MICA
Minerals Intelligence Capacity Analysis

DOCSHEET

Biohydrometallurgy

An industrial reality for the treatment of sulphidic ores, tailings and residues.

Scope

Bioleaching uses the oxidation ability of natural bacteria to dissolve metal sulphides and facilitate the extraction and recovery of precious and base metals from primary ores and concentrates. The involved microbial consortia are composed mainly of acidophilic, autotrophic iron- and/or sulphur-oxidizing bacteria. These micro-organisms get their energy from the oxidation of iron and/or reduced inorganic sulfur compounds, producing sulfuric acid and ferric iron. Ferric iron (Fe^{3+}) is a primary oxidizing agent, attacking sulfide minerals (MS), as seen in Equation 1, and the role of the organisms is the regeneration of Fe^{3+} from Fe^{2+} and the oxidation of sulfur compounds to produce sulfuric acid (Equations 2 and 3).

$$MS + 2Fe^{3+} \rightarrow M^{2+} + 2Fe^{2+} + S^0 \quad [1]$$

$$2Fe^{2+} + 0.5O_2 + 2H^+ \rightarrow 2Fe^{3+} + H_2O \quad [2]$$

$$S^0 + 1.5O_2 + H_2O \rightarrow 2H^+ + SO_4^{2-} \quad [3]$$

Many biomining microorganisms occurring naturally on mineral ores are known[1]. Autotrophic species of the iron- and sulfur-oxidizing *Acidithiobacillus* genus and the iron-oxidizing *Leptospirillum* genus are significant contributors to commercial systems. Mixotrophic or heterotrophic acidophilic microorganisms such as *Sulfobacillus* spp., *Acidimicrobium* spp. and *Ferroplasma* spp. are also important; not only for their contribution to mineral dissolution via iron and/or sulfur oxidation, but

[1] Rawlings, D.E., Johnson, D.B., 2007. Biomining, Springer.

because they breakdown organic materials acutely toxic to the primary bioleaching organisms (see Figure 1).

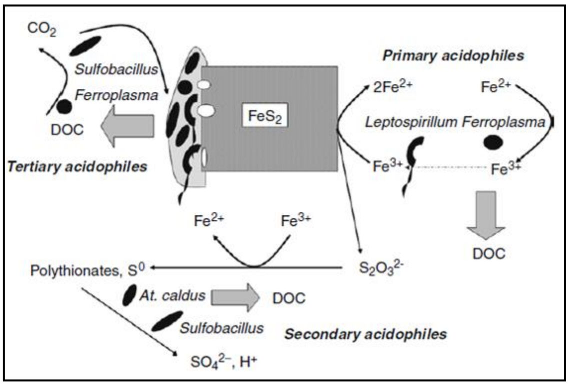

Figure 1. Extracellular polymeric substances mediate bioleaching/biocorrosion via interfacial processes involving iron(III) ions and acidophilic bacteria. From Research in Microbiology 157 (2006) 49–56, Wolfgang Sand and Tilman Gehrke.

This natural ability of microbes to degrade minerals was already used in the Roman times for copper recovery, without awareness of the role of micro-organisms. In the last 35 years, extensive research has been carried out on biomining processes. As a consequence, and where circumstances are favourable, biohydrometallurgy emerged as an industrial reality and a alternative for the treatment of some minerals (mainly sulphides) and the recovery of metals such as copper, gold, Nickel and cobalt.

Biohydrometallurgy is well established for the treatment of certain sulfide minerals for the leaching of low grade copper ores (bioleaching) and the pretreatment of pyritic gold ores and concentrates (biooxidation). Biomining is mostly carried out either by continuous stirred tank reactors or heap reactors. Continuous stirred tank reactors are used for both bioleaching and bio-oxidation processes collectively termed as biomining (see Figure 2).

Figure 2. Dump/heap and tank leaching

Contexts of use, application fields	-> contexts (e.g., environmental, economic, social assessment) -> which types of stakeholder questions are concerned? -> link to published studies that implement the method

Bio-hydrometallurgy has emerged as an industrial reality, providing a complementary technique or an alternative for the treatment of certain mineral resources for the recovery of metals such as copper, gold and cobalt in favourable conditions[2]. Compared to pyrometallurgy, hydrometallurgical processes offer relatively low capital cost and are particularly suitable for small-scale installations. Bioleaching represents an attractive alternative to conventional techniques because it offers several advantages: operational simplicity, lower capital and operating costs, environment friendliness and suitability for the treatment of complex and low-grade ores

Stirred tank bioleaching at industrial scale has been applied for 20 years. Most of the current stirred-tank bioleaching operations are applied to refractory gold arsenopyrite-pyrite flotation concentrates, where the gold trapped in the sulfides is liberated by means of biooxidation of the host minerals and then recovered by conventional cyanide treatment. Bioleaching provides a low energy approach for

[2] Rawlings, D.E., Johnson, D.B., 2007. Biomining, Springer

the treatment of refractory ores. Without pretreatment usually less than 50% of the gold is recovered. After bioleaching more than 95% of the gold is extracted depending on the mineral composition of the ore and extend of pre-treatment.

Figure 3. Kasese Project overview

Biomining was used in the re-processing of a sulfidic mine wastes at the Kasese Cobalt Company site in Uganda (see Figure 3) where cobalt was produced from old copper mining waste tailings[3] using stirred tank bioleaching technology. By contributing to the stabilisation of those wastes, this biohydrometallurgical operation has also drastically decreased the AMD discharge in the environment. Tailings and mining waste containing residual sulphides and metals, often responsible for AMD (Acid Mine Drainage) issues are a potential very good target for biomining activities.

In Finland, the first bioheap leaching treatment of nickel ore was implemented in 2008 and demonstrates that there is potential for Europe to be at the top of the innovation in this area[4]. Bioheap leaching technology was chosen for the extraction of nickel from the ore based on its favorable capital, operational costs and good performance data obtained in a large on-site pilot trial.

[3] Morin, D., d'Hugues, P. (2007). Bioleaching of a cobalt-containing pyrite in stirred reactors: a case study from laboratory scale to industrial application. In: Rawlings, D.E., Johnson, D.B. (Eds), Biomining, Springer-Verlag, Berlin, pp. 35 - 55.
[4]Riekkola-Vanhanen M., Palmu L. (2013) Talvivaara Nickel Mine — from a project to a mine and beyond. In: Battle T. et al. (eds) Ni-Co 2013. Springer.

Input parameters	-> which parameters are needed to run the method

Classical bioleaching requests the presence of sulphides in the ores, the tailings or the residues.

Type(s) of related input data or knowledge needed and their possible source(s)	-> which types of data are needed to run the method, from which sources could they come… -> could be qualitative data or quantitative data, and also tacit knowledge, hybrid, etc.

The potential of bioleaching will request information on the minerological and chemical composition of the mineral target (ores or residues).

Model used (if any, geological mathematical, heuristic…)	-> e.g., geological model for mapping -> e.g., mathematical model such as mass balancing, matrix inversion, can be stepwise such as agent -based models, dynamic including time or quasidynamic specifying time series… -> can also be a scenario

- Not applicable

System and/or parameters considered	-> **the system can be described by its boundaries**. These can refer to a geographic location, like a country, or a city, the time period involved, products, materials, processes etc. involved, like flows and stocks of copper, or the cradle-to-grave chain of a cell phone, or the car fleet, or the construction sector, or the whole economy… -> **parameters** could possibly refer to geographic co-ordinates, scale, commodities considered, genesis of ore deposits and others…

- Not applicable

Time / Space / Resolution /Accuracy / Plausibility…	-> to which spatio-temporal domain it applies, with which resolution and/or accuracy (e.g., near future, EU 28, 1 year, country/regional/local level…) -> for foresight methods can also be plausibility, legitimacy and credibility…

- Not applicable

Indicators / Outputs / Units	-> this refers to what the method is actually meant for. Units are an important part but that is most of the time not sufficient to express the meaning. For example, **the indicators used in LCA express the cradle-to-grave environmental impacts of a product or service**. This can be expressed in kg CO_2-equivalent. But also in €. Or in millipoints. Or in m^2year land use. -> for foresight methods the outputs are products or processes

- Not applicable

Treatment of uncertainty, verification, validation	-> evaluation of the uncertainty related to this method, how it can be calculated/estimated

- Not applicable

• **Main publications / references**	○ **e.g. , ILCD handbook on LCA, standards (e.g. , ISO)** ○ **can include reference to websites/pages** • **-> references to be entered with their DOI**

- Barrie Jonhson D. (2014). Biomining — biotechnologies for extracting and recovering metals from ores and waste materials. Current Opinion in Biotechnology. Volume 30, pp. 24-31. https://doi.org/10.1016/j.copbio.2014.04.008

- Morin D., Lips A., Pinches T., Huisman J., Frias C., Norberg A., Forssberg E. (2006). BioMinE – Integrated project for the development of biotechnology for metal-bearing materials in Europe. Hydrometallurgy, Volume 83, Issues 1–4, pp. 69-76. https://doi.org/10.1016/j.hydromet.2006.03.047

- Welcome to BioMineWiki- the free and live knowledge base focused on biohydrometallurgy. http://wiki.biomine.skelleftea.se/wiki/index.php/Main_Page

- EU-FP6 Bioshale Project – Executive Summary of the Second Year. http://www.brgm.eu/sites/default/files/bioshale_executivesummary_secondyear.pdf

- Watling H.R. (2006). The bioleaching of sulphide minerals with emphasis on copper sulphides — A review. Hydrometallurgy. 84: 81. doi:10.1016/j.hydromet.2006.05.001.

- CEReS, the European project to create value from waste. http://ceres.biohydromet.net/consortium/

Related methods	-> List of comparable methods, their particularities… -> link to one or several other existing fact sheet(s)

Pyrometallurgy and Hydrometallurgy

Some examples of operational tools (CAUTION, this list is not exhaustive)	-> e.g., software… Only give a listing and a reference (publication, website/page…) -> **should be provided only if ALL main actors are properly cited**

► Not applicable

Key relevant contacts	-> list of relevant **types** of organisations that could provide further expertise and help with the methods described above.

Non exhaustive list:

- http://www.zerowastecluster.eu/partner-networks/bioflex/
- BGR: Axel Schippers
  https://www.bgr.bund.de/SharedDocs/Mitarbeiterseiten/schippersA.html

  University of Bangor: Barrie Johnson
  https://www.bangor.ac.uk/biology/staff/johnson.php

  BRGM: Patrick d'Hugues, Anne Gwenaelle Guezennec
  http://www.brgm.fr

Glossary of acronyms /abbreviations used	-> Definition