TRENDS AND TREATMENT OF IMPURITIES IN COPPER MINING

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October 16, 17, 2018 – Japan
Topics

1. Global Trends
2. Ecometales
3. Final Remarks

Ecometales: Environmental solutions for the mining industry
Arsenic
An unresolved problem

**Structural problem:** Most new copper deposits have a high arsenic content.

**Closed circuit:** The process of scorodite, or similar, stable residue is not applied extensively.

**Stricter environmental norms for transporting and processing complex concentrates are expected**
Arsenic content concentrate output is growing fast:

0.13% in 2000...>0.20% in 2016...0.30% in 2020, according to ICSG

Chile is the world’s leading producer of copper in concentrates with 24% of total

- Perú: 14%
- China: 10%
- Australia: 5%
- USA: 4%

Chile should increase its share to 26% by 2030.

**Arsenic content in copper concentrates in Chile and Perú**

- **Perú**
  - El Brocal (Buenaventura): 5 - 8% As
  - Cobriza (Doe Run): 0.4 - 0.6% As
  - Chinalco: 0.5 - 1% As
  - Magistral (Nexa Resources) (*): 1% As
  - Cañariaco (Candente Resources): 1% As
  - Other projects: La Granja, Galeno

- **Chile**
  - DMH (Codelco): 1 - 3% As
  - Chuqui (Codelco): 0.5 - 2% As
  - El Teniente (Codelco): 0.15 - 0.20% As
  - Collahuasi: paying penalties on higher As

(*): Projects;

Sources: Codelco, Cochilco, Anglo American, EcoMetales, ICSG

EcoMetales: Environmental solutions for the mining industry
20% of Chile’s copper is exported to Japan today, compared to 30% in 2008.

Japan is Chile’s second most important destination for copper concentrates after China which represents 41% of the total.

- The volume of Cu concentrates with high As will increase in the international market.
- Blending practice is an option but not a suitable solution.
- Chemical or biological treatment is needed, either using a hydrometallurgical or pyrometallurgical route.

**EcoMetales: Environmental solutions for the mining industry**

Stricter regulations for concentrates with arsenic in storage and transport

Some copper concentrates can be harmful to the marine environment and a risk to crews.

**International Maritime Dangerous Goods Code (IMDG):** packaged copper ores and concentrates.

**MHB:** Materials Hazardous Only in Bulk

**International Maritime Solid Bulk Cargoes Code (IMSBC):**

**China** set a benchmark maximum of 0.5% As in concentrates; other countries have reduced the limits further.

On the first day of 2018, **China ban scraps imports**

The **EU-28** established best available techniques (BAT) in 2016 for waste reduction of copper and other metal industries, including the reduction of quantities of waste sent for disposal from copper production.

**Sources:** ICSG, Cochilco.
Environmental issues & community concerns: a Chilean case

Citizens' perception of the most severe environmental challenges:

- Air pollution 30%
- Urban waste 20%
- Noise 15%
- Pollution in general 10%
- Vehicles (noise, pollution, etc.) 5%
- Chimneys and firewood use 5%
- Water pollution or scarcity 3%
- Release of pollutants from trees 2%
- Lack of green areas 1%
- Street dogs 1%
- Odours 1%
- Climate 1%
- None/other/don't know 0%

EcoMetales: Environmental solutions for the mining industry

Pese a que primer día de alerta sanitaria redujo en 20% el nivel de SOx, restricción en 8 industrias no logra frenar las intoxicaciones: el Hospital de Quintero tuvo que atender a 86 personas

ENAP REFINERÍA ESTIMA EN US$ 200 MILLONES SU INVERSIÓN PARA CUMPLIR CON EL FUTURO PLAN DE DESCOLMAMINACIÓN:

El fantasma de las paralizaciones en Quintero obliga a calcular costos y tomar resguardos extras a las empresas de la zona

En la industria asumen que la autoridad será cada vez más exigente, y aunque en el Ministerio del Medio Ambiente aseguran que no habrá paralizaciones constantes, los privados ya hacen cálculos de eventuales detenciones. Un buque petrolero parado en el mar cuesta entre US$ 25 mil y US$ 35 mil diarios y la menor producción de energía puede significar pérdidas de más US$ 100 mil cada día. • CLAUDIA RAMÍREZ

SOURCES: El Mercurio newspaper, OECD, Ministry of Environment - Chile
Chile’s air quality and emission standards for copper smelters

- **Environmental regulation in Chile** (since 1990) has a shorter history than Japan and US (early 1970s)

- **Chilean smelters are now working to reach a new SO\textsubscript{2} and As emission standard by 2018, which will:**
  
  **A**
  
  Reduce emission limits by 225% for As and by 186% for SO\textsubscript{2}

  **B**
  
  Increase SO\textsubscript{2} and arsenic capture to 95% for current operations and to over 98% for new smelters. Average capture today is about 85%

- **A new stricter air quality standard** for SO\textsubscript{2} is being analyzed for a 2020 startup

- Chile is working hard to reduce emissions but needs to close the gap with international standards such as those in Japan, EU or China

Details on standards in Annex I
Chilean regulations for waste treatment and disposal of impurities

**D.S. Nº 148/2003: Management of Hazardous Waste:**

- **Scope:** Generation, storage, transport, treatment, reuse & recycling, disposal

- **Focus on** characterization and toxicity (TCLP test), but not on Best Available Techniques

**Extended producer responsibility (EPR)**

* (mining waste not included)

**Some figures in copper smelters (7 operations)**

- +110 kt/y of flue dusts (1-15% As) and 4,000 m³/y of acid effluents (acid plants)

- 85% of total flue dust with As is treated at EcoMetales plant and As disposed as scorodite together with Sb and other impurities

- Almost all the As from acid effluent is treated with lime, while one operation uses NaSH

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In summary, regulatory trends will place greater requirements/obligations on the treatment and disposal of unstable waste containing impurities in Chile

Details per operation in **Annex II**

**EcoMetales:** Environmental solutions for the mining industry
Copper smelters and other metallurgical plants in Chile face the following challenges:

- **Improve** environmental performance
- **Reduce costs** and to increase productivity
- **Introduce more automation** and technological improvements
- **Energy recovery**
- **Recovery of strategic metals** (Bi, Ge, Sb, etc.) and alternative uses for waste like slag or sulfur.

**EcoMetales**: Environmental solutions for the mining industry
Topics

1. GLOBAL TRENDS
2. ECOMETALES
3. FINAL REMARKS

EcoMetales: Environmental solutions for the mining industry
About EcoMetales Limited (ECL)

ECL is a 100% subsidiary of CODELCO, established to implement environmental solutions and metal recovery processes in the mining industry.

Our facilities are strategically located 35 kms northeast of Calama. ECL has a total workforce of about 300 and more than 250 environmental permits for the transportation, treatment and disposal of hazardous waste.

ECL currently processes waste from CODELCO and is looking for opportunities to work with other mining companies.

EcoMetales: Environmental solutions for the mining industry
EcoMetales’s development plan

- Copper Recovery
- As-Sb Stabilization (AAA)
- Recovery of Cu, H₂O, H₂SO₄

To meet the Codelco needs with new processes.

Growth with new customers. Commercial Know-how

MINING WASTE & VALUE RECOVERY

EcoMetales: Environmental solutions for the mining industry
**Projects & business**

**CURRENT PLANT**
Flue dust leaching & As disposal as Scorodite

- **Productivity Improvement**
  2018/2017: +47% Production and –22% cost
- **Declassification Scorodite 2018**: It will allow its disposal under less demanding conditions

**WASTE VALORIZATION**
Leached residue: Recovery of Ag, Cu and Ge. A new hydro process in evaluation
- **Tailings**: Recovery of minor elements. Tailings characterization and lab testing.

**PLCC PLANT**
Pressure Leaching of Complex Concentrates
- **Feasibility engineering completed in 2017**
- **Environmental permit approved in 2018**
- **Independent Review Approval and decision to go forward in 2018**

**DET PLANT**
Improvement of arsenical waste generation, transport and disposal at El Teniente Division, Codelco
- **Environmental permit approved in 2018**
- **Definition of El Teniente Division for project continuity in 2018**

2018
- **Scorodite 2.0**: Volume reduction and encapsulation (2019)
- **Replacement of calcium arsenite by scorodite**
- **Geo-polymer study for existing calcium arsenite deposits**
- **End of the transfer area**

2019/2020
- **Leached residue**: First Milestone Cu recovery (2019)
  Second Milestone recovery of other elements (2020).
- **Tailings**: Technical-economic process evaluation (2019).
- **Begin detailed engineering by 2019**
- **Start-up in Northern District by December 2020**

**EcoMetales**: Environmental solutions for the mining industry
Arsenic stabilization process
(Chilean Patent Grant 50423)

ECOMETALES LANDMARKS:
We had a problem...

Continuous learning during the plant operation

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>Precipitation of scorodite at laboratory scale.</td>
</tr>
<tr>
<td>2010-2012</td>
<td>PAA Project. Pilot Plant Trials. PAA Construction. PAA Start-up.</td>
</tr>
<tr>
<td>2013</td>
<td>Start of operation of PAA.</td>
</tr>
<tr>
<td>2014</td>
<td>Improvement of boiler use and limestone preparation stage.</td>
</tr>
<tr>
<td>2015</td>
<td>Optimization of ferric solution preparation stage.</td>
</tr>
<tr>
<td>2016</td>
<td>Improvement of oxidation stage.</td>
</tr>
<tr>
<td>2017</td>
<td>Optimization of precipitation stage.</td>
</tr>
<tr>
<td>2018</td>
<td>Improvement of automatic control.</td>
</tr>
</tbody>
</table>

EcoMetales: Environmental solutions for the mining industry
Since 2007, EcoMetales has processed about 470,000 tonnes of flue dust and 782,000 m³ of acid effluent, recovering about 90,000 tonnes of copper. More than 12,000 tonnes of arsenic have been disposed as scorodite since 2013.
EcoMetales plant: Arsenic stabilization process

Limestone slurry
Steam
Magnetite
PLS

Storage tank
Oxidation stage
1st precipitation stage
2nd precipitation stage
THICKENER
FILTER

PLS to SLX-EW

7.352 tonnes Fine copper

H₂O₂ 70%

25.902 tonnes scorodite

3.560 tonnes of As

Scorodite to EcoMetales landfill

EcoMetales: Environmental solutions for the mining industry
The process involves the leaching of complex copper concentrates through a high-pressure vessel. The arsenic stabilization is also performed inside the vessel.

The project capacity is 200,000 t/y, the go-ahead decision should be taken during 2018.

**Advantages:**

- Almost zero emission
- Stable waste as scorodite
- Utilization of existing SX-EW facilities
- Low water consumption
- Competitive costs

Environmental permit approved in 2017

The schedule defines the start-up for the new facilities in 2020-21

Capex USD $ 324 million
El Teniente Project
Arsenic removal from sulfuric acid plant effluents (weak acid)

The project will produce arsenic trisulfide instead of the current process based on treating arsenic with lime.

**Advantages:**

- 5 times less waste volume
- less than 1 ppm of [As] in treated effluent
- 500,000 m³ landfill facility inside El Teniente facilities, avoiding current transportation through populated areas outside Codelco’s division

Environmental permit was approved in 2018

Capex USD $70 million

EcoMetales: Environmental solutions for the mining industry
Other developments & cooperation opportunities

- Recovery of trace elements (Ag, Bi, Sb and Ge) from smelter flue dusts (in cooperation with K-UTEC Salt Technologies and RMC with CORFO – Eureka support)
- Tailings processing & recovery of value metals (in cooperation with JRI Ingeniería Chile, CORFO project)
- Oxidation of As (III) and Fe (II) using new biotechnological methods (in cooperation with CeBiB – University of Chile)
- Increase of current copper recovery of flue dust treatment plant (ECL)
- Treatment of Acid Mine Drainage (AMD)

EcoMetales: Environmental solutions for the mining industry
ECOMetales: Environmental solutions for the mining industry
The treatment of arsenic remains an unsolved problem worldwide with several pending challenges in the mining sector:

Transportation of higher As content and more complex concentrates

Stricter regulations for air emissions and waste disposal

Communities deeply concerned about environmental pollution issues

Metallurgical facilities’ management of flue dust and acid effluent still needs to improve treatment and disposal of arsenic and other impurities. More research is needed for the removal of As from water sources, as well as for more efficient disposal alternatives.

EcoMetales supports JOGMEC’s initiative related to the separation of impurities from copper raw materials at the mineral processing stage.

From a more integral perspective, it is also necessary to find the best solution for the residual fraction of high arsenic concentrate.

EcoMetales is looking for synergies and collaboration to solve the challenge posed by arsenic treatment and disposal.

**EcoMetales:** Environmental solutions for the mining industry
Thanks you!!!
FILIAL CODELCO

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Annex I.

Evolution of regulations affecting copper smelters in Chile (from 1990 to present)

- **1991**
  - DS 185/91: Min of Mining:
    - Quality Air Standard for SO₂ and MP10

- **1994**
  - Environmental Law 19,300

- **1999**
  - DS 165/99: As emission standard for smelters
  - Decontamination plans to reduce SO₂, MP and As emissions from smelters:
    - Ventanas (1992)
    - Chuquicamata (1993)
    - Paipote (1995)
    - Potrerillos (1998)
    - Caletones (1998)

- **2000**
  - D.S. 90: Discharges of industrial wastes into water

- **2003**
  - DS 148: Sanitary Regulation on Handling of Dangerous Wastes

- **2007**
  - D.S. 248: Tailing Management

- **2012**
  - Law 20.551 Mine Closure (*)

- **2013**
  - D.S. 28: Air emission standard for smelters: As and SO₂

(*) Including technical, safety and financial obligations for large, medium and small scale operations

Future environmental regulations? Stricter air quality standards for SO₂ by 2020 and proposed national policy for tailing dams, focused on abandoned tailings.

**EcoMetales**: Environmental solutions for the mining industry
Annex II.

Air emission standards and emission data for SO$_2$ and arsenic from existing copper smelters

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>SULFUR DIOXIDE (KT/Y)</th>
<th>ARSENIC (TON/Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Emissions</strong></td>
<td><strong>Emission Standard</strong></td>
</tr>
<tr>
<td>CHUQUICAMATA</td>
<td>92</td>
<td>85.8</td>
</tr>
<tr>
<td>CALETONES</td>
<td>119</td>
<td>69.0</td>
</tr>
<tr>
<td>POTRERILLOS</td>
<td>82</td>
<td>60.2</td>
</tr>
<tr>
<td>ALTONORTE</td>
<td>44</td>
<td>17.7</td>
</tr>
<tr>
<td>VENTANAS</td>
<td>19</td>
<td>13.9</td>
</tr>
<tr>
<td>CHAGRES</td>
<td>14</td>
<td>9.9</td>
</tr>
<tr>
<td>PAIPOTE</td>
<td>23</td>
<td>17.4</td>
</tr>
<tr>
<td>DMH(*)</td>
<td>-</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

(*) Roasting plant in operation since 2014

- Sulfur and arsenic capture must be equal or superior to 95%. For new smelters: 98% for SO$_2$ and 99.97% for As
- Over US$ 2 billion in investment to reach new standards, without any increase in smelting capacity

SOURCE: AL Prospecta's analysis using data from Ministry of Environment and Superintendant of Environment, Chile
Annex III.

Treatment of flue dusts and acid effluents in Chilean metallurgical facilities

ALTONORTE SMELTER (GLENCORE):
- Dust leached with acid effluents and PLS solution sent to SX-EW facilities

PAIPOTE SMELTER (ENAMI):
- Dust partially recycled into the smelting process, as well as storage for further processing
- Acid effluent sold for further processing

CHAGRES SMELTER (ANGLO AMERICAN):
- Dust recycled into the Flash smelting process
- Effluent treated to produce a clean weak acid to the market, while As is neutralized with NaSH

VENTANAS SMELTER (CODELCO) (*):
- Dust treated at EcoMetales plant and As disposed as scorodite
- As from acid effluent treated with lime

CHUQUICAMATA SMELTER (CODELCO) (*):
- Dust treated at EcoMetales plant and As disposed as scorodite
- As from acid effluent treated with lime

DMH ROASTING PLANT (CODELCO):
- Dust recycled into the roasting plant
- As from acid effluent treated with lime (190 tpd of calcium arseniate)

POTRERILLOS SMELTER (CODELCO) (*):
- Dust treated at EcoMetales plant and As disposed as scorodite
- As from acid effluent treated with lime

TENIENTE SMELTER (CODELCO):
- Dust treated at local plant and As disposed as ferric Arsenate
- As from acid effluent treated with lime

(*) it includes a refinery

SOURCES: EcoMetales, Codelco, ENAMI, AngloAmerican, Glencore

EcoMetales: Environmental solutions for the mining industry
Current examples of Chilean research on As treatment and removal

**UNIVERSIDAD DE TARAPACÁ**
- Simultaneous UV-oxidation and ferric precipitation of As

**U. CATÓLICA DEL NORTE**
- Pressurized oxidation of Cu concentrate & ferric arsenate precipitation
  (Chilean patent pending cl201602183)

**UNIVERSIDAD DE ANTOFAGASTA**
- As stabilization by using an extremophile microorganism
  (Chilean patent pending CL201701324)

**U. DE ANTOFAGASTA / CSIRO**
- Alkaline leaching of Cu concentrates and As stabilization in ceramics

**U. DE CHILE / ECOMETALES**
- Oxidation of Fe(II) and As(III) using microorganisms

**UNIVERSIDAD DE SANTIAGO**
- Iron nanoparticles for As removal / As absorption in Lupinus microcarpus

**FRAUNHOFER CHILE RESEARCH**
- PVDF membranes for As removal / As processing in the mining industry

EcoMetales: Environmental solutions for the mining industry