Bioleaching in stirred tank reactors to process Kupferschiefer-type ore: current status and perspectives

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Introduction

In Europe, most of the primary resources with high or moderate metal grade, reasonable accessibility and easy to process are exhausted. European primary resources still available for exploitation have more complex mineralizations (e.g. polymetallic and polymineral, carbon rich), or low metal contents; they also have higher levels of toxic impurities such as arsenic, antimony and mercury, penalizing current pyrometallurgical technologies. As existing processes and technologies are often not profitable for these types of unconventional resources, new process options still need to be developed in order to overwhelming the complexity of the ore composition while remaining cost effective. In this context, bioleaching is more and more considered as a promising technology. Even though heap and dump bacterial leaching of sulphidic minerals are well established and the bacterial treatment of refractory gold concentrate using stirred tank reactors (STR) is an industrial reality, the European mineral industry is still sceptical and reluctant to adopt biohydrometallurgical techniques. Heap leaching is often considered as un-adapted due to space constraints, slow leaching kinetics and low recovery rate. The possibility of using STR for the treatment of other metals than refractory gold, such as copper sulphides, has already been demonstrated but improvements are still needed to achieve economic viability.

The Kupferschiefer deposits host the largest known copper reserve in Europe [1]. These black shale type ores are currently exploited in Poland through pyrometallurgical smelting. In Germany exploration campaigns were recently leaded in order to assess and prepare future exploitation of this ore deposit type. The main copper-bearing minerals are: chalcocite, bornite, chalcopyrite and covellite. This type of ore is also characterized by high amounts of carbonate and organic carbon as well as potentially rich with arsenic (volatile in pyrometallurgical processes). In the last years the ores are characterized by increased As and C contents, and lower Cu contents. It leads to a lower quality concentrate as well as operating and environmental issues during smelting. In this context, several European research projects have been dedicated to the development of new bioleaching approaches as alternative and complementary routes to the conventional smelting methods for the processing of Kupferschiefer ores (BioShale in EC-FP6, ProMine in EC-FP7, BIOMOre). By using a multi-scale approach from molecular techniques to bench-scale small pilot continuous tests, Cu recovery from this type of ores using bioleaching was demonstrated to be technically feasible and efficient. The stirred tank bio-reactor (STR) was shown as the best process option when compared to heap leaching due to the high content of carbonate in the ore.

This paper gives an overview of the work performed on this topic in the last decade. The R&D challenges necessary to tackle in order to improve the process economy will be analysed and compared. It will also discuss the new insights and future developments brought by ECOMETALS, a German and French joint research project, for the integration of bioprocess options in the metallurgical treatment of Kupferschiefer ores.

Selection and adaptation of microbial consortia

Several types of microbial consortia were tested: acidophilic autotrophic bacteria, acidophilic and neutrophilic heterotrophic bacteria. No evidence of efficient biodegradation was found with heterotrophic bacteria. Amongst the different types of autotrophic microorganisms used to bioleach Kupferschiefer ore, the best performances were obtained with the "BioShale-BRGM" consortium which is co-dominated by *Acidithiobacillus (At.) caldus* and *Leptospirillum (L.) ferriphilum*. The species *Sulfobacillus (Sb.) benefaciens BRGM2* and *Sb. thermosulfidooxidans* are also present in lower ratios.

Bioleaching development in stirred tank reactor

Following successful cultures in batch tests, several continuous bioleaching operations were carried out using the consortium presented in the preceding section in a laboratory-scale unit equipped with three stirred reactors, one of 50 L (R1) followed by two of 20 L of operating capacity (R2, R3). The reactors are arranged in cascade so that the pulp flows from one tank to the next one by overflowing. CO_2-enriched air (1%) is injected beneath the turbine at the bottom of the tank. The mixing system (BROGIM® - BRGM/MRM) is mounted in all tanks on a rotating shaft. In the reactors temperature was maintained constant at 42 °C and pH was regulated around 1.5. The agitation speed and the aeration flow were progressively slowed down (from 450 to 250 rpm and from 2000 to 100 L h^{-1}) in order to decrease redox potential and improve chalcopyrite dissolution. The influence of the solid concentration was also studied (15% to 25% w/w).

Cu dissolution was positively impacted by the decrease of the agitation and aeration rate (Fig. 1). As can be seen in Fig. 2, Cu recovery is not affected by the increase of the solid load from 15% (w/w) to 25% (w/w). This solid content is quite high compared to those encountered in most of the commercial applications of bioleaching in CSTR (between 15 and 20%). No mixing or microbial issues were encountered. The Bioshale-BRGM consortium (which is mesophile to moderately thermophile) has shown a rare copper tolerance since copper content increased up to more than 40 g L^{-1} without any negative effect on the bacterial community.

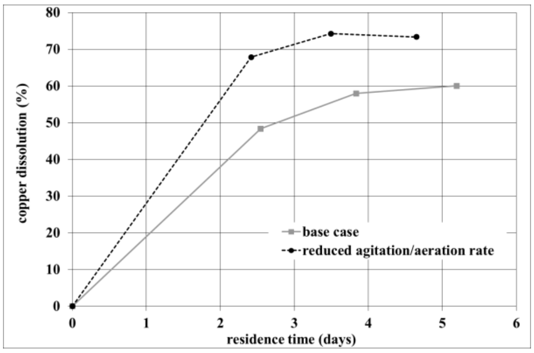

Figure 1. Influence of reduced agitation/aeration rate on copper dissolution

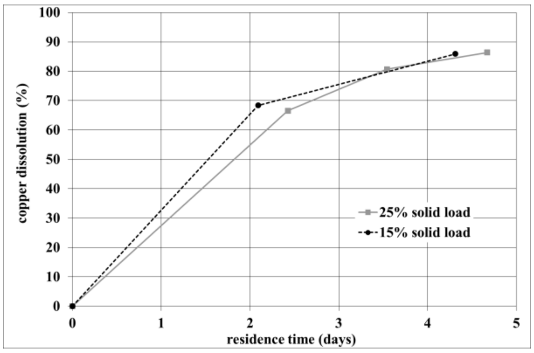

Figure 2. Influence of solid load on copper dissolution

Economic assessment and future developments

Based on the experimental data a preliminary techno-economic evaluation of the bioleaching option was established. The CAPEX is considerably decreased with a process design at higher solid load. This is mainly due to the reduction of the global bioreactor volume: operating at 25% solid load requires 2.3 less volume than operating at 15% solid load for the same Cu recovery and the same residence time. Following these calculations, elements on process economy were reviewed in order to point out the most pertinent ways to improve it. The highest investments costs generally come from bioleaching reactors and agitators. One option to decrease the CAPEX and to improve bioleaching process economy might be to develop new types of bioreactors as an alternative to classical CSTR. This new concept has already been proposed for other types of resources and is currently tested on Kupferschiefer ores in the German and French research project ECOMETALS [2].

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