ОБОГАЩЕНИЕ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

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Hydrometallurgical processes of leaching at mining enterprises of the Republic of North Ossetia–Alania

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Abstract

Research relevance. *With the change in the economic management system after the 1990 reforms, state-subsidized mining enterprises of the North Caucasus ceased functioning. One reason of reduced production capacity is metal production resource base weakening caused by selective mining of deposits' rich areas and cessation of exploration work. The state strategy of the North Caucasus republics provides for increased contribution of the extractive industry to the economy, which makes the problem under consideration very relevant.*

Methods of research. *The results of research carried out in the Republic of North Ossetia–Alania were used to substantiate the possibility and effectiveness of hydrometallurgical techniques of obtaining metals from ores. The research included the critical analysis and technical and economic assessment of prospects.*

Research results. *Restoration of the non-ferrous metal production potential is possible with the involvement of raw materials that are substandard for traditional technologies. The Sadon lead and zinc plant, the Tyrnyauz Mining and Processing Plant and the Urup Mining and Processing Plant used open stope mining methods as well as inconsistent backfilling with waste material, which reduced the quality of ores and increased the cost of metals. Advanced leaching technologies based on metals conversion into highly soluble compounds and further extraction from a collective solution make it possible to develop depleted reserves of the North Caucasian metal deposits. That technology was used at the Bykogorsky deposit for non-commercial reserves for a long time. For the first time in mining practice, the technology was also used to mine the Fiagdon group ore of the Sadon ore cluster. Rather limited experience of a plant production capacity improvement shows that raw materials that are substandard for traditional technologies can ensure the profitability of metal production when combined with traditional technology. It is important that all metals are extracted when leaching into the product solution, which increases the recoverable value of ores.*

Conclusions. *The localization features of the North Caucasian deposits are favorable for the allocation of lost ore concentration areas within the spent ore bodies, their leaching, and reagent solutions feed and metal-saturated solutions delivery through wells from the surface.*

Keyword: *metal; ore; deposit; condition; technology; leaching; extraction; economics; ecology.*

Introduction. The 1990 reforms made state-subsidized mining enterprises of the North Caucasus cease or reduce ore production. Changes in pricing policy resulted in mineral resource base weakening, exposing the drawbacks of field development technologies [1–2].

One way of restoring enterprise capacities is using non-commercial ore underground and using the products of sorting low-grade ore and tailing grading waste on the surface

through hydrometallurgical processes including metals transfer into a mobile state with subsequent precipitation [3–5]. The technology is known as mine hydrometallurgy and is regularly applied in the mining industry.

Hydrometallurgical processes in mining and processing differ from traditional processes. Their particular characteristics include providing channels for solution filtration during loosening, ore crushing and grinding; metals solubilizing using chemicals; precipitation of metals from solutions and sediment processing and concentrates production on the territory of a mining enterprise.

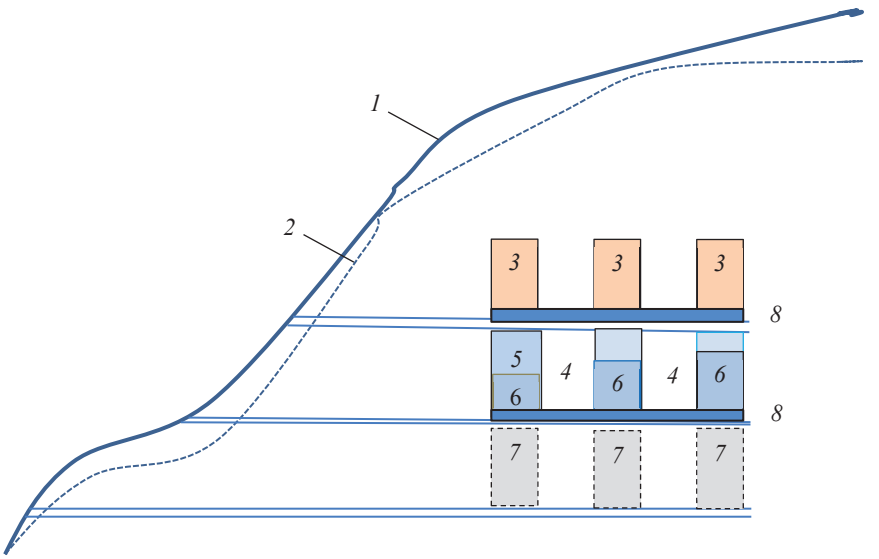

Figure 1. Technology with an open stope: *1* − earth surface; *2* – sediment boundary; *3* − spent chamber; *4* – inter-chamber pillars; *5* − unbroken ore; *6* – broken ore; *7* − chamber in preparation; *8* − stump pillar

Рисунок 1. Технология с открытым выработанным пространством: *1* − земная поверхность; *2* − граница наносов; *3* − отработанная камера; *4* − межкамерные целики; *5* − неотбитая руда; *6* − отбитая руда; *7* − камера в подготовке; *8* – надштрековый целик

In underground blocks and heaps, hydrometallurgical and mining processes are combined to achieve a synergistic effect [6–8]. In the history of mining, hydrometallurgical methods were used to extract metals from raw materials which contained metal that could not be feasibly processed by traditional methods [9–11]. The history of leaching development began with non-commercial and low-grade uranium ore processing and continues with commercial ore reserves development on an industrial scale (Priargunsky Mining and Chemical Plant). Mining waste treatment technologies as a way to expand the mineral resource base of mining and metallurgy are considered in works [12–14]. Aspects of technogenic deposits impact on natural ecosystems are detailed in articles [15–17]. The basic principles of obtaining, transferring and storing information about the parameters of the technogenic cycle of a mining and metallurgical enterprise are set out in works [18–20]. Ostroushko I. A., Khulelidze K. K., Gorodnichev A. P., Kondratiev Iu. I., Kelin V. N., Rostovanov S. E., Golik V. I., Evdokimov S. I. and others contributed to the theory and practice of metal leaching.

The North Caucasus republics have favorable conditions for profitable production of non-ferrous metals and involvement of substandard raw materials through technologies based on hydrometallurgical processes. The share of mining and processing within the gross regional product does not exceed 10%. The North Caucasus republics were assigned the task of developing the mineral resource base through new field development technologies.

Advanced ore processing technologies make it possible to extract into concentrates the richest part of mining and processing waste. However, secondary tailings cannot be used in the production of goods due to the presence of metals.

Research objective is to analyze the practice of using hydrometallurgical leaching processes at mining enterprises of the Republic of North Ossetia–Alania.

The history. The Sadon lead and zinc plant has been operating since 1853, when the Sadon mine and the Alagir silver-lead plant were built. The reserves of the Sadon

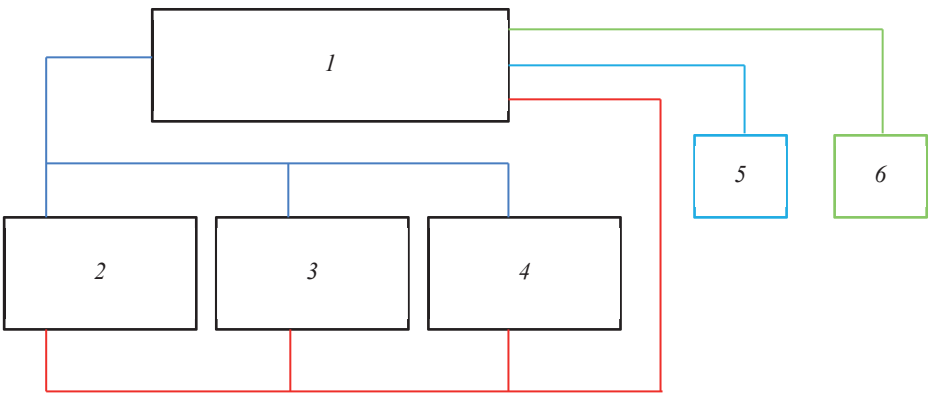

Figure 2. Scheme of metal extraction: *1* – reagent solution processing workshop; *2* – underground leaching; *3* – heap leaching; *4* – leaching in a disintegrator; *5* – metals; *6* – tailings

Рисунок 2. Схема добычи металлов: *1* – цех переработки растворов реагентов; *2* – подземное выщелачивание; *3* – кучное выщелачивание; *4* – выщелачивание в дезинтеграторе; *5* – металлы; *6* – хвосты

deposits account for about 2% of Russia's lead reserves. In Sadon, in the territory of ten deposits, polymetallic ores were mined using open stope mining methods (ore losses were up to 20% with dilution up to 60%).

Low ore quality and high cost of metal production were caused by open stope mining methods. Another reason was early production of rich ore and reserves depletion.

The stope was kept open or filled with discrete rocks which moved downwards as the chamber was undermined, forming a mass of discrete dilution rocks. In the course of mining the chamber reserves, ore quality was satisfactory, but it often decreased to a rejectable quality level during pillar recovery (Figure 1).

The plant capacity reach 745 thousand tons per year. There was a time when Ossetia fully met the USSR's demand for lead and 2/3 demand for zinc. Since the 1970s the plant carried out the plan for concentrates, mainly by means of raw materials brought from offsite.

The amount of ore which was left in the Sadon deposits and may provide a basis for metal leaching, reaches 30 million tons. Active reserves are localized in the Sadon and Arkhon deposits. The most possible raw material base may be provided by the reserves of the Bozang area of the Djimidon deposit.

Hydrometallurgical processes of ore processing. Profitable development of the North Caucasus reserves is possible with new technologies based on hydrometallurgical processes of ore processing and metals transfer into a mobile state with subsequent precipitation. The Republic of North Ossetia–Alania was the first region to make an attempt to use such technologies.

At the Fiagdon mine, 32 tons of zinc were precipitated from mine discharge in 48 days. At the Arkhon mine, 40 tons of zinc were precipitated from mine discharge in 51 days.

For the first time in world practice, commercial ore leaching was carried out in 1974 at the Kakadur deposit of the Fiagdon group. During the project implementation, 60 tons of concentrate containing 15% zinc were obtained. Leaching technology differs from traditional technologies in that it ensures the recovery of metals previously lost in tailings. Their total cost can be by several fold greater than the cost of the recovered metals.

Profit from the involvement of previously unused mineral resources in processing increases when traditional technologies are combined with advanced leaching technologies. The value of the rate of recovery is comparable to its value when producing metal using traditional technology. This increases the recoverable value of ores being an important factor in choosing a mining method.

A scheme of metal extraction using hydrometallurgical processes is shown in Figure 2.

Table 1. Indicators of the quality of mined ores (North Caucasus)
Таблица 1. Показатели качества добываемых руд (Северный Кавказ)

Deposits	Form	Rocks	Ores	Losses, %	Dilution, %
Sadon group	Steeply dipping veins 1–5 m thick	Shales, limestones, granites, porphyrites	Galena, sphalerite, pyrite, pyrrhotite	20	40
Tyrnyauz group	Steeply dipping up to 130 m thick	Shales, gneisses, granites, porphyries, diorites	Molybdenite, scheelite, molybdoscheelite	20	50
Urup group	Low dip beds 1–5 m thick	Diabases, albitophyres, shales, tuffs, sandstones	Pyrite, chalcopyrite, sphalerite, bornite, hematite	15	30

The Kakadur field development project involved feeding reagent solutions from the surface and delivering production solutions for processing through wells. Zinc precipitation was carried out with sodium biocardonate or zinc dust. The concentrate was headed for the hydrometallurgical plant. With an installation productivity of 150 m^3 of solutions per hour and 60% extraction of metals from ores, the cost of 1 ton of metals was 352 rubles, while with traditional technology it was 900 rubles/t. The new technology ensured the extraction of up to 70% of metals lost under the traditional method, generated profit from selling recovery by-products, and drastically reduced the negative impact of tailings on natural ecosystems.

The leaching technology capabilities have been confirmed by the experience of the Bykogorsky uranium deposit, where uranium was produced for 30 years at a content twice as low as the balance threshold.

The North Caucasus enterprises' experience is united by the use of technologies with rock mass natural management, associated ore losses and dilution, and negative consequences of storing tailings. The low quality of extracted ores increased the cost of metals (Table 1).

A close analogue of the new technology is the practice of extracting metals into solution from ores using aqueous solutions of reagents and delivering them to the surface for processing. Mountainous landscape contributes to that scheme together with the possibility of using data ascertained during the ore extraction, which makes it possible to identify ore field areas promising for leaching.

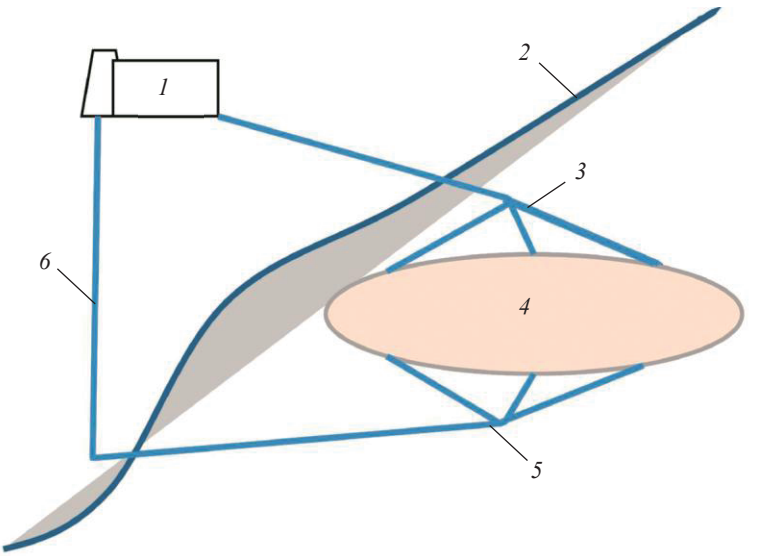

Figure 3. Leaching scheme of lost reserves: *1* – workshop for the preparation and processing of solutions; *2* – the earth's surface; *3* – reagent solution; *4* – lost ores; *5* – production solution; *6* – mine working
Рисунок 3. Схема выщелачивания потерянных запасов: *1* – цех приготовления и переработки растворов; *2* – земная поверхность; *3* – раствор реагентов; *4* – потерянные руды; *5* – продукционный раствор; *6* – шахтная выработка

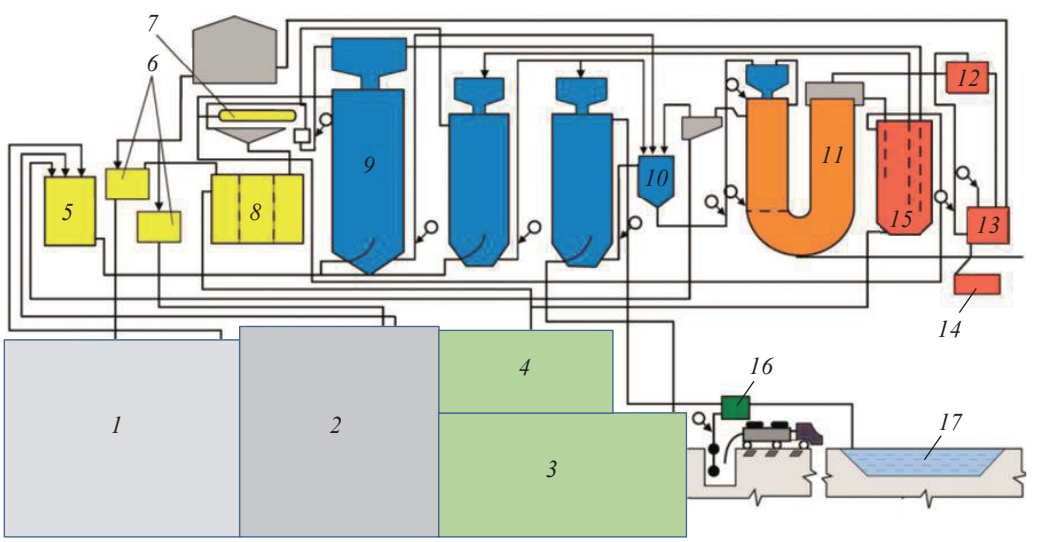

Figure 4. Combined technologies of leaching metals and substandard raw material: *1* – heap; *2* – underground leaching blocks; *3* – pile; *4* – activator; *5–8* – preparation group; *9–11* – sorption-desorption group; *12–16* – supplement group; *17* – pond
Рисунок 4. Комбинирование технологий выщелачивания металлов из некондиционного сырья: *1* – куча; *2* – блок подземного выщелачивания; *3* – отвал; *4* – активатор; *5–8* – группа подготовки; *9–11* – группа сорбции-десорбции; *12–16* – вспомогательная группа; *17* – пруд

Prospects for the Sadon deposits development. Underground leaching of metals from ores left in goaf using reagent solutions may be an analogue of the future technology for the Sadon deposits development. At the Taboshar deposit (Central Asia), after mining commercial ores, non-commercial ores were caved in and flooded with a sulfuric acid solution. At the Degtyarskoye deposit, copper was leached from lost ores using water. That technology was also used at the Meggen field (Germany).

Experimental leaching of oxidized zinc was carried out at the Yuzhnaya vein of the Arkhon mine (Republic of North Ossetia–Alania). The reagent solution was fed into the goaf, and the production solution flowed into a collection tank.

Table 2. Extraction of metals into solution (the Sadon deposit), %

Таблица 2. Извлечение металлов в раствор (Садонское месторождение), %

Content in tailings, %	Leaching in agitator 0.2–1.0 hours		Leaching in disintegrator 10 s.	
	Extracted	Residual	Extracted	Residual
Zinc – 0,95	24	72	28	69
Lead – 0,84	16	71	24	62

As far as the environmental protection is concerned, the technogenic extraction of metals from tailings in a closed, controlled medium with the generation of secondary tailings available for unlimited use is an environmental measure, and its effectiveness has not yet been assessed representatively.

A possible scheme for lost reserves leaching at the Sadon deposits is shown in Figure 3.

If the extraction of metals from tailings by traditional methods is ineffective, surfactants can intensify the process. Tailings are activated by combined mechanical and chemical action in blocks, heaps and in a high-speed disintegrator mill (Figure 4).

The results of experimental leaching of metals from tailings of the Sadon deposits are summarized in Table 2.

The new technology is based on transferring some hydrometallurgical processes of metal extraction to the field of mining, which makes the technology more economical by eliminating a number of flow processes. The economic effect of using the new technology increases with a realistic assessment of the damage from storing tailings left from processing metal-containing mineral raw materials on the earth's surface and in the subsoil.

Conclusions. The lost potential of North Caucasian mining and processing enterprises can be restored by combining traditional and advanced mining methods based on hydrometallurgical processes. The technologies are combined by extracting and processing rich ores using traditional technology and extracting metals in disintegrators with mechanical and chemical activation of processes.

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Гидрометаллургические процессы выщелачивания на горных предприятиях Республики Северная Осетия–Алания

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Реферат

Актуальность. *С изменением экономической системы хозяйствования после реформ 1990 г. ранее дотируемые государством горные предприятия Северного Кавказа прекратили функционирование. Причинами сокращения производственной мощности являются ослабление минерально-сырьевой базы производства металлов вследствие выборочной отработки богатых участков месторождения и прекращение геологоразведочных работ. Государственная стратегия республик Северного Кавказа предусматривает увеличение вклада добывающей отрасли в экономику, что делает рассматриваемую проблему весьма актуальной.*

Методика исследования. *Для обоснования возможности и эффективности гидрометаллургических методов извлечения металлов из руд использованы результаты выполненных в Республике Северная Осетия–Алания исследований с критическим анализом и технико-экономической оценкой перспектив.*

Результаты исследования. *Восстановление потенциала производства цветных металлов возможно при вовлечении в эксплуатацию некондиционного для традиционных технологий сырья. Садонский свинцово-цинковый комбинат, Тырныаузский горно-металлургический комбинат и Урупский горно-металлургический комбинат применяли системы разработки с открытым или бессистемно заполненным продуктами добычных работ выработанным пространством, что снижало качество руд и удорожало стоимость металлов. Освоение обедненных запасов Северо-Кавказских металлических месторождений возможно новыми технологиями выщелачивания, основанными на переводе металлов в легкорастворимые соединения и последующем извлечении металлов из коллективного раствора. Такая технология длительное время применялась на Быкогорском месторождении для отработки забалансовых запасов, впервые в мировой горной практике – при отработке руд Фиагдонской группы Садонского рудного узла. Сравнительно небольшой опыт увеличения производственной мощности предприятий показывает, что привлечение некондиционного для традиционных технологий сырья способно обеспечить рентабельность производства металлов при комбинировании с традиционной технологией. Важно, что при выщелачивании в продукционный раствор извлекаются все металлы, что повышает извлекаемую ценность руд.*

Выводы. *Особенности локализации Северо-Кавказских месторождений благоприятны для выделения в пределах отработанных рудных тел участков концентрации потерянных руд и их выщелачивания с подачей растворов реагентов и выдачей насыщенных металлами растворов по скважинам с поверхности.*

Ключевые слова: *металл; руда; месторождение; кондиция; технология; выщелачивание; извлечение; экономика; экология.*

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