Anode Issues during Smelter Capacity Creep

19TH INTERNATIONAL CONFERENCE ON NON-FERROUS METALS 2015 BHUBANESWAR
Profitability of a smelter can be improved by

- Higher metal output
- Lower energy consumption
- Higher current efficiency

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Change</th>
<th>Earnings / year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production +10%</td>
<td>+ 60'000 tAl/year</td>
<td>+ 30.0 Mio $</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>- 0.5 MWh/tAl</td>
<td>+ 6.0 Mio $</td>
</tr>
<tr>
<td>Current efficiency</td>
<td>+ 1 %</td>
<td>+ 7.8 Mio $</td>
</tr>
</tbody>
</table>

Example

- Smelter: 600'000 tAl/year
- Production cost: 1’500 $/tAl
- LME: 2’000 $/tAl
- Energy: 20 $/MWh
- Al₂O₃: 350 $/t
Impact of Increased Line Current

Higher metal output through increased line current

<table>
<thead>
<tr>
<th>Line current</th>
<th>kA</th>
<th>300</th>
<th>360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pot voltage</td>
<td>V</td>
<td>4.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>kWh/kgAl</td>
<td>12.9</td>
<td>14.5</td>
</tr>
</tbody>
</table>

- Increased line current by constant cell ohmic resistance leads to higher cell voltage and increased energy consumption
- Increasing the line current rises the heat input
- By unchanged cell ohmic resistance and insulation, the thermal equilibrium is disturbed
Maintain Thermal Equilibrium

The thermal equilibrium by line current creep can be maintained through:

- **Decreasing cell voltage**
  - Lower bath resistance by squeezed anode-cathode distance
  - Higher bath electrical conductivity (chemistry)
  - Cathode design and materials improvement
  - Longer and slotted anodes

- **Higher heat losses**
  - Collector bars design and materials
  - SiC sidewall block
  - Anode cover bath material
  - Higher metal level
  - Anode stub design
  - Cell tub design
Magnetic Stability

- A high noise factor is an indication for thermal-electrical and magneto-hydrodynamic instability
- Risk of «shorting» between anode and metal
- Increasing ACD damps waves at the metal-bath interface (noise)
Improve Magnetic Stability

The magnetic stability of the cells can be improved by:

- Thermal-electrical (TE) and magneto-hydrodynamic (MHD) optimization
- Precise anode setting
- Shaped cathode surface
- Improved cathodic current distribution
- Optimized busbar design
- BETTER ANODE QUALITY
Influence of Anode Quality on Cell Performance by Line Current Creep

Thermal-electrical and magneto-hydrodynamic computation

• Parameters

- Line current 360 kA to 410 kA
- Anode properties

<table>
<thead>
<tr>
<th>Anode parameters</th>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific electrical resistance</td>
<td>μΩm</td>
<td>46 - 60</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/mK</td>
<td>3 - 5</td>
</tr>
<tr>
<td>Baked apparent density</td>
<td>kg/dm³</td>
<td>1.50 – 1.64</td>
</tr>
<tr>
<td>Butt cross section</td>
<td>%</td>
<td>60 - 100</td>
</tr>
</tbody>
</table>

• Goal

Quantification of the impact of anode properties on thermal and magnetic cell stability by line current creep
**Anode Specific Electric Resistance SER and Thermal Conductivity TC**

Calculated noise factor by increased line current

- **Anodes with high standard deviation of SER and TC**
- **Anodes with low standard deviation of SER and TC**

- Cell instability (noise) increases over-proportionally by line current creep
- Anodes with high standard deviation of SER and TC lead to higher noise by increased line current
Anode Apparent Density Variations

Anode density variations

Anodes with different densities (weight) in the same cell disturb current distribution up to 25%
Anode Reactivity and Permeability

Influence of butt section on anode current.

Anodes with poor CO₂-, AIR-reactivity and permeability lead to reduced butt size and formation of carbon dust

• Reduced butt size disturbs the anode current distribution up to 40%
Carbon Dust in the Bath

Excessive carbon dust in the bath leads to:

- A significant increase of the ohmic bath resistance, which causes a squeezed anode-cathode distance (ACD)
- The formation of anode spikes
- Higher bath temperature and lower current efficiency
- Disturbed magnetic and thermal stability

Vicious circle!
Influence of Anode Quality on Cell Performance by Line Current Creep

Results

- Anode properties influence significantly the magnetic and thermal cell stability
- Anodes with high quality variations deteriorate the cell stability dramatically
- Cells with high current density are more sensitive to anode quality variations

High current density cells require better and more consistent anodes (BENCHMARK anode quality)
**BENCHMARK Anode Quality for High Current Density Cells**

<table>
<thead>
<tr>
<th>BENCHMARK anode properties</th>
<th>Unit</th>
<th>Mean</th>
<th>Max 2 STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baked apparent density</td>
<td>kg/dm³</td>
<td>min. 1.58</td>
<td>0.015</td>
</tr>
<tr>
<td>Specific electrical resistance</td>
<td>µΩm</td>
<td>max. 54</td>
<td>3</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/mK</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>Air permeability</td>
<td>nPm</td>
<td>max. 0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Air reactivity residue</td>
<td>%</td>
<td>min. 85</td>
<td>4</td>
</tr>
<tr>
<td>Air reactivity dust</td>
<td>%</td>
<td>max. 3</td>
<td>2</td>
</tr>
<tr>
<td>CO₂ reactivity residue</td>
<td>%</td>
<td>min. 90</td>
<td>3</td>
</tr>
<tr>
<td>CO₂ reactivity dust</td>
<td>%</td>
<td>max. 2</td>
<td>2</td>
</tr>
</tbody>
</table>

- **BENCHMARK** anodes compared with *state of the art* anodes show **significantly better mean values** and **at least 50% lower standard deviations**

- **Important**: Routine representative anode quality control is mandatory
Raw Materials for BENCHMARK Anodes

- **Calcined petroleum coke**
  - High bulk density
  - Low specific electrical resistance
  - Excellent CO$_2$ and AIR reactivity
- **Coal tar pitch**
  - Constant physical properties
  - Low Na and Ca content
- **Butts**
  - Well cleaned, Na < 300 ppm
  - Coarse
  - No burnoffs

- **Important**: Routine quality control of all raw materials
Increased Line Current Require More and Better Anodes

Increasing production in existing paste plant and baking furnace leads to lower quality and higher variations
Paste Plant Requirements

Paste plant operation parameters

<table>
<thead>
<tr>
<th>Paste plant</th>
<th>Unit</th>
<th>Start-up</th>
<th>Actual</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line current</td>
<td>kA</td>
<td>300</td>
<td>360</td>
<td>410</td>
</tr>
<tr>
<td>Green paste production</td>
<td>t/year</td>
<td>315'000</td>
<td>375'000</td>
<td>420'000</td>
</tr>
<tr>
<td>Green anode weight</td>
<td>kg</td>
<td>915</td>
<td>1'030</td>
<td>1'120</td>
</tr>
<tr>
<td>Green mill throughput</td>
<td>t/h</td>
<td>2 x 28</td>
<td>2 x 33</td>
<td>2 x 36</td>
</tr>
<tr>
<td>Specific mixing energy</td>
<td>kWh/t</td>
<td>10</td>
<td>8.5</td>
<td>7.8</td>
</tr>
</tbody>
</table>

Bottlenecks by higher throughput
- Coke blending facility
- Ball mill production capacity
- Preheating of dry aggregate
- Insufficient specific mixing energy
- Paste cooler capacity
- Vibroformer availability and process control
- Green anode cooling capacity

Estimated cost 20 to 30 Mio $

Downtime 2 to 3 months
Baking Furnace Productivity and Quality

- Anode handling and flue design
Baking Furnace
Anode Arrangement in Pit

- Anode arrangement in pit

Long anodes must be placed horizontally
Baking Furnace
Production and Quality

• Baking furnace operation parameters

<table>
<thead>
<tr>
<th>Baking Furnace</th>
<th>Unit</th>
<th>Start-up</th>
<th>Actual</th>
<th>Future 6 fires</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line current</td>
<td>kA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baked anodes requirement</td>
<td>t/year</td>
<td>280'000</td>
<td>335'000</td>
<td>380'000</td>
</tr>
<tr>
<td>Production per fire and year</td>
<td>t</td>
<td>46'700</td>
<td>55'800</td>
<td>63'300</td>
</tr>
<tr>
<td>Tons per section</td>
<td>t</td>
<td>167</td>
<td>188</td>
<td>180</td>
</tr>
<tr>
<td>Fire cycle time</td>
<td>h</td>
<td>31.4</td>
<td>29.5</td>
<td>24.9</td>
</tr>
<tr>
<td>Total heat up time</td>
<td>h</td>
<td>188</td>
<td>177</td>
<td>149</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Solution</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Future + 1 fire</td>
<td></td>
</tr>
<tr>
<td>410</td>
<td></td>
</tr>
<tr>
<td>380'000</td>
<td>54'300</td>
</tr>
<tr>
<td>180</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td></td>
</tr>
</tbody>
</table>

With the existing 6 fire furnace, the production of 380’000 t/year of BENCHMARK quality anodes is impossible

• Reasons
  - Top row anodes exceed pit height
  - Total heat up time 149 hours does not allow a homogeneous anode heat treatment
  - Increased waste gas volume of 38 % doubles the pressure drop in the flues
  - Higher pressure drop in the flues leads to a lack of oxygen in the fire zone (soot)
Baking Furnace
Production increase

Investments for in house baking of 380’000 t/year of BENCHMARK anodes

• Addition of one fire (54’300 t/year)
• Increase flue height in existing 6 fire furnaces
• Adaption of handling system to horizontal anode setting for 7 fires
• Expansion of waste gas cleaning installation
• Update of anode cleaning and slotting facilities
• Improved process and quality control

Estimated cost 50 to 70 Mio $

Prior to a substantial line current creep, the availability of BENCHMARK anodes must be guaranteed.
Merchant BENCHMARK Anodes

Investment of 70 to 100 Mio $ in paste plant and baking furnace can be avoided by purchasing merchant BENCHMARK anodes

To be considered

- **Availability** Long term contracts with optimum lot sizes
- **Price** Raw material or LME related
- **Quality**
  - BENCHMARK anode specification
  - Determination by third party laboratory before shipping
  - Defined actions for anode lots out of specifications
Aminco Anodes

A Merchant Anode supplier in partnership with R&D Carbon since 1997

More than 2.0 million tons of anodes delivered to smelters around the world

Highest anode quality – through limitation of variability is Aminco’s competitive advantage
Merchant BENCHMARK Anodes

Impact of merchant anodes on in house production

**Paste plant**
Decreased throughput and higher mixing energy allows production of green anodes with the required values and consistency without further investment.

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Without</th>
<th>With</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line current</td>
<td>kA</td>
<td>410</td>
<td>410</td>
</tr>
<tr>
<td>Green paste production</td>
<td>t/year</td>
<td>420'000</td>
<td>357'000</td>
</tr>
<tr>
<td>Green mill throughput</td>
<td>t/h</td>
<td>2 x 36</td>
<td>2 x 31</td>
</tr>
<tr>
<td>Specific mixing energy</td>
<td>kWh/t</td>
<td>7.8</td>
<td>9.1</td>
</tr>
</tbody>
</table>

**Baking furnace**
A heat up time of 174 h and horizontal loading of the anodes allows the production of BENCHMARK anodes in the existing 6 fires baking furnace with refurbishment cost below 10 Mio $.

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>In house production</th>
<th>Merchant anodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baked anodes requirement</td>
<td>t/year</td>
<td>325'000</td>
<td>55'000</td>
</tr>
<tr>
<td>Production per fire and year</td>
<td>t</td>
<td>54'200</td>
<td></td>
</tr>
<tr>
<td>Fire cycle time</td>
<td>h</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Total heat up time</td>
<td>h</td>
<td>174</td>
<td></td>
</tr>
</tbody>
</table>
Summary

• Variable anode properties influences the cell stability by
  - Non uniform anode current distribution
  - Disturbed cell thermal equilibrium
  - Carbon dust in the bath

• TE and MHD computations have shown an over-proportional influence of anode quality variations on cell stability by increased current density.

• Smelter improving their profitability by line current creep need more and better anodes

• Entire in house production of more and better anodes require substantial investments in paste plant and baking furnaces.

• Purchase of merchant anodes allows the production of BENCHMARK anodes in the existing carbon plant without further investments
Your partners for total carbon solutions