DEVELOPMENTS IN COPPER SMELTING AND REFINING

A DISCUSSION OF CHANGES IN COPPER SMELTING AND REFINING INDUSTRY IN THE LAST 40 YEARS AND SOME IDEAS LOOKING INTO THE FUTURE

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Outline

• Copper and technology developments in the 1970’s

• Comparison between 1970’s and the present decade (we will see some similarities/some differences)

• Challenges ahead – and some ideas
World Refined Copper Production: 1960-2012
(in 1000s tonnes Cu/yr)

Source: ICSG, 2013
The Top Copper Smelting Countries in the World -1976

(Typically, mine sites had their own captive smelters – many of these smelters now closed)

1976 - USA No. 1 producer
Chile No. 3, Japan No. 4, Canada No. 6
(In the mid-1970s, China produced less than 20% of the USA output)
Source: USGS
Top Seven Copper Concentrate Countries - 2014

Source: ICSG Copper Bulletin 2015

Top Seven Copper Concentrate Producer Countries - 2014
(Total Production: 14.81 Mt/y)
Excludes SX-EW

% of Copper Production

Country

Chile
China
Peru
Australia
United States
Russian Federation
Zambia

Source: ICSG Copper Bulletin 2015
The Top Seven Copper Smelting Countries in the World - 2014

2014 – China No. 1 producer
USA, Canada and Zambia dropped out of top 7, Japan now No. 2
(China followed the Japanese model of the 70s/80s building modern custom smelters)

Source: ICSG, Copper Bulletin 2015
Copper Smelting Production by Technology - 2013

Survey of top 60 smelters in the world
Representing 90% world capacity (includes Cu scrap)

- **Bath Smelting, 40%**
  - Bath includes: Vanyukov, TSL, Noranda, El Teniente

- **Flash, 49%**

- **Reverberatory, Blast Furnace, 0**
- **Electric, Modified Reverberatory, 0**

"The Peirce-Smith converter still the “workhorse” but continuous converting increasing"

Some Observations - 2014

• South America is the most important copper mining region
  • More than 35% of world copper concentrate originated in South America
  • But only 13% of world copper concentrate was smelted in South America

• Chile is the world’s largest copper mine producer

• China is the world’s largest smelting country

• China produced only 11% of total world mine production but smelted 31% of world concentrate.

• Source: ICSG, Copper Bulletin 2015
Changes ..... and Challenges
Key Technical Challenges Identified in the 1970’s

Rising energy costs due to higher oil prices

SO₂ fixation not possible with low strength reverberatory furnace off-gas.

The Industry Response: A Golden Age

- Knowledge Generation
  - Process Fundamentals
- Development of New Smelting Technologies
  - Focused on new methods of smelting (more tonnes/operator=higher process intensity)
  - Use of tonnage oxygen (as in steel making)
- Increase in Sulfur Capture
  - Acid Plants for main process gas
  - Secondary emissions capture
- Electro-refining transformation
  - Permanent Cathode Technology
  - Automation
Technology Evolution: A response to the challenges


Production increment
Cu leach-solvent Extraction-EW (began Arizona 1968)
Noranda Reactor Canada
Mitsubishi Process Japan
Sirosmelt Lance Industrial test at MIM Australia
El Teniente Reactor Chile
Permanent Steel Cathode Technology ISA Process Australia

All these developments initiated by copper producers themselves
Technology Evolution: A response to the challenges

1980 - 1995

Inco Flash Furance

1992

Cu ISASMELT™
USA & Australia

1995

Kennecott – Outokumpu
Flash Converter

1997

PT Smelting
Mitsubishi Process

1999

Noranda
Converter

2000 -

Large Smelters

2008

BBS

Teniente
Converter
Consolidation
Copper Electrorefining

From Conventional Method To Permanent Cathode

Table 6 – Productivity comparison between stainless steel and starter sheet facilities

<table>
<thead>
<tr>
<th>Average Productive Value</th>
<th>Cu Starter Sheet</th>
<th>Permanent Cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man-hours per tonne of cathode</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>Cathode current density (A/m²)</td>
<td>278</td>
<td>312</td>
</tr>
<tr>
<td>kWh per tonne of cathode</td>
<td>337</td>
<td>329</td>
</tr>
<tr>
<td>Current efficiency (%)</td>
<td>95.5</td>
<td>96.6</td>
</tr>
</tbody>
</table>

Ref.: M. Moats et al, “Global Survey of Copper Electrorefining Operations and Practices”. Cu 2013, Santiago, Chile
Benefits of the Permanent Cathode Technology

- Reusable cathode sheet
- Lower in-process copper inventory
- Better cathode quality associated with the straightness and verticality of the stainless steel cathode
- Better current efficiency (97% Vs 96%)
- Increased productivity
  (Current Density above 310 A/m²)
- Allows increased automation
- Lower energy consumption
  (330 Vs 340 kWh/t Cu)

*Note: Data are industry averages, some numbers rounded*
Smelting Response to Energy Challenge

Specific Energy Reduction of 35-40% for 2014 compared to 1976

Table V. Comparison between energy consumption for copper production (concentrate to anode) for the reverberatory furnace and for selected modern copper smelting technologies

<table>
<thead>
<tr>
<th>Processing route</th>
<th>Electric energy*</th>
<th>Fossil fuel*</th>
<th>Total*</th>
</tr>
</thead>
<tbody>
<tr>
<td>KH-hot calcine reverberatory</td>
<td>2173</td>
<td>15,935</td>
<td>18,108</td>
</tr>
<tr>
<td>Flash smelting–flash converting–slag flotation</td>
<td>9266</td>
<td>1518</td>
<td>10,784</td>
</tr>
<tr>
<td>Isasmelt–Peirce–Smith converting-rotary slag cleaning</td>
<td>6903</td>
<td>4175</td>
<td>11,078</td>
</tr>
<tr>
<td>Mitsubishi Process (Mitsubishi Materials Corporation, Tokyo, Japan)</td>
<td>8508</td>
<td>4175</td>
<td>11,063</td>
</tr>
<tr>
<td>Noranda–Teniente with dry feed + slag flotation</td>
<td>10,088</td>
<td>2687</td>
<td>12,775</td>
</tr>
<tr>
<td>Noranda reactor (filter cake) + PSCs + slag flotation</td>
<td>8946</td>
<td>4127</td>
<td>13,072</td>
</tr>
<tr>
<td>Bottom blowing smelting (filter cake) + PSCs + slag flotation</td>
<td>9263</td>
<td>2370</td>
<td>11,634</td>
</tr>
</tbody>
</table>

*All energies are expressed in MJ/t of anode copper.


1970s technology 18,018 MJ/t Anode copper

Today technology 11,720 +/- 1,000MJ/t Anode copper
## Process Intensity - Smelting and Refining I

### Table: Technology Comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>Nominal inst smelting rate, t/hr</th>
<th>Annual Cu, t/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outotec Flash</td>
<td>173</td>
<td>400,000</td>
</tr>
<tr>
<td>ISASMELT™</td>
<td>164</td>
<td>380,000</td>
</tr>
<tr>
<td>Noranda</td>
<td>151</td>
<td>350,000</td>
</tr>
<tr>
<td>Mitsubishi</td>
<td>132</td>
<td>306,000</td>
</tr>
<tr>
<td>El Teniente</td>
<td>86</td>
<td>200,000</td>
</tr>
<tr>
<td>SKS*</td>
<td>86</td>
<td>200,000</td>
</tr>
<tr>
<td>Vanyukov</td>
<td>54</td>
<td>125,000</td>
</tr>
</tbody>
</table>

(*) Planned for 2016

Sulphur Fixation Response

The smelter stack of the 1970’s signaled prosperity at the time

“SO₂ fixation by country and world by year 1960 to 2010”
Modernization – Continuing to Occur

• Tighter Chilean Emission Standards (7 smelters, 13% of world capacity)
  • $SO_2$ and arsenic emission controls
  • Several projects under study: Increase $SO_2$ fixation and better capture of fugitive gas

• New Peruvian Standards for $SO_2$ emissions
  • “Of the 16 smelters operating in the United States in the late 1970s, 8 have closed permanently—most because the capital investment to meet regulations was unwarranted given current and anticipated market conditions”

• United States Environmental Protection Agency, 2010
  • “The rules issued by the US Environmental Protection Agency (EPA) require that $SO2$ from the smelter be reduced from 140 ppb (parts per billion) to 75 ppb (average over 1 hour).
Our business is now living in a new era where commercial and environmental regulations are playing an increasingly important role in affecting the long term sustainability of the business.
Challenges Faced by the Copper Industry

A more complex world since 1970’s when there were two key challenges identified:

1. Financing and managing capital projects
2. Addressing sustainability issues
3. Complying with regulatory & reporting requirements
4. Managing risk
5. Reduced R&D Budget
6. Recruiting and retaining a skilled workforce
7. Mining transactions and industry consolidation
8. Improving performance and operational effectiveness

These challenges are interconnected and require a holistic approach to address them effectively.
What can we expect tomorrow

1. Global growth this year may approach 3% and hold its own next year—accordingly, copper demand is expected to stabilize and show a weak upward trend (as occurred in the 1970s)

2. Location...Location...Location!
   - Additional smelting/refining capacity to meet demand via brownfield expansions in many cases;
   - Greenfield smelters in key places in Africa and Asia;
   - We will see a return to smelters close to the mine site in some cases;
   - Avoid transport of complex concentrates;
   - Smelters close to concentrators and sea (Altonorte);
   - Tend to see synergies between mine/concentrator/smelters (i.e. Kazzinc Cu (synergies between base metals), Mount Isa Mines (dust processing))
What can we expect tomorrow

3. Complexity of concentrates will exert additional pressure on current technologies - they were developed for a different feed scenarios;

4. Increasing environmental requirements will trigger need to continue modernizing smelters with the next natural steps being of replacing the converting technology with continuous units;

5. Increasing automation and process intensity in smelters and refineries;

6. Needs concerted effort in new development work by producers (as in 1970s) plus Universities/Institutes
### Example Synergies (for complex conc.): Kazzinc Cu ISASMELT™

<table>
<thead>
<tr>
<th>ISASMELT™ Furnace Parameters</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal target feed rate</td>
<td>40</td>
<td>dry t/h</td>
</tr>
<tr>
<td>Cu content in concentrate</td>
<td>25</td>
<td>%</td>
</tr>
<tr>
<td>((\text{As} + \text{Sb} + \text{Pb} + \text{Zn}))</td>
<td>8.2</td>
<td>%</td>
</tr>
<tr>
<td>Copper matte grade</td>
<td>55-60</td>
<td>%</td>
</tr>
<tr>
<td>SiO(_2):Fe in slag</td>
<td>0.83</td>
<td>--</td>
</tr>
<tr>
<td>Oxygen Enrichment</td>
<td>55</td>
<td>%</td>
</tr>
</tbody>
</table>
## Example of Synergies: Mount Isa Dust Leaching Plant

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant throughput</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment rate – dry solids</td>
<td>t/a</td>
<td>27,200</td>
</tr>
<tr>
<td>Availability</td>
<td>%</td>
<td>90</td>
</tr>
<tr>
<td>Instantaneous treatment rate</td>
<td>t/h (dry)</td>
<td>3.5</td>
</tr>
<tr>
<td>Smelter Dust Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>%</td>
<td>17.3</td>
</tr>
<tr>
<td>Co</td>
<td>%</td>
<td>0.097</td>
</tr>
<tr>
<td>As</td>
<td>%</td>
<td>6.70</td>
</tr>
<tr>
<td>Fe</td>
<td>%</td>
<td>20.49</td>
</tr>
<tr>
<td>S</td>
<td>%</td>
<td>10.27</td>
</tr>
<tr>
<td>Cu recovery thru cementation</td>
<td>%</td>
<td>&gt;99</td>
</tr>
</tbody>
</table>
How the Future Plant Shall Look Like

1. Large custom smelter (350-450ktpa of Cu), continuing most likely to be in China and India with a single smelting unit, and more dedicated smaller to medium size smelters to process complex concentrates.
2. Oxygen smelting technology like TSL ISASMELT™, Mitsubishi or Outotec Flash.
3. Converting: Continuous converting replacing Peirce-Smith Converters.
4. Full sulphur capture and potential for high sulphur streams processing
5. Refinery adjacent to smelter.
6. Requires over 120 MW power (smelter & refinery).
Acknowledgments

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