



Heap leaching as a key technology for recovery of values from low-grade ores – A brief overview



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ABSTRACT

Heap leaching technology is finding increasingly widespread application to recover values from low-grade ores, especially in the gold and copper industry. The particular attractiveness of the process is the relatively low-cost recovery of the target metal at site without the need for energy intensive comminution, providing the process can be combined with a selective solution recovery technology (for example solvent extraction). However, this is contrasted with often slow and inefficient recovery, and technical issues such as poor heap permeability and post-closure stability. This paper gives a comprehensive overview of the principles of heap leaching, offers a critical analysis of the economic viability of the process and how certain technical drawbacks of the technology affect this, as well as providing a brief overview of emerging and potential future applications of the technology.

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1. Introduction

Heap leaching forms part of the group of technologies known as percolation leaching, which includes in situ leaching, dump leaching, heap leaching and vat leaching (Bartlett, 1998; John, 2011). Common to all these technologies is migration of leach solution through a fixed bed of ore particles, on its path interacting with the solid, releasing the target minerals into solution with which they are carried out of the bed. The target species are subsequently recovered from solution using conventional hydrometallurgical techniques, especially solvent extraction (SX), before returning the barren solution to the leach process.

The distinction between the different processes lies in the degree of preparation of the ore bed. In in situ leaching the ore remains underground and solution flows either through the natural porosity of the ore (typical for example for uranium bearing sandstones), or a pore structure is created through some form of mechanical cracking (in-situ blasting or hydraulic fracturing). Dump leaching refers to as-mined ore that is piled in rock depositories ('dumps'), which are irrigated with leach solution that percolates through the bed and is collected at the base for further treatment. This process is applied usually only to very low-grade waste rock as a 'value-add', since the costs of installing the irrigation system and treating the resulting stream are marginal. Due to the absence of any crushing prior to stacking, the

particle size ranges from a few centimetres to large boulders of one metre and more, and consequently dump leaching is associated with poor extractions (20–30%). In heap leaching the ore is crushed, usually to below 1 in. (25 mm), and heaps are much more carefully engineered to maximise percolation of leach solution through them. The higher investment in operating the process is offset by significantly higher recoveries (typically >70%) and the process is applied often to low- to intermediate grade ores. Heaps are also operated for limited time periods before being removed or abandoned as a permanent deposit. Finally, vat leaching refers to placing more finely crushed ore (1–10 mm) in a large basin where it is subsequently flooded with leach solution and left to react, before draining the solution again for treatment and removing the ore for final storage.

Heap leaching is practised all over the world for three key applications: cyanide leaching of gold ores, acid leaching for copper oxide ores and oxidative acid leaching of secondary copper sulphide ores, invariably with the assistance of certain microorganisms. A few heap leach operations for uranium also exist (acid and alkali leaching), although the technology is less common, partly due to environmental concerns (Scheffel, 2002). Uranium heap leaching has been pioneered since the 1950s, whereas both, copper oxide and gold/silver heap leaching emerged in the US from the late 1960s (Kappes, 2002; Bartlett, 1998). Large scale copper heap leaching commenced in Chile from the 1980s, and sulphide heap leaching emerged essentially as a consequence of acid leaching from mixed oxide/sulphide ores from the 1990s (Watling, 2006).

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2. Principles of heap leaching

A detailed description of the heap leach process and the underlying mechanisms has been given elsewhere (Petersen and Dixon, 2007a, 2007b; Watling, 2006; Bartlett, 1998), and only some key aspects are discussed here. Fig. 1 shows in a schematic representation a typical copper sulphide heap leach circuit – the principle is the same for other heap leach processes.

A heap is a constructed pile of crushed, and in most cases agglomerated, rock material built on an impermeable under-liner fitted with a solution collection system. Where sulphide minerals are targeted, aeration pipes are also placed underneath the heap. The heap is stacked by conveyor belt; truck dumping is also practiced, but generally results in undesirable compaction of the heap surface by the trucks. Heap heights are typically 6–10 m, but taller heaps are also common to reduce the footprint of the operation. The heap is irrigated from the top surface, either by sprinklers, sprays or drip emitters.

Typical irrigation rates are in the order of 5–20 L/m²/h, and aeration, where present, in to order of 0.1–0.5 m³/m²/h. Irrigation is mostly continuous, but intermittent (on-off) schemes are used in some operations. Solution percolates downwards through the crushed ore bed (typical top particle size is 3/4 in. to 1 in. (19–25 mm)) where it partially saturates pore spaces and partially migrates through the bed in discrete flow channels. Where aeration is present, air migrates upwards counter-currently to solution through unsaturated void spaces. Mineral grains contained in the rock interact with chemical species in the solution (introduced with the feed) to dissolve and release dissolved species into solution, which are then transported to the base of the heap and recovered as pregnant leach solution (PLS) in the solution collection system. Target metals are then recovered from the PLS, and the barren solution is made up with fresh reagents and returned to the heap.

Three key types of chemistry are employed in heap leaching at present: sulphuric acid leaching predominantly of copper oxides, alkali cyanide leaching of gold/silver bearing ores and oxidative sulphuric acid leaching of secondary copper sulphides (usually in the context of supergene porphyry ores). The latter process is invariably catalysed by microorganisms, which colonise within the heap bed (Demergasso et al., 2005), and facilitate the oxidation of ferrous to ferric by atmospheric oxygen as well as the oxidation of reduced sulphur intermediates (S_n²⁻, S₂O₃²⁻, etc) to sulphate (Sand et al., 2001). Bio-oxidation occurs naturally, but in some operations is promoted through the deliberate inoculation of heaps with microbial cultures (Gericke et al., 2011). Heap bio-leaching has also been demonstrated for the pre-oxidation of refractory gold ores prior to cyanide leaching (Logan et al., 2007).

At the particle level, heap-leaching is governed by the migration of reactive species into and dissolved species out of pores and cracks, which is based on molecular diffusion, invariably a very slow process (Sánchez-Chacón and Lapidus, 1997). Overall leach kinetics in a heap are a complex interplay between reagent transport to and from site,

gas–liquid mass-transfer between the air and solution phases, as well as migration through stagnant liquid in agglomerates and through particle pores. Further effects are microbial colonisation behaviour, mineral location and liberation within particles, mineral reaction kinetics as well as generation and dissipation of reaction heat (through exothermic sulphide leaching) (Petersen and Dixon, 2007a).

Leach periods typically extend to 60–100 days for heap cyanidation, 4–6 months of acid copper leaching, and 1–3 years for secondary copper sulphides. The long leach times, especially of sulphide minerals, has resulted in this technology being employed only for low-grade ores for which other technologies, requiring a higher degree of comminution, are uneconomical. Further, to achieve meaningful overall production rates, very large inventories of ore need to be kept under leach at the same time, occupying a sizeable footprint and solution inventory for operation. As a consequence, many heap operations employ multiple lifts, with new ore being stacked on top of spent heaps (Bartlett, 1998; Scheffel, 2002).

The PLS concentrations of the target metals are usually low (2–10 g/L for Cu, ppm levels for Au) and, especially in acid leach solutions, many impurities are present. Selective recovery of copper by the highly selective SX reagents, and of gold cyanide onto activated carbon ensure the success of heap leaching of these commodities. Raffinate solution is, after make-up, recycled to the heap. As a result there is a gradual build-up of dissolved species (especially Al, Mg and Fe sulphates), which at critical concentrations may begin to precipitate within the heap and consequently block pores and sprinkler nozzles. Adverse effects of such dissolved species on bioleaching microorganisms have also been observed (Ojumu et al., 2008), but management of bleed solutions in industrial heaps is not systematically practiced.

Irrigation is usually discontinued after around 80–90% extraction for gold and copper oxide leaching and 70–80% for copper sulphide leaching. The reason is that extraction rates become so slow that the costs of continued operation begin to outweigh the value of metal recovered. Spent heaps are either, reclaimed and deposited on a separate waste ore dump to use the cleared lined ground for a new heap, or a new lift is built on top of the old heap, with a view to using the existing infrastructure and potentially recovering additional unleached values, as leach solution from the fresh ore percolates through the spent ore underneath (Scheffel, 2002).

Optimally, heap leaching should be a low-cost technology for the recovery of values from low-grade ores, suitable especially for remote mine sites. However, the complexities that govern the leach kinetics are often underestimated, resulting in underperforming heaps. Historically, treatment of low-grade ores by heap leaching was seen as an add-on process to recover additional values from a particular ore body without it determining the profitability of the operation as a whole. Hence, less care was applied in their design, and the understanding of the process was built more on operator experience than hard science.

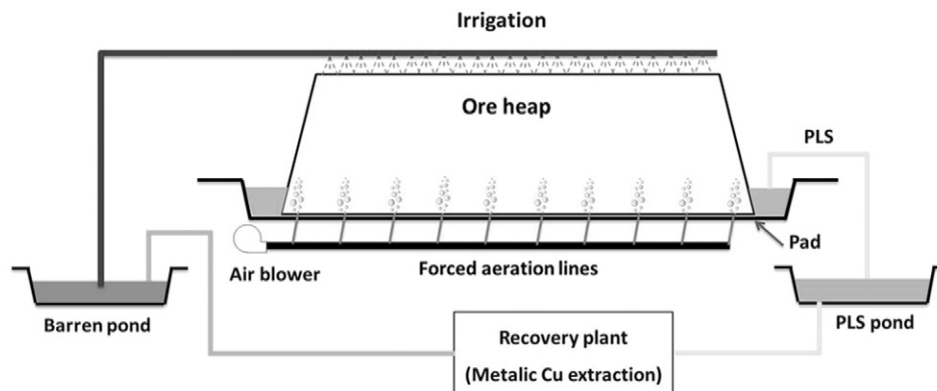


Fig. 1. Schematic of a typical copper sulphide heap leach circuit.

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