Arsenic Management for the Copper Smelting Industry

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1. Introduction

2. Understanding the supply

3. Technological options

4. Discussing strategies

5. Concluding remarks
### Markets for standard copper raw materials
- Increasing mine output and rising levels of copper scrap
- Smelter capacity increasing worldwide
- Competition for standard raw materials
- Volatile treatment and refining charges

### Markets for complex raw materials
- Increasing metal prices make complex raw materials more attractive
- Mine-specific composition of complex concentrates
- Global e-scrap levels are increasing, collection rates are still low
- Increasing levels of valuable industrial residue

### Product markets
- Delayed development of mining projects could lead to cathode deficits
- Demand for copper products bolstered by mega trends
- Growth in application markets increases the demand for metals that accompany copper
- Sulfuric acid markets remain volatile

### Societal trends
- UN Sustainable Development Goals (SDG)
- Global knowledge society
- Change & disruption
- Using resources responsibly

Our market environment: Opportunities and challenges for further development

23.10.2018
<table>
<thead>
<tr>
<th>Rising Copper Demand</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urbanization, growing middle class, mobility and energy related trends will drive refined copper demand overcompensating substitution effects</td>
<td>Global expansion of copper production capacity needed</td>
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<table>
<thead>
<tr>
<th>Multipolar Business World</th>
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<tbody>
<tr>
<td>Emerging countries (especially China) will outpace Western countries</td>
<td>Demand for global delivery and international production platforms</td>
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<thead>
<tr>
<th>More Complex Materials</th>
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<tbody>
<tr>
<td>Rising no. of elements and decreasing metal content in primary and secondary raw materials</td>
<td>Requires extensive production know-how, innovative technologies and customized solutions for suppliers</td>
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<table>
<thead>
<tr>
<th>Increasing Recycling Efforts</th>
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<tbody>
<tr>
<td>Waste avoidance / recycling becoming critical due to rising resource scarcity</td>
<td>Extended recycling capacity and capability needed to meet customer and supplier requirements</td>
</tr>
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<tr>
<th>Growing Sustainability Ambitions</th>
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<tbody>
<tr>
<td>Shifting customer values towards sustainability</td>
<td>Sustainable activities balancing economy, environment and people</td>
</tr>
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</table>
Our metals for an innovative world: our copper will enable the trends of the future.

Sustainable growth in copper demand expected.

- Green energy
- E-mobility
- Digitalization
- Urbanization
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Copper will be needed but...

- Ore grade development is indicating increasingly complex raw materials for mines AND smelters.
- We face a growing dilemma: We want a sustainable society, where copper plays a crucial role, however we have to take care of fundamental issues associated with the mining and processing of this resource.
- Main demand for copper will be where develop is expected: South East Asia...BUT resources will come mainly from abroad.

**Graph:**
- **Copper Grade Cu%**
- **Long term downward**
- **Higher prices enable lower cut off grades**
- **New projects mining higher grade during early years.**
- **Higher grade underground mines ramping up**

Source: Wood Mackenzie
Copper will be needed but…

Fundamental change in the market compared with 10 year ago: Dramatic increase in Chinese smelting capacity

» Chinese smelting capacity grows faster than concentrate supply

» BASE metal smelters get an ever-decreasing part of the metal value and are under pressure

» Restrictions in smelters support business of traders (but no sustainable solution)
Copper will be needed but...

Arsenic content in concentrate have gradually increased compromising the blending ability.

At least 70,000 tpa of As are shipped from South America around the world, every year. This material has to be properly stabilized for safe disposal.

Miners take a free ride with penalties that might not be sufficient to solve the issue.

Copper exported to the world does not come alone
Over 70,000 tpa of As exported from Chile and Peru to smelters around the world.

Base Aurubis internal data and Wood Mackenzie
Standard Concentrate Supply

Gradual increase in As concentration in concentrates to smelters

Complex Concentrate Supply

High As concentration in concentrates

Base Aurubis internal data and Wood Mackenzie
A coordinated and sustainable approach to solve Arsenic Management in non-ferrous industry is required

This effort has to address not only high As deposits but also the gradual increase of As content in standard concentrates
Agenda

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Arsenic in non-ferrous metal smelter feedstock constitutes a major source of concern:

- Transport of materials
- Interferes with metal extraction
- Production cost
- Product quality
- Environmental (management and disposal)
- Health and safety aspects (toxicity)

- More strict environmental regulations

- Miners rely on a system that “restrict their profitability” with penalties and subsequently “award” the smelter with additional revenues and “liabilities”

- The As is becoming a spider net issue as it is be distributed across the smelters
Mine side changes expected in the next decade

- Decline in head grades
- For some porphyry mines ratio of chalcopyrite to secondary minerals (i.e. chalcocite) will increase
- Minor tendency to increase As content

New “probable operations“ (marketable concentrates with existing technologies)

- General higher As
- Finer grained (10 to 20 microns finer than today’s)
- Higher chalcopyrite than current average

Base: Data comes from a review of data from existing operations and proposed greenfield projects by Mineralis Consultants
Our information indicates that based on available information average will increase

Impact at smelters

- By increasing, emissions & inmissions will also increase requiring more CapEx to capture them
- OpEx for neutralization/stabililization will increase
- Content of As in slag will increase (specially for Flash Furnace)
- Dust processing may be required
Available Technologies for both sides of the coin

At the mine site

» Ore sorting
» Differential flotation
» Hydro solutions offered for high As containing materials (i.e. CESL Toowong, Nonox, ROL, etc)

Prior to smelting

» Blending
» Roasting
» Upgrade of concentrates (Towoong): to clean As rich concentrates

Specific solutions available for high As containing ores/concentrates depending on local needs

In addition, blending is the trend to meet smelter intake limitations

At the smelter: Standard concentrates

» Blending
» Additional hooding and fume capture systems
» Slag chemistry & As removal via slagging
» Slag processing
» Dust treatment (high volume, low concentration)
» Integral effluent treatment and As stabilization

At the smelter: As Processing Hub

» Roasting
» Bath Smelting Furnace
» Slag chemistry & As removal via slagging
» Dust treatment (lower volume, high concentration)
» Integral effluent treatment and As stabilization
Roasting Option: How much we progress in the last 30 years?

<table>
<thead>
<tr>
<th>Type</th>
<th>Residual Sulphur</th>
<th>Calcine</th>
<th>Furnace Type</th>
<th>Application Type</th>
<th>Purpose</th>
<th>Arsenic Removal</th>
<th>Operation</th>
<th>Status</th>
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<tr>
<td>Partial</td>
<td>20-25</td>
<td>FeS</td>
<td>Fluidized Bed</td>
<td>Cu conc.</td>
<td>Pre-treat. As removal</td>
<td>Good</td>
<td>Pasar (Lepanto)</td>
<td>Closed due to env. reasons</td>
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<tr>
<td>Partial</td>
<td>25-27</td>
<td>FeS</td>
<td>Multi Hearth</td>
<td>Cu conc.</td>
<td>Pre-treat. As removal</td>
<td>Good</td>
<td>Boliden El Indio</td>
<td>Closed due ore depletion</td>
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<tr>
<td>Partial</td>
<td>20-25</td>
<td>FeS</td>
<td>Fluidized Bed</td>
<td>Cu conc./Cu-Ni conc.</td>
<td>S removal</td>
<td>n.a.</td>
<td>Inspiration</td>
<td>Closed due to env. reasons</td>
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<tr>
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<td>5-7</td>
<td></td>
<td>Multi Hearth</td>
<td>As removal</td>
<td>Good</td>
<td></td>
<td>Capper Pass</td>
<td>UK, closed to Env. reasons</td>
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<tr>
<td>Partial</td>
<td>n.a.</td>
<td></td>
<td>Fluidized Bed</td>
<td>As removal</td>
<td>Good</td>
<td></td>
<td>P.U.K. Bou Azzer</td>
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<tr>
<td>Dead</td>
<td>≤ 1.0</td>
<td>Fe₂O₃</td>
<td>Multi Hearth</td>
<td>S removal</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dead</td>
<td>1 - 1.5</td>
<td>Fe₂O₃</td>
<td>Fluidized Bed</td>
<td>S removal</td>
<td>Good</td>
<td></td>
<td>Boliden</td>
<td></td>
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<tr>
<td>Dead</td>
<td>3 - 5</td>
<td>Fe₂O₃</td>
<td>Multi Hearth</td>
<td>S removal</td>
<td>Good</td>
<td></td>
<td>Barreiro</td>
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<tr>
<td>Dead</td>
<td>&lt; 0.1</td>
<td>Fe₂O₃</td>
<td>Fluidized Bed</td>
<td>S/As removal</td>
<td>None</td>
<td></td>
<td>Inco Falconbridge</td>
<td>Closed to poor economics</td>
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<tr>
<td>Magnetite</td>
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<td>Fe₂O₃</td>
<td>Fluidized Bed</td>
<td>S/As removal</td>
<td>Good</td>
<td></td>
<td>Boliden (Häalsingb,)</td>
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<tr>
<td>Dead</td>
<td>1.0-1.5</td>
<td>Fe₂O₃</td>
<td>Fluidized Bed</td>
<td>S/As removal</td>
<td>Good</td>
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<td>Barreiro</td>
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<tr>
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<td>1.5-2.0</td>
<td>Fe₂O₃</td>
<td>Fluidized Bed</td>
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<td>Good</td>
<td></td>
<td>Campbell Gian Yelloknife</td>
<td>Closed to env, reasons</td>
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<tr>
<td>Chloridizing</td>
<td>0.1-0.4</td>
<td>Fe₂O₃</td>
<td>Multi Hearth</td>
<td>Pyrite cinders</td>
<td>None to Little</td>
<td>Sulfation of non-ferrous metals</td>
<td>DKH, Barreiro</td>
<td></td>
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Mostly small operations to meet particular needs
All them close
- **Principle**: As volatilization
- **Limits**: Suitable for high As concentration
- **Final product**: Calcine
- **Indicators**: Pilot plant
  - As in feed ≤ 5.8%
  - As in calcine ≤ 0.3%
  - As to flue dust require further processing
- **Advantages**: Suitable as complementary solution to reduce intake of As to smelter
- **Disadvantages**: Produce a low energy calcine
- **Stabilization of residue**: Requires dedicated As plant for further processing (Ecometales)
- **Development stage**: Fully industrial

Ref.: [www.outotec](http://www.outotec)
Smelter side

- Deportment to slag and gas is highly dependant on type of smelting technology
- Further use of slag as by-product depends on immobilization of these metals in the crystalline structure
- Maximum removal during smelting levels is preferable. This will contribute to minimise outlets
- Deportment for standard 1000 ppm As in concentrate
Understanding the Impact: Smelter Side

Dramatic increase in Arsenic in copper anodes in the last 13 years

Impurity Average Increment in Copper Anode (%)
2003 to 2016

Moats et al. Cu 2016, „Survey of Copper Electrorefining Operations“
Aurubis: Standards, Indicators and Actions

**EU ARSENIC REGULATION AIR EMISSION**

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<th>1986</th>
<th>2002</th>
<th>2017</th>
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<tr>
<td>mg/m³</td>
<td>1.2</td>
<td>1.2</td>
<td>0.2</td>
<td>0.2</td>
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</table>

**ArSENIC pollution at measuring site Kaltehofe in ng/m³**

<table>
<thead>
<tr>
<th>Year</th>
<th>06</th>
<th>07</th>
<th>08</th>
<th>09</th>
<th>10</th>
<th>11</th>
<th>12</th>
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</thead>
<tbody>
<tr>
<td>ng/m³</td>
<td>7.4</td>
<td>5.0</td>
<td>2.7</td>
<td>5.3</td>
<td>4.1</td>
<td>5.1</td>
<td>3.4</td>
<td>3.4</td>
<td>5.4</td>
</tr>
</tbody>
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**EU target value: 6 ng/m³**

1 gram (g) = 1 billion nanograms (ng)

**Fig. 2.13: Arsenic emissions at the Hamburg site**

Arsenic in g/t of copper output

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</thead>
<tbody>
<tr>
<td>g/t of copper</td>
<td>9.0</td>
<td>6.6</td>
<td>6.0</td>
<td>5.1</td>
<td>4.8</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Base: Aurubis Sustainability Report 2017
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Mapping of potential ways to move forward within the smelter

Current situation
Requested values in product can only be achieved by controlling input level of As to the system.

Smelting and refining

Pretreatment of concentrate
Prospects (literature review)
Pros and cons

Flue dust
Set off recycling of flue dust
Prospects (literature review)
Pyro- or Hydrometallurgy
Pros and cons

Offgas
Changing offgas treatment to increase As input to WuK
Pros and cons

Slag
Specific slag treatment prospects
Pros and cons

Distribution Copper process
Circulating streams
Input streams
Output streams

Mineralogy
Characteristics of the different compounds of the e.g. flue dust and slag

Process parameters
Although theoretically is possible to adjust them, in practice degree of freedoms are limited

Slag metallurgy
Behaviour of minor elements in different kinds of slag

Behaviour of minor elements in different kinds of slag

... enables
Metal production

Synergy ...
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A coordinated and realistic effort required to locally manage As input into the smelting business is required.

The As issue has to be analysed from two angles:

- Increase of standard concentrates As content,
- Alternatives to deal high As contained concentrates

Bath smelting technologies are better prepared to concentrate and manage arsenic streams minimizing content in slag and maximizing content in offgas and dust.

Increasing intake of As by the smelters will require:

- Additional CapEx to meet environmental standards
- A hydro solution to manage dust and liquid effluents (advantage for bath smelting in concentration)
- Address increase in As content in the slag
- Potential use of Soda to match refinery standards
For the second case, alternative processing prior to smelting or direct leaching for specific cases might be more efficient than blending.

However, a superior solution to smelting by whole-of-concentrate leach processes remains to be seen. Scale up, engineering, and economics will remain significant barriers, and these technologies will only be applied in special conditions.

Geographical hubs will probably provide solutions to high As deposits using hydrometallurgical/pyrometallurgical

However there might be a better potential for partial leach before smelting, particularly for atmospheric processes which are lower capital, simpler to operate, and easier to engineer with less aggressive chemistry.
Forward-looking statements

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