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Review

In situ recovery, an alternative to conventional methods of mining: Exploration, resource estimation, environmental issues, project evaluation and economics

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ABSTRACT

This paper discusses the history and application of in situ recovery (ISR) to a wide variety of metals. The increasing application of ISR may provide an important method to address a key issue for the mining industry, namely the cost of production.
ISR transfers a significant proportion of hydrometallurgical processing to mineralised bodies in the subsurface to directly obtain solutions of metals of interest. As a result, there is little surface disturbance and no tailings or waste rock are generated at ISR mines. However, for ISR to be successful, deposits need to be permeable (either naturally or artificially induced), and the metals of interest readily amenable to dissolution by leaching solutions in a reasonable period of time, with an acceptable consumption of leaching reagents.
The paper discusses the following aspects of ISR:

- *History*. ISR for uranium was introduced in 1959 in the USA, and subsequently applied in many countries over last 50 years, particularly in the USSR. The share of uranium mined by ISR reached 51% of world production in 2014, and the capacity of ISR mining of uranium is now comparable with that from conventional uranium mines.
- *Commodities*. A review of the use of ISR for mining other commodities, namely copper, gold, nickel, scandium, rhenium, rare earth elements, yttrium, selenium, molybdenum, and vanadium. ISR for copper was introduced in the 1970s and there were several successful natural tests and mines. Scandium, rhenium, rare earth elements, yttrium, selenium, molybdenum, and vanadium were mined in pilot tests as by-products of uranium extraction. ISR of gold, copper, nickel, rare earth elements and scandium has been successfully developed over recent years. The paper discusses other commodities that have potential to be mined using ISR.
- *Applicability of ISR* is addressed by a discussion of the features of mineralisation that need to be considered during different stages of ISR projects. Permeability,[1] hydrogeological conditions and selective leachability are the most critical parameters for ISR, and must be defined in the evaluation and exploration stages. Morphology and depth of mineralisation, thicknesses and grades, distribution of mineralisation, presence of aquicludes, and environmental conditions are also important factors for ISR projects.
- *Environmental issues*. ISR allows the extraction of mineralisation with minimal disturbance to existing natural conditions. In contrast to underground and open pit mining, there are smaller volumes of mining and hydrometallurgical effluents that require management. Clearly contamination of groundwater by ISR reagents is the critical aspect requiring management during an ISR operation. Control of leaching in ISR operations and various ways of cleaning aquifers are discussed in the paper.
- *Economics*. ISR operations deliver a range of benefits including lower CapEx costs for mine development, processing plant and infrastructure. ISR enables production to start at low capital cost and then a modular increase in production, as well as very flexible production capacity. The costs of ISR for different commodities (copper, gold, nickel, scandium, rhenium, rare earth elements, yttrium, selenium, molybdenum, vanadium) are discussed, with economic parameters for uranium production from ISR and conventional provided for comparison. The CapEx, OpEx and common cut-off grades for ISR for different commodities are discussed.

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[1] More accurately is hydraulic conductivity or permeability coefficient, m/day.

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• *Exploration, resource estimation and the development of ISR projects* require a number of different approaches compared to conventional mining projects. These criteria and the necessary methodology for resource estimation for ISR projects are described in the article.

Contents

1. Introduction

Globally, the mining industry faces a number of challenges, including:

- increasingly rapid depletion of low-cost, high profit, deposits, mined by conventional methods;
- increasing costs of mining and processing;
- accumulation of tailings, requiring expensive management and ongoing monitoring;
- reduced and variable commodity prices (Bloomberg Commodity Index, 2015); and,
- consequently, reduced profitability and return on investment.

Innovation and new approaches to the extraction of minerals provide answers to these challenges.

In situ recovery (ISR) is the one of the most effective methods to address the costs of mining. The key feature of ISR is transferring a significant proportion of the hydrometallurgical processing the mineralised bodies to the subsurface to directly obtain solutions of metals of interest.

ISR technology has been in existence for 65 years, but was only widely developed for uranium production in South Kazakhstan last the last 10–15 years with strong improvements in experience in applying ISR. This technology has been used for copper for 40 years, but the first experience was not entirely positive. Copper and gold mines have operated successfully over the last 10-15 years in Russia building on the uranium ISR experience. At Dalur, a uranium mine in Russia, a plant is under construction to extract scandium and rare earths as by-products from the uranium pregnant solutions. It is the authors' opinion that the growing experience in ISR technology will allow the technique to be adopted more widely.

The evaluation of the suitability of deposits for ISR requires different and/or modified approaches compared to traditional mining/extraction techniques. Furthermore, some deposits that are currently uneconomic to extract using traditional mining methods may be a profitable as ISR operations.

An important reason for the slow uptake of ISR technology is the lack of experience and expertise in ISR, and the need for a somewhat more complex approach for resource estimation for deposits to use ISR.

This article is aims to highlight key features of current ISR practice, based on modern technologies and in challenging economic conditions.

2. What is *in situ* recovery?

Conventional mining in open pit and underground mines involves removing ore (and waste) from the ground, and then processing it to extract the metals of interest.

In situ recovery (ISR), also known as *in situ* leaching (ISL), use solutions that are pumped through the mineralized body *in situ* (underground) to recover metals by leaching. *In situ* mining according to Bates and Jackson (1987), a definition endorsed by The National Academy of Sciences (2002), is the "removal of the valuable components of a mineral deposit without physical extraction of the rock".

Operations at typical ISR mines comprise well field/s and an extraction process plant/s. Leaching solutions are pumped into the mineralized zone/s through a network of injection bores and extracted by production bores. In the process, the leaching solution dissolves the metals of interest, which are brought to surface in a pregnant solution (Fig. 1).

The pregnant solutions are treated at an extraction plant producing a chemical concentrate of the target metal/s.

As a result, there is little surface disturbance and no tailings or waste rock are generated at ISR mines.

However, for ISR to be effective the mineralized body needs to be permeable (either naturally or artificially) to the solutions used, and located such that the solutions do not contaminate groundwater away from the mineralized body. Target minerals need to be readily soluble in the leaching solutions for recovery in a reasonable period of time, and these should be a reasonable consumption of leaching reagents.

3. History of ISR

In situ recovery (ISR)[2] uranium mining technology was developed independently in both the USSR and in the USA in the late 1950s to early 1960s. It was developed in both countries using similar engineering and technological approaches. However, the Soviets adopted the acid leach system, while the US specialists employed an alkaline, primarily carbonate-based, system (IAEA, 2001) (Fig. 2).

The first field tests of acid ISR technology for extracting uranium took place at the Devladovo Deposit, Ukraine. But the first commercial scale ISR operations in the USSR took place at the large sandstone-

[2] Also known as *in situ* leaching or ISL.