Redox-Controlled Bioleaching: a Generic Approach for Extracting and Recovering Metals from Oxidised and Reduced Mineral Wastes

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Background

Waste materials generated and disposed of at metal mine sites include low metal-grade waste rock, tailings produced by froth flotation and metal-rich overburden layers (such as limonite zones at laterite mines) that are not suitable for processing using available technologies. Quite often, these waste material contain concentrations of critical and other metals that make them attractive for reprocessing using bioleaching technologies, which has the important secondary benefit that this can eliminate or greatly reduce the threat that these wastes pose to the surrounding environments.

Sulfur-enhanced bioleaching: microbially-accelerated dissolution of minerals carried out under both oxidising and reducing conditions, where zero-valent sulfur (ZVS) is added to stimulate the process.

Oxidative bioleaching

Key reaction → Iron oxidation
Acidity → often generated
Additional electron donor → no
Electron acceptor → oxygen
PLS generated → oxidised

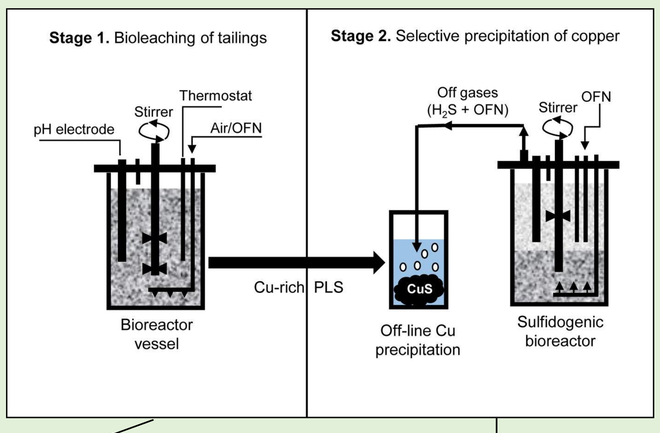
Re-processing of sulfidic mine tailings

Falagán et al. (2017) *Minerals Engineering*

Cobre Las Cruces, Spain operated by First Quantum Minerals Ltd.
Generation of ~1.5 million tonnes tailings per annum

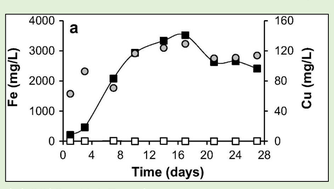
Elements	(%)
Cu	0.72
Fe	28.1
S	22.1
Mg	12.5
Si	7.22
Ca	1.87
Zn	0.13
As	0.23
P	0.19
Ti	0.17
Pb	0.76
Ag*	30

* mg/kg

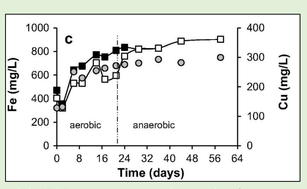


Consortia of bioleaching microorganisms were used in stirred bioreactors operated aerobically at either 30°C or 45°C and pH 1.7, or at 45°C with no pH control.

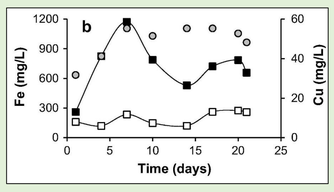
Soluble copper was selectively precipitated from the polymetallic leachate as a sulfide phase.



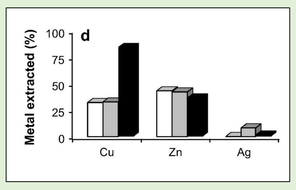
(a) 30°C, pH 1.7 and constant aeration



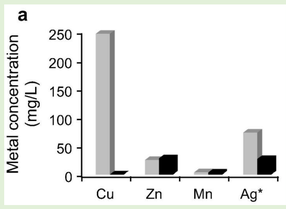
(c) 45°C, no pH control, aerobic/anoxic conditions



(b) 45°C, pH 1.7 and constant aeration



(d) 30°C, pH 1.7 (white), 45°C (grey), 45°C no pH control (black)



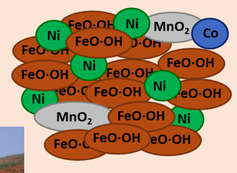
Grey bars - metals in PLS before
Black bars - after, contacting with biogenic H_2S.
*Silver concentrations are shown as µg/L.

Estimated additional revenue to the mining operation by extracting and recovering the copper alone **70 US$ million per annum** (2018 prices).

Reductive bioleaching

Key reaction → Iron reduction
Acidity → consumed
Additional electron donor → yes
Electron acceptor → Fe^{3+} (in minerals)
PLS generated → reduced

"Biomining in reverse gear"



(i) Reduction of goethite phase:
$6FeO{\cdot}OH(Ni) + 2S^0 + 10H^+ \rightarrow 6Fe^{2+} + SO_4^{2-} + 8H_2O + Ni^{2+}$

(ii) Reduction of asbolane phase:
$(Ni,Co)_xMn(O,OH)_4.nH_2O + 2Fe^{2+} \rightarrow xNi^{2+} + xCo^{2+} + Mn^{2+} + 2Fe^{3+}$

Limonitic wastes

Çaldag mine (Turkey) Source: Prof. Richard Herrington

Metal content (wt%)

Sample	Co	Ni	Fe	Mn	Al
PenaMax (New Caledonia)	0.16	1.34	48.7	0.91	2.9

Moderate thermophilic consortium
pH 0.75 and 60°C
- *Acidianus (Ac.) brierleyi*
- *Ac. sulfidivorans*
- *At. caldus* BRGM1

Stage 1
Biomass growth

Stage 2
Bioleaching

EU - H2020 CROCODILE
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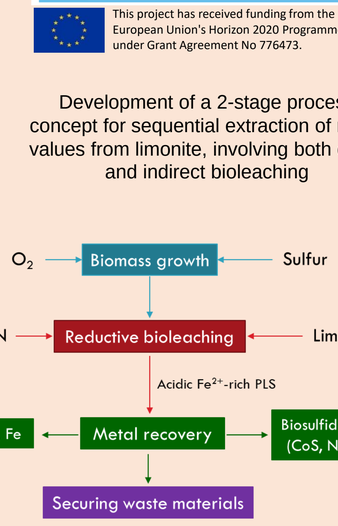
Development of a 2-stage process concept for sequential extraction of metal values from limonite, involving both direct and indirect bioleaching



Source: Prof. Barrie Johnson

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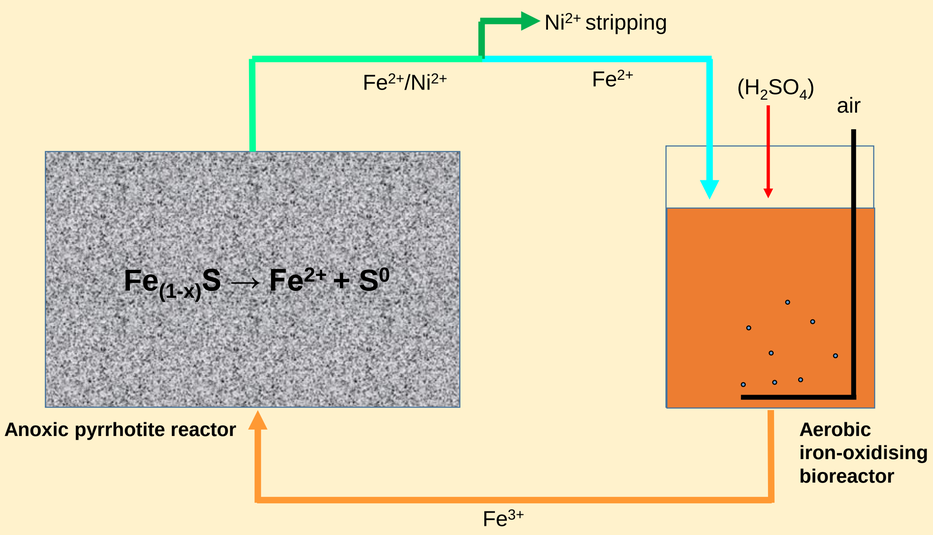
Pilot-scale Field test in Piauí, Brazil (in association with Brazilian Nickel)

Anaerobic Oxidative Bioleaching

Redox-controlled oxidation of pyrrhotite tailings has been proposed to concurrently recover nickel and limit acid generation:

- Tailings are oxidised in the absence of oxygen by a microbially-generated ferric iron lixiviant, resulting in the dissolution of pyrrhotite and the solubilisation of ferrous iron and nickel
- the sulfur moiety is oxidised from -2 to 0 (elemental S, which accumulates in the reactor)
- ferric iron is regenerating by acidophilic microorganisms in a separate aerated bioreactor



Natural Biomines

Relic features (e.g. underground mines, mine wastes such as rock dumps and tailings) that generate run-off waters which contain concentrations of base metals that are high enough to make their recovery economically viable.

Mynydd Parys, Wales

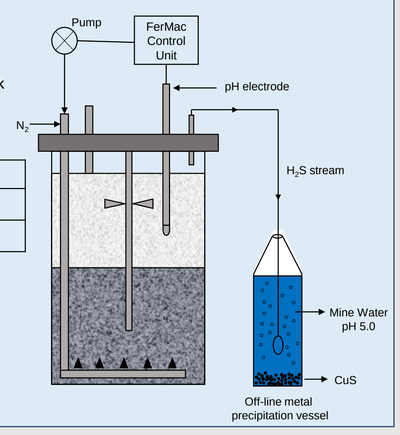
- once the world's largest Cu mine
- discharges ~315,000 m³/year of extremely acidic, metal-rich water directly into the Irish Sea (via the *Afon Goch* drainage stream)
- Cu and Zn were recovered sequentially using sulfidogenic biotechnology

	Consumable costs/year $	Metal value /year $
copper	10,500	88,000
zinc	34,500	56,500
Total	45,000	144,500

Rio Tintillo, Spain

- catchment for discharge from a vast area of biologically-active rock waste accumulated over centuries around the Rio Tinto mine
- contains significant concentrations of cobalt

	Zinc	Copper	Cobalt
Price ($/kg)	3.07	6.78	88.9
Value ($/m³)	1.69	1.23	3.99



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