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54th International October Conference on Mining and Metallurgy

PROCEEDINGS

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Editors:
Ljubiša Balanović
Dejan Tanikić

18-21 October 2023, Bor Lake, Serbia

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PREFACE

On behalf of the Organizing Committee, it is a great honor and pleasure to welcome all esteemed participants of the 54^{th} International October Conference on Mining and Metallurgy (IOC 2023), scheduled to take place at the picturesque Bor Lake, Serbia, from October18^{th} to 21^{st} 2023.

The collaborative efforts of the University of Belgrade, the Technical Faculty in Bor, and the Mining and Metallurgy Institute Bor have meticulously organized this year's IOC. Our focus remains unwavering on showcasing the latest research findings and advancements in geology, mining, metallurgy, materials science, technology, environmental protection, and other engineering disciplines. Our primary objective is to foster a dynamic environment where academics, researchers, and industry professionals can come together to share their knowledge, experiences, and innovative ideas while exploring opportunities for collaborative research endeavors.

Our conference agenda is rich and diverse, encompassing plenary sessions, engaging invited lectures, technical presentations, enlightening oral and poster sessions, informative technical tours, a diverse exhibition, and memorable social gatherings. At the heart of this event lies our strong commitment to sustainable development within the mining and metallurgy sector. We are dedicated to exploring ecologically conscious methodologies, responsible resource extraction practices, and cutting-edge technologies that reduce the industry's environmental impact and enhance the well-being of local communities.

The conference proceedings comprise 129 papers authored by individuals from universities, research institutes, and industries in 22 countries. We are proud to welcome participants from Bosnia and Herzegovina, Bulgaria, Canada, China, Croatia, Germany, Greece, India, Iran, Kazakhstan, Libya, North Macedonia, Montenegro, Morocco, Romania, Russia, Slovakia, South Africa, Spain, Turkey, United States, and, of course, Serbia.

We are excited to host the 8^{th} International Student Conference on Technical Sciences (ISC 2023) as part of IOC 2023. This event offers students from Serbia and the wider region a unique chance to showcase their research and discuss the future of their fields with experts.

We sincerely thank the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia for their generous financial support. In addition, we express our profound gratitude to all our sponsors, exhibitors, and friends of the Conference for their contributions and unwavering support for playing a pivotal role in ensuring the success of IOC 2023.

We would like to express our heartfelt thanks to all authors, committees, reviewers, speakers, and chairpersons for their invaluable contributions in shaping IOC 2023.

We look forward to welcoming you to the 55th International October Conference on Mining and Metallurgy (IOC 2024), which will be held in October 2024.

On behalf of the 54^{th} IOC Organizing Committee,

Prof. dr Ljubiša Balanović

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POSSIBILITY OF COPPER ORES EXPLOITATION USING THE IN SITU LEACHING METHOD

Mladen Radovanovic, Dejan Petrovic, Jelena Ivaz, Dragan Zlatanovic

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Abstract

Underground exploitation takes place at greater depths which causes the need to reduce the operational costs of excavation. That can be achieved by choosing an appropriate mining method. Large scale mining methods are commonly used to excavate deposits with a low content of useful components that lie at greater depths. Sometimes conventional mining methods cannot produce the satisfying results. In that case application of unconventional mining methods or combination of both conventional and unconventional mining methods can be used for exploitation of metal ores. In situ leaching is one of unconventional methods that can be used for exploitation of copper deposits, and which in the near future may become one of the most favorable methods for the excavation of copper ores.

***Keywords**: (leaching, underground mining, unconventional method)*

1. INTRODUCTION

The main characteristic of the exploitation of copper ores over the years is the decreasing of copper content due to the fact that the richer deposits lying closer to the surface have been exploited and as a result of the change in the types of deposits that are exploited. In recent years, the main production of copper comes from porphyry deposits with a lower content of useful components [1,2]. Figure 1 shows the trend of decreasing copper content in ore for the last thirty years.

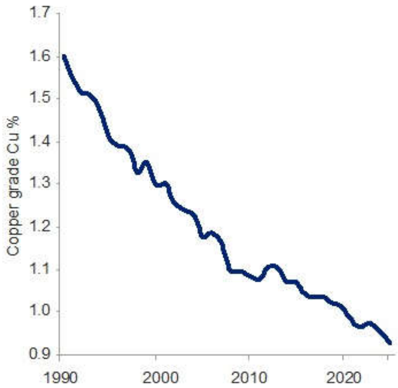

Figure 1 - Copper content in world deposits for the period 1990-2022.

The underground exploitation takes place at ever greater depths. This causes the need to reduce the operational costs of excavation, which can be achieved by choosing an adequate mining method. High mining costs, increasing depths and lower ore grades open the possibility to consider exploitation using non-conventional mining methods.

One of the most commonly used unconventional mining method is in situ leaching. In situ leaching (ISL) is most often used in the exploitation of uranium, and today over 50% of the produced uranium in the world is obtained by applying this method. In situ leaching can also be successfully applied to obtain other metals, especially copper. About 25% of the copper produced annually in the US is obtained using this mining method.

In the exploitation of copper ores, the ISL method is mainly used as a procedure for increasing the recovery of metal from the deposit, for the exploitation of inaccessible parts of the deposit, for obtaining copper from caved ore after the application of caving mining methods, etc.

In situ leaching represents the circulation of liquid through the deposit with the aim of obtaining the desired metal or mineral with the subsequent return of the liquid to the surface for further treatment [3]. In some cases, a lixiviant is used to treat the ore through a system of injection and return wells (Figure 2). In other cases, the lixiviant is flooded or sprayed over residual ore in mines, often after using explosives to fragment and comminute the ore and increase the surface area exposed to the lixiviant [4].

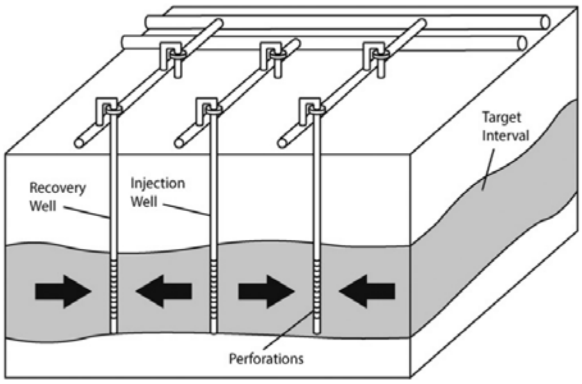

Figure 2 - A system of wells for the application of in situ leaching method

2. EXPERIMENTAL

To apply the ISL method, there are two critical parameters that must be

satisfied:

• mineralization must be located in a permeable environment;

• the lixiviant should be suitable for the selective extraction of a certain component from the deposit.

The exploitation of copper by leaching is based on copying the natural processes of dissolution (leaching) and precipitation (precipitation) that took place over millions of years, and are still taking place. Known as supergene enrichment, this natural process has been observed in many of the world's copper deposits. This process takes place when hypogene (ie primary) ores, containing sulphide minerals such as pyrite (FeS_2), chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4), oxidize over time. During the oxidation process, the iron contained in these minerals turns into red, red-brown, orange and yellow colored iron oxides, while the sulfur combined with groundwater creates a weak solution of sulfuric acid. The copper in the rock is dissolved in acidic solutions while it is filtered (filtered) down to the upper limit of the groundwater (water table), where copper is deposited in the form of chalcosine (Cu_2S) in reduced conditions (the amount of oxygen is reduced). Over time, these processes create an oxidized zone (ie, leach cap, iron hat) above the thick copper-rich overburden zone, known as the enrichment layer. Thus, a solution rich in copper is obtained, which is collected and transported to processing plants, where copper is obtained. The presence of large covers, i.e. layers (rich in copper) for beneficiation in many of the world's porphyry copper deposits, enable the economic extraction of copper from these deposits [5].

The dissolution of oxide minerals is relatively easy and is carried out in simple reactions. The greatest practical and economic importance is the leaching of copper oxide minerals, which can be successfully dissolved in water. As solvents also can be used following compounds: H_2SO_4, HCl, HNO_3, NH_3, $Fe_2(SO_4)_3$, $FeCl_3$, $NaCl$ and $NaOH$. Metal sulfides appear in more complex forms, which makes it difficult to define the oxidation process that precedes the leaching process. The leaching solution must contain an oxidant and there are different leaching systems in which acids or alkali are used as reagents.

Good leaching results to a large extent, are achieved by crushing the ore as much as possible. In order to better "open" of the minerals, the material to be leached is previously subjected to appropriate preparation, when there are prerequisites for this. It consists in shredding by crushing or blasting, and also in the previous chemical processing of the mineral raw material. All this is done in order to convert the metal or its compounds from hard-to-dissolve compounds to easily-soluble ones as much as possible. For this purpose, various chemical procedures are applied: frying, oxidation or reduction, chlorination, sulphation, etc. Beside purely chemical leaching, the so-called bacterial leaching also can be applied, in which the oxidation process of the raw material being leached is improved by using special bacteria.

There are several methods of in situ leaching. Heap leaching is used to treat mineral raw materials with a low content of useful components. The essence of this procedure is the special preparation of the terrain and the disposal of poor ore or mineralized overburden from surface mining, which is then leached in one of the described ways. Underground leaching is the process of converting metal from ore into a liquid state in the deposit itself, and then, usually on the surface, the resulting solutions are processed by cementation, liquid-liquid extraction or some other processes. Underground leaching can provide greater recovery of metals from the deposits thanks to their extraction from poorer ores, which cannot be economically exploited by traditional methods. Underground leaching is based on ion exchange of metals during the directed movement of reagents through a massif with natural permeability or through previously crushed or in different ways stored ore. The basic prerequisite for the successful application of underground leaching is the presence of a useful component in compounds soluble in mineral or organic acids or alkalis, salt solutions, etc. Modern underground leaching facilities consist of an exploitation, pipeline and processing complex. The principle scheme includes a complex of rooms and facilities for carrying out the technological process of obtaining metal extraction solutions. Depending on the method of opening, there are: borehole, pit and combined method of underground leaching.

3. RESULTS AND DISCUSSION

ISL can be successfully applied to increase ore recovery in caving mines. After mining has been completed using some traditional sublevel or block caving method, a significant amount of ore may remain in the caved material. Underground leaching can be used for exploitation of remain ore in caving mines. In that case the combination of traditional caving methods and leaching can be used for exploitation of copper deposits on greater depths with low grade ores. In US in situ leaching already takes important place in copper production. Experiences from mines where ISL method are applied shows that this method can be wide use in future for excavation of copper deposits.

In block caving mines exploitation by leaching takes place above in the inactive part of mine. A solution used for leaching is introduced into the deposit using perforated pipes laid on the surface of the ground above the ore body and a series of shallow injection wells. Solutions containing copper are collected in a collector in a pit below the caved part and pumped to the surface, where they undergo further treatment. When ISL is used as a main excavating method, exploitation is carried out by introducing the solution through injection wells to the copper-bearing ores, which should be characterized by intensively fractured rocks. Solution movement through the rock is controlled by pumping from adjacent return wells, which creates a hydraulic gradient that causes introduced solutions to flow from the injection wells to the adjacent return wells. After being pumped to the surface, copper-containing solutions are further processed to obtain the desired product – copper cathode.

ISL enables the exploitation with minimal impact on the environment. Unlike classic surface and underground mining methods, this time there is no degradation of large areas by mines, landfills and depots, no the need to relocate rivers or springs and other objects on the surface of the terrain, the amount of waste water generated by mining and hydrometallurgical activities is significantly lower, and there is also no environmental pollution with dust, noise and exhaust gases.

From an ecological aspect, using the ISL method, there is a risk of soil and surface and groundwater contamination from reagents and solutions used for leaching, however if the process is properly managed, the chances of contamination are minimal [6].

4. CONCLUSION

In situ leaching is one of the most effective available methods that can be used to exploitate ores in inaccessible parts of the deposit, ores remaining in the sides and mined parts of the massif, remaining metals in the caved ore after the application of caving mining methods. In addition, the in situ leaching method achieves lower production costs compared to traditional mining methods, which enables the application of this method for the exploitation of low-grade deposits or their parts.

Although ISL is auxiliary method to traditional mining benefits of ISL usage is large and they are reflected in better economic aspects (less investments for the development of the mine itself, processing plant and infrastructure, the possibility of starting production with low capital costs followed by an increase in production and flexibility of production capacities). Also ISL enables the exploitation of ore with minimal impact on the environment as long as projects are properly planned and managed.

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