driven by the need for enhanced efficiency, cost savings, and sustainable energy management. Industrial enterprises, particularly those with energy-intensive processes, are under increasing pressure to optimize their energy consumption. As industries continue to expand, so does their demand for energy, which has resulted in higher operational costs and an increased environmental impact. These challenges emphasize the need for advanced systems that can monitor, control, and optimize energy usage at various stages of production. In Uzbekistan, the Almalyk Mining and Metallurgical Complex (AMMC) plays a pivotal role in the production of copper, molybdenum, and other valuable metals. The energy-intensive processes involved in mineral beneficiation, especially in the copper and molybdenum production stages, require efficient energy management strategies to ensure both economic feasibility and environmental sustainability [1,2]. Addressing these needs, the integration of digital and automated systems for energy management can support the AMMC in achieving greater operational efficiency and minimizing resource waste.

This research paper aims to explore the application of digital automation and intelligent systems in managing energy loads and technological processes within the AMMC. By analyzing existing energy consumption patterns and identifying optimization opportunities, this study seeks to develop actionable insights for improving energy efficiency [3,4]. Through real-time monitoring and automated control, the research aims to contribute to a sustainable industrial model that supports resource conservation and cost-effective operations. The findings of this study have implications for energy-intensive industries globally, highlighting pathways to leverage digitalization and automation for a more sustainable future in industrial energy management.

2. Methods and materials

This study employs a combination of quantitative and qualitative research methods to analyze, monitor, and optimize energy consumption in the Almalyk Mining and Metallurgical Complex (AMMC). The methods applied in this research include data collection and analysis, energy monitoring, statistical and mathematical analysis, modeling and simulation, experimental testing, and the development of practical recommendations. To understand current energy consumption patterns, data was collected from AMMC's existing records, focusing on energy usage in the copper and molybdenum beneficiation processes. Key metrics such as electricity, natural gas, and steam consumption were compiled and analyzed to identify high-consumption areas and evaluate energy use efficiency across different production stages [5,6,7].

Advanced energy monitoring systems were employed to track real-time energy consumption in critical production areas. Automated sensors and monitoring devices were installed in high-consumption sections to continuously measure energy usage and detect inefficiencies. This provided a comprehensive dataset on energy patterns, enabling precise monitoring and control. The collected data was further analyzed using statistical and mathematical models to identify patterns and correlations in energy consumption. By applying methods such as regression analysis and trend forecasting, key variables affecting energy efficiency were identified, highlighting specific process stages with the highest energy demand and areas where improvements were most needed [8].

Digital modeling and simulation were used to create a virtual representation of AMMC's energy systems, allowing for the testing of various energy optimization scenarios without disrupting actual production. Simulation software was used to model the effects of energy-saving measures on production efficiency, enabling the team to predict potential outcomes and select the most effective strategies. Based on modeling results, selected energy optimization techniques were experimentally implemented in high-consumption areas to measure their impact on energy usage [9]. Following data analysis and experimental testing, an analytical review was conducted to develop recommendations, including intelligent control systems for energy distribution, optimized load management, and strategies for continuous monitoring.

3. Results and Disscussion

In selecting the research object, we analyzed the production facilities of the Almalyk Mining and Metallurgical Complex (AMMC), specifically focusing on their production technology and the status of automated energy consumption accounting systems installed within these facilities. AMMC is a large industrial enterprise in Uzbekistan specializing in the production of non-ferrous and ferrous metals. Established in 1957, AMMC is one of the world's largest enterprises for processing copper, zinc, lead, and other metals. Today, the plant holds a leading position in the global market for copper and zinc production, exporting its products to Europe, Asia, Africa, and Latin America. The majority of the plant's output consists of copper products. In the first half of 2023 alone, the plant exported 30,012 tons of copper, 17,549 tons of zinc, and 446 tons of molybdenum, amounting to a total export value of $361.954 million (Figure 1) [10].

The technological process at AMMC involves the consumption of electricity, natural gas, thermal energy (in the form of steam), and water. Table 2.1 presents the distribution of energy consumption by resource type in 2022, with the majority of energy consumed in the production of copper and molybdenum products.

Table 1. Energy Consumption by Type at AMMC in 2022

№	Energy Types	%
1	Electricity	44
2	Natural Gas	28
3	Thermal Energy	17
4	Other	11

In the production stages of copper and molybdenum products, the copper beneficiation stage represents the highest energy-consuming segment. Therefore, the research focuses on AMMC's second copper beneficiation plant (referred to as CBF-2). Within the plant's energy consumption balance, electricity usage is significantly higher than that of other energy resources, thus making it the primary focus of this study. CBF-2 is one of Uzbekistan's largest facilities for producing copper and molybdenum concentrates. Its primary activity centers around the processing of copper-molybdenum ores extracted from the "Kalmakyr" and "Sary-Cheku" mines, as well as the production of a collective copper-molybdenum concentrate [10]. CBF-2 has implemented several energy management initiatives, including measures to reduce the consumption of freshwater by utilizing recycled water from waste processing.

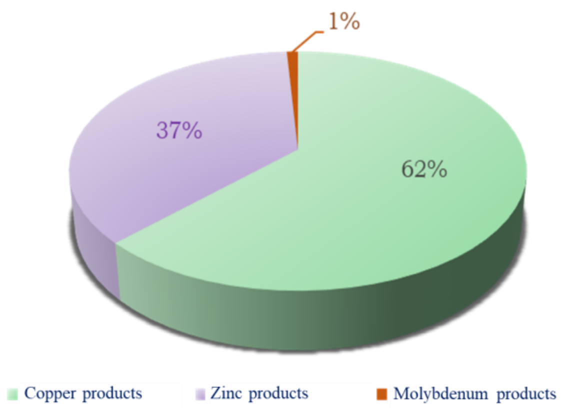

Fig.1. Share of AMMC's Annual Exports by Product Type

The electricity supply to CBF-2 is provided by the "TPS" joint-stock company, which includes both the "Yangi-Angren" and "Syrdarya" power stations. External electrical supply to the plant is sourced from two system substations, "Almalyk" and "Kora-Qiya-Soy," with voltage levels of 220/110 kV. Through specific feeder connections (7, 10, 16, and 18) from the "Kora-Qiya-Soy" substation, the plant receives electricity at 6 kV via cable lines. The supply is further distributed across fourteen 6-kV substations, three distribution substations, and four transformer substations (Figure 2). For production needs, hot water is provided by the Almalyk district heating system, while steam for technological processes is sourced from Almalyk's Industrial Energy Facility. The technological process in CBF-2 involves the beneficiation of raw materials (slag) supplied from the Kalmakyr and Sary-Cheku mines and AMMC's other production plants. This involves flotation-based beneficiation to produce copper and molybdenum concentrates.

Historically, copper and molybdenum concentrate production employed both gravitational and flotation methods. However, since January 2004, all gravitational equipment and apparatus chains have been removed from the plant's process scheme, making flotation technology the sole method for ore processing [11]. This shift towards a fully flotation-based system was undertaken to increase process efficiency and align with modern industry standards, which prioritize flotation as a more efficient and controlled method of mineral beneficiation. In summary, CBF-2's technological and operational setup for producing copper and molybdenum concentrates has evolved to incorporate more sustainable and efficient methods. The reliance on automated monitoring and control systems, along with optimized resource use (such as recycled water), underlines AMMC's commitment to energy efficiency and resource management. The study of CBF-2's energy consumption, particularly focusing on its high electricity demand, aims to provide valuable insights into further optimizing energy use, reducing costs, and enhancing sustainability in mineral processing operations.

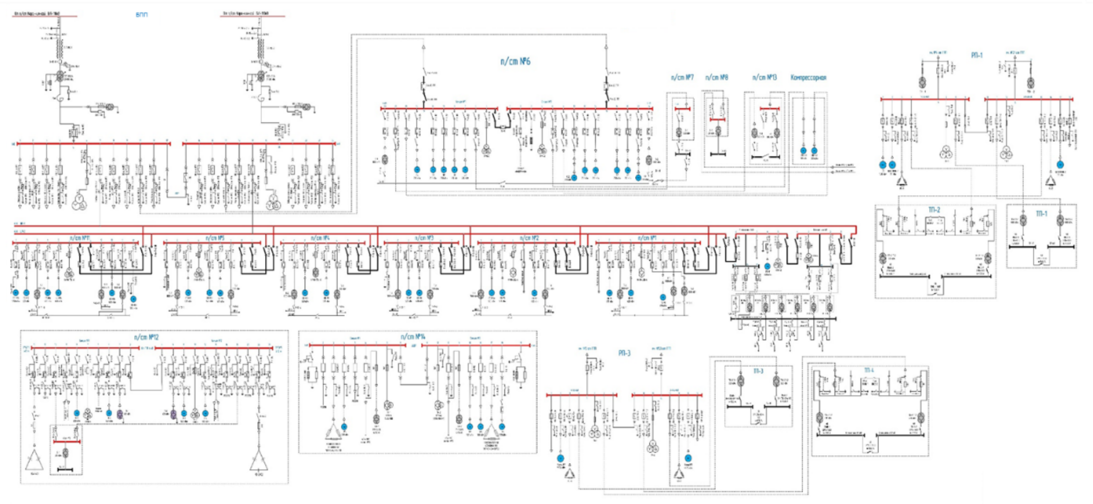

Fig. 2. Single-line electrical supply diagram of CBF-2

Copper Beneficiation Technological Process at CBF-2. Initially, copper-molybdenum ore with a thickness of 1200 mm is received and crushed in three crushing units. Only at the third stage of crushing is slag added to the process. In the subsequent stage, the crushed ore is further refined in the crushing and flotation section, where twelve processing units grind the ore down to a particle size of 0.038-0.020 mm. The beneficiation process is then completed using flotation across six flotation units, where the material undergoes further enrichment through the flotation method.

I	Асосий технологик жараён учун	86.46%
1	**Майдалаш:**	**9.50%**
1.1	ДЦ-1	5.76%
1.2	УДИ	0.83%
1.3	ДОК-2	2.91%
2	**Силлиқлаш:**	**87.48%**
2.1	ЦИнФ	66.88%
2.2	УДИ	8.57%
2.3	ДОК-2	24.55%
3	**Реагент бўлими**	**0.15%**
4	**Ф С Ц**	**1.96%**
5	**Молибден ажратиш**	**0.91%**
II	**Ёрдамчи технологик жараён учун**	**13.54%**
1	**Механика**	**0.20%**
2	**Техник чиқиндилар**	**85.51%**
3	**Энергоцех**	**2.31%**
4	**Бошқа эхтиёжлар учун**	**3.66%**
4.1	Ёритиш	25.00%
4.2	Вентиляция	33.33%
4.3	бошқалар	41.67%
5	**Ташувчи қурилмалар**	**8.10%**
5.1	ДЦ-1	8.60%
5.2	ДОК-2	26.18%
5.3	ЦИнФ	49.13%
5.4	ЦСХ	16.09%
6	**Ёрдамчи хўжалик истеъмоллари**	**0.22%**
6.1	Ошхона	44.44%
6.2	Бош бино	55.56%

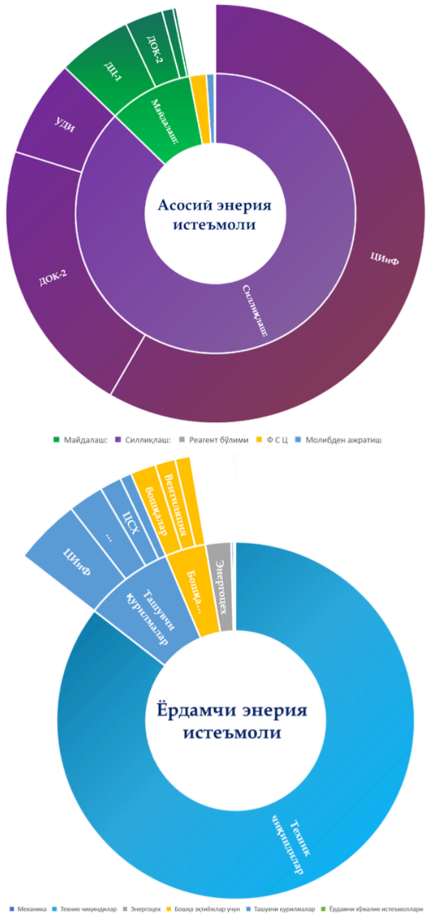

Fig. 3. Electricity Consumption Balance of the Main Technological Structures of CBF-2 (note: the result is gotten from interface of the software. Асосий технологик жараён учун – For main technological process, Асосий энергия истеъмоли – Main energy consumption, Ёрдамчи технологик жараён учун – For auxiliary technological process, Ёрдамчи энергия истеъмоли , Auxiliary energy consumption, Легенда – Legend, Мибденум – Molybdenum, Сланецни аралаштириш – Slime mixing, Ёрдамчи қайта ишлаш – Auxiliary processing, Рудани қайта ишлаш – Crude ore processing, Силлиқлаш – Grinding. Abbreviations represent workshop names)

The technological structure and electricity balance of CBF-2 have been designed to ensure efficient monitoring and distribution of electricity across its operations. In CBF-2, electricity consumption is monitored across 11 technological structures, with the distribution of electricity shown in Figure 3. This copper beneficiation plant has an annual processing capacity of 38 million tons of ore, with an average yearly electricity consumption of approximately 950 MWh. According to the electricity balance presented in Figure 3, the largest portion of electricity consumption is dedicated to the main technological process, particularly in the grinding section [12,13,14]. This section accounts for 87.48% of the total electricity usage, equivalent to 718 MWh, highlighting its energy-intensive nature. The high demand for electricity in the grinding process is due to the need for substantial mechanical power to achieve the desired particle sizes in ore processing, which is crucial for efficient downstream flotation and concentration of copper and molybdenum. This detailed energy monitoring and allocation framework within CBF-2 underscores the importance of targeted energy management strategies, especially in high-consumption areas like grinding. By understanding specific electricity demands within each process stage, the plant can explore opportunities to optimize energy usage, reduce costs, and minimize its environmental footprint. This focus on energy efficiency aligns with broader industry trends toward sustainable resource management and the integration of smart energy solutions within high-demand industrial settings.

4. Conclusion

This study highlights the critical role of digitalization and automation in optimizing energy management within energy-intensive industrial processes. Focusing on the copper beneficiation operations at the Almalyk Mining and Metallurgical Complex (AMMC), we analyzed energy consumption patterns, identified key areas with the highest energy demands, and proposed strategies to improve energy efficiency. The findings indicate that a substantial portion of electricity consumption is concentrated in the grinding stage, accounting for over 87% of the total electricity usage for the main technological processes. This presents a significant opportunity for targeted energy optimization efforts. By implementing intelligent systems for real-time monitoring and control, AMMC can enhance the precision and efficiency of its energy distribution. The study's insights emphasize that adopting automated, digital energy management systems can lead to considerable operational cost savings, reduced environmental impact, and sustainable resource use. The successful application of these strategies in AMMC demonstrates their potential applicability across similar industrial settings. In conclusion, the integration of smart energy management solutions in industrial operations not only promotes economic efficiency but also supports environmental sustainability. Future work could explore the application of advanced predictive analytics and machine learning algorithms to further enhance energy optimization in real time. This study reinforces the value of intelligent systems as essential tools for achieving sustainable industrial development in energy-intensive sectors.

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