Eco-efficient metal production methods and utilisation of secondary materials

From Espoo (2009) to Levi (2013) – An Overview

WP4 ProMine Final Conference
Levi, Finland 23.4.2013
P. d’Hugues (BRGM)
WP4 R&D Objectives

• Study of innovative technologies, new integrated flowsheets and new equipment for mineral processing and extractive metallurgy
  • to demonstrate that these technologies/processes will enable the exploitation of more diversified and complex existing European resources
  • to show that these technologies/processes will improve the eco-efficiency of extractive methods (increasing the opportunity of transforming wastes into new products; reduction of the metal grades in the wastes, minimizing environmental impact).
<table>
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<th>Description of the resources (+ origin of the information)</th>
<th>Potential Technical option</th>
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<td>Lubin concentrate Cuprum / KGHM Cu flotation concentrate (Cu, Silver) - From KGHM</td>
<td>Bioleaching CSTR or Low Duty Bioreactor Concept (+/- pre-concentration step).</td>
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<tr>
<td>Slag from treatment of non-ferrous materials in Waste processes at Boliden &amp; Outotec</td>
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<td>Slag from treatment of dust from copper metallurgy at KGHM PM and KGHM Cuprum</td>
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<td>Lubin run-of-mine Cuprum / KGHM Cu flotation concentrate (Cu, Silver) - From KGHM</td>
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<td>Mansfeld Mine Waste (Zn, Cu, Ni, Mo) - From Boliden</td>
<td>Low Duty Bioreactor Concept</td>
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<td>Most promising secondary Technologies: Development Fund Outsourc</td>
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<td>Maurliden Mine Water (Zn, Cu, Ni, Mn) - From Boliden</td>
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<td>Low Duty Bioreactor Concept</td>
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<td>ODDA CLinker (Sb, Sn, Pb) - From Boliden</td>
<td>Low Duty Bioreactor Concept</td>
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<td>Acid leaching</td>
<td>Low Duty Bioreactor Concept</td>
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<td>São Domingos mining area Mining wastes (pyrite ore, gossan, host rocks, slag, Roman slag, roasted pyrite, contaminated landfill) - (Au, Silver) - From LNEG</td>
<td>Bioleaching CSTR or Low Duty Bioreactor Concept (+/- pre-concentration step).</td>
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<td>Bor tailings (old copper flotation tailings) - Cu - From BioMin &amp; CIB</td>
<td>Bioleaching CSTR or Low Duty Bioreactor Concept (+/- pre-concentration step).</td>
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<td>Aguablanca tailings flotation tailings - Cu - From BioMin &amp; CIB</td>
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<td>Lubin middlings flotation tailings from the 1st cleaning stage - Cu - From KGHM</td>
<td>Low Duty Bioreactor Concept</td>
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<tr>
<td>Lubin tailings Cuprum / KGHM final flotation tailings of Lubin concentrator (Cu) - From KGHM</td>
<td>Low Duty Bioreactor Concept</td>
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<tr>
<td>Stratoni flotation tailings Hellas Gold</td>
<td>Bioleaching (rejected)</td>
</tr>
<tr>
<td>Old Stratoni pyrite by-products Hellas Gold</td>
<td>Bioleaching (rejected)</td>
</tr>
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<td>Salau mining wastes (France) - From BRGM WP1</td>
<td>Bioleaching CSTR or Low Duty Bioreactor Concept (+/- pre-concentration step).</td>
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<td>La Troya mining wastes (France) - From BRGM WP1</td>
<td>Bioleaching CSTR or Low Duty Bioreactor Concept (+/- pre-concentration step).</td>
</tr>
<tr>
<td>Waste from phosphoric acid production - Rare Earth Oxides - From KGHM Cuprum</td>
<td>Not determined</td>
</tr>
<tr>
<td>Dusts and slag from copper smelting - Rhenium of Cu, Zn, Mo - From KGHM Cuprum</td>
<td>Not determined</td>
</tr>
<tr>
<td>Chromite slag - Chromium resource - From KGHM Cuprum</td>
<td>Not determined</td>
</tr>
</tbody>
</table>
Exploitable result N°1
Improved (bio)processing methods

Complete flowsheet for bioleaching of Lubin Concentrate
Exploitable result N°2
Transformation of environmentally hazardous waste slags into mineral resources: metals and aggregates

Slags from different metallurgical operations

Slide text:

TECHNOLOGICAL DEVELOPMENT AND DEMONSTRATION

Exploitable result N°2
Transformation of environmentally hazardous waste slags into mineral resources: metals and aggregates

Slag processing:
- resmelting
- sulphides oxidation
- reduction and fuming
- slag correction

CRUSHING < 50 mm

TSL REACTOR

Slag

Fuel
Air

Coke breeze
Silica sand

off-gas

Steam

Zn-Pb dust

Flue gas

Copper matte

Silica slag

COOLING

Waste Heat Boiler

DEDUSTING
Cyclone/Bag Filter

SO₂ REMOVAL
Scrubber

CRUSHING

GRAIN
CLASSIFICATION

Construction aggregates

Waste
Heat Boiler

Cyclone/Bag Filter

Scrubber

Silica sand

Coke breeze

Steam

Zn-Pb dust

Flue gas

Sulphides oxidation

Reduction and fuming

Slag correction

Copper matte

Silica slag

Construction aggregates

Gypsum
Exploitable result N°3
New Bioreactor for Bioleaching application

Aitik Flotation Tailings - case study
Exploitable result N°4
Metal recovery from Mine waters

• Novel bio-mineralization techniques for the selective recovery of metals from acidic mine waters: Pyhäsalmi and Maurliden cases
Development of Mineral Processing Steps

Comminution step: fragmentation technology (BRGM)
Concentration step: New Flotation Device (INPL Nancy)
Leaching Step: Bioleaching (Warwick)

Comparison of conventional cells and reactor-separator cell:

Milling,
200 rotations in Bond test Jar

Y. Menard
New embrittlement technologies

78°C
Investigation of potential new bioprocess innovations

(1) Evaluation of anaerobic bio-processing for ore heap leaching improvement by:
   (i) removal of ore surface-passivating iron precipitation and
   (ii) removal of channel-blocking iron precipitation in ore columns/heap.

(2) Evaluation of bio-processing of Lubin copper/silver concentrate at high temperature.
ore fragments leached with strain J2 at 70°C: alternating aerated and anoxic periods increased iron removal and the yield of zinc (also of nickel and copper)
Ore fragments leached with *Sulfolobus thermosulfidooxidans* at 47 °C in ore columns: almost twice the removal of iron after an initial anoxic phase and no ultimate detriment to zinc and other target metal leaching.
(2) Evaluation of bio-processing of Lubin copper/silver concentrate at high temperature

Left: rapid, essentially complete leaching of copper from Lubin concentrate at 76 °C with the HIOX culture (duplicate reactors for residue collection); silver was concentrated in the residue.

Silver extraction efficiency with different solvents depended on the temperature of bio-residue production: ferric chloride leaching was efficient with 30 °C residue; thiosulfate was the best solvent with 78 °C residue.

Below: extraction efficiency also differed between bio- and chemically-leached residues.
Prospects.

(1) Anaerobic bio-processing for ore heap leaching improvement:

Desired effects of anoxic phases were demonstrated (increased iron removal and equal or improved target metal release), probably for the first time. Real benefit (particularly solution flow) would have to be demonstrated on a pilot scale. Some current industrial heap leaching development is focused on real problems of improving the aeration, which is more critical, but at least one company has some research directed towards assessing anaerobic potential.

(2) Evaluation of bio-processing of Lubin copper/silver concentrate at high temperature.

This work was the most extensive so far attempted with the Lubin concentrate at high temperature, with the aim of improving the basic rates and yields associated with its bioleaching in reactors. The potential was demonstrated but culture stability was less assured than with other copper concentrates and hydrometallurgical silver extraction remained inadequate. Silver extraction was dependent on solvents used and on the nature of the leached residues – including the temperature of their production. A mineralogical analysis of the residues is planned before the final conclusions on the likely basis of the extraction specificities, and on the prospects for optimisation, can be made.
The aims of this part of WP4 consist in recovery of metals by flotation from any kind of industrial waste or waste water solutions.

Description of work

1. Demonstration of the feasibility of new reactor-separator concept to fine particle flotation and effluent treatment.

2. Carry out pilot plant tests to determine the optimum operating parameters for the recovery of high value metals from industrial by-products or wastes.

LEV FILIPPOV

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**New flotation cell**

- *special zone for each subprocesses*

- Pulp aeration (Re = $10^4$-$10^5$)
- Bubble-particle Collision (Re = $10^3$-$10^4$)
- Separation of loaded bubble from pulp (Re = $10^2$-$10^3$)

**Conventional flotation cell**

- *All flotation subprocesses at the same hydrodynamic conditions*

Application of RS allows to:

- reduce the number of roughing operations;
- increase flowrate by 1.5-2;
- increase metallurgical performance
Comparison of existing cells of intense flotation with RS developed in PROMINE by Université de Lorraine (UL)

Decrease of pulp residence time by optimising pulp-bubble stratification in the separator part
New RS provides a special zone for Ultrasound to enhance the flotation efficiency

The ultrasound treatment effect in the conventional impeller flotation machines will exist only at the contact point because of the rapid damping of the ultrasonic frequencies in slurry.

Vargas-Hernandez, Y. et al., 2002
Chalcopyrite recovery increases with ultrasound by 15-20 %

\[
E = (1 - \Theta)[1 - \exp(-K_f t)] + \Theta[1 - \exp(-K_s t)]
\]

Ultrasound treatment increases the slow component flotation kinetics by 6 told
Comparison of flotation efficiency of new and conventional flotation machines for quartz/feldspars separation

Wemco: lab scale flotation cell = “perfect separator” (V=3L)
STEVAL: circuit of conventional mechanical cell (V=100 L, Q= 0.5 m3/h)
RS: new intensive flotation machine (Promine) (V=5 L, Q=0.5 m3/h)
The new multizone flotation machine show very high efficiency in specific air use to recover unit mass of mineral.
The RS 5 shows an optimum grade/recovery ratio with low collector dosage.

The RSC mode is enough selective to obtain the tailings with a very low Py grade in the final tailings.
Comparison of technical characteristic of new RS flotation machine with existing reactor-separator (Jameson cell, Pneuflot).

<table>
<thead>
<tr>
<th>Cell type</th>
<th>RS cell</th>
<th>Jameson Cell</th>
<th>Pneuflot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>RS 5</td>
<td>Z1200/1</td>
<td>Pneuflot</td>
</tr>
<tr>
<td>HWD (m)</td>
<td>0.15x0.15</td>
<td>1.2x0.75</td>
<td>1.2x0.75</td>
</tr>
<tr>
<td>Cell volume (m³)</td>
<td>0.005</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Surface occupied (m²)</td>
<td>0.04</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Pulp flow rate (m³/h)</td>
<td>0.5</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Specific pulp flow rate ((m³/h)/m³)</td>
<td>100</td>
<td>33.3</td>
<td>20</td>
</tr>
<tr>
<td>Specific surface (m²/(m³/h))</td>
<td>0.08</td>
<td>0.08</td>
<td>0.13</td>
</tr>
</tbody>
</table>

RS advantages:
✓ Increase of Specific pulp flow rate by 3-5 times
✓ Decrease of Cell volume and surface occupied
Acknowledgement

For Anna

Future ?:  
In R&D: EIP/horizon2020 & collaborative projects  
Drivers for application: Market Opportunities & Regulation