Bayer Process Alumina Production -
Alcan Bayer Experimental Centre

By: Guy Forté, Collaborator: Régis Girard
Alcan International Ltd., Bauxite & Alumina, Arvida R&D Centre, Jonquière, QC
Outline

> The Making of Aluminium
> The Bayer Process
  – Bauxite
  – Alumina
  – Bayer Process Flowsheet and Chemistry
> The Alumina Industry Challenges
  – Alumina Technology Roadmap
> Alcan Bayer Experimental Centre
  – Historical Background
  – Environment, Health and Safety (EH&S)
  – Tested Technologies and Applications in the Alumina Industry
> Conclusions
The Making of Aluminium

MAIN ELEMENTS FOUND IN EARTH'S CRUST (%)

- 47% Oxygen
- 8% Aluminum
- 2.6% Potassium
- 2.1% Magnesium
- 2.8% Sodium
- 3.6% Calcium
- 5% Iron
- 28% Silicon

Titanium, Manganese, Nickel, Copper, Zinc, Lead
The Making of Aluminium

Bayer  Hall-Héroult  Casting/Rolling

> Alcan production capacity in Canada:
  – 1.7 million tons aluminium and 1.3 million tons alumina

> Alcan world production capacity:
  – 3.2 million tons aluminium and 6.4 million tons alumina
The Making of Alumina
The Bayer Process

> Inventor:
  - Karl Josef Bayer, an Austrian chemist (1847-1904)

> Patented in 1888

> What it is:
  - A caustic pressure hydrometallurgical process which extracts aluminium species from bauxite ore and produces alumina, an aluminium oxide (Al₂O₃), via an intermediate product called hydrate, which is an aluminium oxide tri-hydrate (Al₂O₃·3H₂O)
Bayer Refineries

Gove, Australia

Vaudreuil, Jonquières, Québec
> **World production:**

- 130 million tons/year
  from which 70 % in Australia, Guinea, Brazil and Jamaica
### Bauxite: Typical Composition

<table>
<thead>
<tr>
<th>Components</th>
<th>Wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>(as metallic oxide</td>
<td>(as metallic oxide</td>
</tr>
<tr>
<td>if not indicated</td>
<td>if not indicated</td>
</tr>
<tr>
<td>otherwise)</td>
<td>otherwise)</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>30-60</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>1-30</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>&lt;0.5-10</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>&lt;0.5-10</td>
</tr>
<tr>
<td>Organic Carbon (as C)</td>
<td>0.02-0.40</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.02-1.0</td>
</tr>
<tr>
<td>CaO</td>
<td>0.1-2</td>
</tr>
<tr>
<td>V$_2$O$_5$</td>
<td>0.01-0.10</td>
</tr>
<tr>
<td>ZnO</td>
<td>0.002-0.10</td>
</tr>
<tr>
<td>Ga$_2$O$_3$</td>
<td>0.004-0.013</td>
</tr>
<tr>
<td>Cr$_2$O$_3$</td>
<td>0.003-0.30</td>
</tr>
<tr>
<td>S</td>
<td>0.02-0.10</td>
</tr>
<tr>
<td>F</td>
<td>0.01-0.10</td>
</tr>
<tr>
<td>Hg (ppb)</td>
<td>50-1000</td>
</tr>
</tbody>
</table>
Bauxite: Typical Composition
-Majors

- Al₂O₃ (boehmitic) < 0.2 - 20 %
- SiO₂ (as quartz) 0.2 - 10 %
- Fe₂O₃ 1.0 - 30 %
- Al₂O₃ (gibbsitic) 30 - 60 %
- TiO₂ 0.3 - 10 %
- SiO₂ (as clay) 0.3 - 6 %
## Bauxite: Typical Minerals

<table>
<thead>
<tr>
<th>Major Elements</th>
<th>Mineral</th>
<th>Formula</th>
<th>Caustic Soluble at °C (operating kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>Gibbsite</td>
<td>Al(OH)_3 or Al_2O_3.3H_2O</td>
<td>150 (800)</td>
</tr>
<tr>
<td></td>
<td>Boehmite</td>
<td>AIOOH or Al_2O_3.H_2O</td>
<td>250 (5500)</td>
</tr>
<tr>
<td></td>
<td>Diaspore</td>
<td>AIOOH or Al_2O_3.H_2O</td>
<td>&gt; 260 (&gt;6000)</td>
</tr>
<tr>
<td>Silicon</td>
<td>Quartz</td>
<td>SiO_2</td>
<td>250 (5500)</td>
</tr>
<tr>
<td></td>
<td>Kaolinite</td>
<td>Al_2Si_2O_5(OH)_4 or</td>
<td>150 (800)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Al_2O_3.2SiO_2.2H_2O</td>
<td>i</td>
</tr>
<tr>
<td>Iron</td>
<td>Hematite</td>
<td>Fe_2O_3</td>
<td>i</td>
</tr>
<tr>
<td></td>
<td>Goethite</td>
<td>FeOOH or Fe_2O_3.H_2O</td>
<td>i</td>
</tr>
<tr>
<td>Titanium</td>
<td>Anatase</td>
<td>TiO_2</td>
<td>250 (5500)</td>
</tr>
<tr>
<td></td>
<td>Rutile</td>
<td>TiO_2</td>
<td>i</td>
</tr>
</tbody>
</table>

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Bauxite: Typical Composition

- **Diaspore**  
  \(\text{Al}_2\text{O}_3\cdot\text{H}_2\text{O}\)
- **Boehmite**  
  \(\text{Al}_2\text{O}_3\cdot\text{H}_2\text{O}\)
- **Gibbsite**  
  \(\text{Al}_2\text{O}_3\cdot3\text{H}_2\text{O}\)
- **Hematite**  
  \(\text{Fe}_2\text{O}_3\)
- **Aluminian Goethite**  
  \((\text{Fe,Al})_2\text{O}_3\cdot\text{H}_2\text{O}\)
- **Anatase**  
  \(\text{TiO}_2\)
- **Rutile**  
  \(\text{TiO}_2\)
- **Kaolinite, Halloysite**  
  \(\text{Al}_2\text{O}_3\cdot2\text{SiO}_2\cdot2\text{H}_2\text{O}\)
- **Quartz**  
  \(\text{SiO}_2\)
- **Phosphate (Crandallite, Apatite)**  
  \(\text{CaAl}_2(\text{PO}_4)_2(\text{OH})_6\text{H}_2\text{O}\)
  \(3\text{Ca}_3(\text{PO}_4)_2\text{Ca(F,Cl,OH)}_2\)
- **Calcium (Calcite)**  
  \(\text{CaCO}_3\)
- **Organic Carbon**  
  Humic materials
- **Vanadium**  
  \(\text{V}_2\text{O}_5\)
- **Chromium**  
  \(\text{Cr}_2\text{O}_3\)
- **Arsenic**  
  \(\text{As}_2\text{O}_5\)
- **Zinc**  
  \(\text{ZnO}\)
- **Fluorine**  
  \(\text{F}\)
- **Sulphur**  
  \(\text{S}\)
- **Mercury**  
  \(\text{Hg}\)
- **Manganese (Lithiophorite)**  
  \((\text{Li,Al})\text{MnO}_2(\text{OH})_2\)

* May be present in significant concentrations in Jamaican bauxite

**Legend:**
- **Major**
- **Minor or Trace**
Alumina

> A commodity product

> The raw material of the Hall-Heroult electrolysis process to produce aluminium

> Also a speciality chemical:
  – spark plugs
  – fire retardant
  – synthetic marble
  – catalyst
  – tooth paste
  – alun, aluminium fluoride
  – ceramic
  – refractory
## Alumina Typical Composition

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Wt.% (as metallic oxide)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al$_2$O$_3$ (by diff.)</td>
<td>99.3-99.7</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>0.30-0.50</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>0.005-0.025</td>
</tr>
<tr>
<td>CaO</td>
<td>&lt;0.005-0.040</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>0.005-0.020</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.001-0.008</td>
</tr>
<tr>
<td>ZnO</td>
<td>&lt;0.001-0.010</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>&lt;0.0001-0.0015</td>
</tr>
<tr>
<td>Ga$_2$O$_3$</td>
<td>&lt;0.005-0.015</td>
</tr>
<tr>
<td>V$_2$O$_5$</td>
<td>&lt;0.001-0.003</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>&lt; 0.05-0.20</td>
</tr>
</tbody>
</table>
The Bayer Process

- Bauxite Grinding
- Predesilication
- Digestion
- Heat Exchanger
- Decantation Filtration
- Precipitation
- Classification Clarification
- Residue Treatment
- Alumina
- Calcination
- Steam
- Caustic
- Flocculant
- Wash Water
The Bayer Process

Bauxite Handling and Grinding

Digestion

Extraction

Precipitation

Hydrate Precipitation & Classification

S/L Separation

Residue Settlers and Washers

Autoclaves

Heat Exchangers

Live Steam

Alumina Calciners

Residue Disposal
The Bayer Chemistry

> In Digestion:

- \( \text{Al}_2\text{O}_3\cdot3\text{H}_2\text{O} \ \text{sol} + 2\text{NaOH} \ \text{aq} \rightarrow 2 \ \text{NaAlO}_2 \ \text{aq} + 4\text{H}_2\text{O} \)
- \( \text{Al}_2\text{O}_3\cdot\text{H}_2\text{O} \ \text{sol} + 2\text{NaOH} \ \text{aq} \rightarrow 2 \ \text{NaAlO}_2 \ \text{aq} + 2\text{H}_2\text{O} \)
- a) \( 3(\text{Al}_2\text{O}_3\cdot2\text{SiO}_2\cdot2\text{H}_2\text{O}) \ \text{sol} + 18 \ \text{NaOH} \ \text{aq} \rightarrow 6\text{Na}_2\text{SiO}_3 \ \text{aq} + 6\text{NaAlO}_2 \ \text{aq} + 15\text{H}_2\text{O} \)
- b) + \text{Na}_2\text{CO}_3 \ \text{aq} \rightarrow \ 3(\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot2\text{SiO}_2\cdot2\text{H}_2\text{O})\text{Na}_2\text{CO}_3 \ \text{sol} + 12 \ \text{NaOH} \ \text{aq} + 3 \ \text{H}_2\text{O} \)

> In Precipitation:
- \( 2 \ \text{NaAlO}_2 \ \text{aq} + 4\text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3\cdot3\text{H}_2\text{O} \ \text{sol} + 2\text{NaOH} \ \text{aq} \)

> In Calcination:
- \( \text{Al}_2\text{O}_3\cdot3\text{H}_2\text{O} \ \text{sol} \rightarrow \text{Al}_2\text{O}_3 \ \text{sol} + 3\text{H}_2\text{O} \ \text{vap} \)
Alumina Technology Roadmap

> Initiators:
  - The Aluminium Association
  - The U.S. Department of Energy, Office of Industrial Technologies
  - Australian Mineral Industries Research Association (AMIRA)
  - Australian Department of Industry, Science and Resources

> Contributors:
  - Alcan Inc
  - Alcoa World Alumina
  - Aluminium Pechiney
  - Comalco Aluminium Limited
  - CSIRO Minerals
  - Eurallumina S.p.A.
  - Hydro Aluminium Metal Products
  - Hindalco Industries Limited
  - Kaiser Aluminium
  - Nabalco Pty Ltd.
  - Queensland Alumina Ltd.
  - The AJ Parker Research Centre
  - Worsley Alumina Pty Ltd.
Alumina Industry Goals 2001-2020

> Reduce operating costs of existing refineries by 3 % per year

> Reduce total energy consumption by 25 % from current best practice

> Target new plants capital costs at < US $500/annual ton with IRR > 18 %

> Target major expansion capital costs at < US $250/annual ton

> Contribute to reduce impact on environment, health and safety

> Contribute to global sustainable development

> Produce a commodity product that meets customer’s current and future needs.
Specific Goals

> Increase refineries productivity, yield by 20 %
> Reduce caustic consumption by 50 % to 30 kg/ton Al₂O₃
> Reduce process variability to < 5 %
> Reduce effects of scaling and blockages
> Improve calcination and cogeneration
> Develop combustion and power generation from waste heat sources
> Reduce or recycle inputs and outputs including water, odours, VOCs, mercury, oxalates, organics, impurities, etc.
> Develop ecological, sustainable storage of residue and/or reuse
R&D Opportunities

> Accelerate precipitation rates
> Residue: cost effective inerting and alternative uses
> Conversion of monohydrate to a more beneficial state
> Direct reduction of bauxite or other aluminium materials
> Full automation/improved control strategies
> Impurity removal from bauxite (beneficiation)
> Impurity removal from Bayer liquor
> Knowledge management and best practices
> Reduction in caustic consumption
> Scale management
> Technical solutions for refinery releases
> Waste heat recovery
Precipitators

- Tanks of 4000 to 6000 m³
- Slow kinetic with 48 hours of residence time

- **Phenomena:**
  - nucleation
  - agglomeration
  - growth
  - attrition
R&D Opportunities

> Accelerate precipitation rates

> Residue: cost effective inerting and alternative uses

> Conversion of monohydrate to a more beneficial state

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> Impurity removal from Bayer liquor

> Knowledge management and best practices

> Reduction in caustic consumption

> Scale management

> Technical solutions for refinery releases

> Waste heat recovery
Residue Stacking/Reuse
R&D Opportunities

- Accelerate precipitation rates
- Residue: cost effective inerting and alternative uses
- Conversion of monohydrate to a more beneficial state
- Direct reduction of bauxite or other aluminium materials
- Full automation/improved control strategies
- Impurity removal from bauxite (beneficiation)
- Impurity removal from Bayer liquor
- Knowledge management and best practices
- Reduction in caustic consumption
- Scale management
- Technical solutions for refinery releases
- Waste heat recovery
Alcan Deep Thickeners

> More efficient washing, higher underflow solid content

> More compact:
  – Typically 10 m in diameter against 30 m for conventional thickeners
R&D Opportunities

> Accelerate precipitation rates
> Residue: cost effective inerting and alternative uses
> Conversion of monohydrate to a more beneficial state
> Direct reduction of bauxite or other aluminium materials
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> Impurity removal from Bayer liquor
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> Reduction in caustic consumption
> Scale management
> Technical solutions for refinery releases
> Waste heat recovery
Alcan Bayer Experimental Centre - BEC - Historical Background

> Located at the Alcan Arvida R&D Centre in Jonquière, QC, 58 years of tradition with a Bayer pilot plant

The Bayer Experimental Centre-BEC was built in 1990
– today, it is worth about $ 3.5 million CAD
– with working space of 370 m² on two floors

> Justifications:
– the need for a rugged experimental step between lab or bench scale tests and industrial applications.

> It is now an R&D tool for development of new technologies and successful scaling up and technology transfer
Arvida R&D Centre
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Bayer Experimental Centre - BEC

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BEC - Capacity and Equipment

> 150 L/h of solution, 20 kg/h of bauxite ore (scale 1:12,000)
> Batch or continuous operation around the clock
> Grinder (wet and dry)
> Tanks with mixers
> Preheaters (steam, electric)
> Digestion
  – LT autoclaves
  – HT autoclaves
  – HHT tube autoclave
  – Flash vessels
> S/L separation
  – atmospheric decanters
  – pressure decanters
  – filters (vacuum, pressure)
  – C-FLOC™, a dynamic settling analyser
BECS - Capacity and Equipment

- 150 L/h of solution, 20 kg/h of bauxite ore
- Batch or continuous operation around the clock
- Grinder (wet and dry)
- Tanks with mixers
- Preheaters (steam, electric)
- Digestion
  - LT autoclaves
  - HT autoclaves
  - HHT tube autoclave
  - Flash vessels
- S/L separation
  - Atmospheric decanters
  - Pressure decanters
  - Filters (vacuum, pressure)
  - C-FLOC™, a dynamic settling analyser
Low Temperature Autoclaves
High Temperature Autoclaves
BEC - Capacity and Equipment

> 150 L/h of solution, 20 kg/h of bauxite ore
> Batch or continuous operation around the clock
> Grinder (wet and dry)
> Tanks with mixers
> Preheaters (steam, electric)
> Digestion
  – LT autoclaves
  – HT autoclaves
  – HHT tube autoclave
  – Flash vessels
> S/L separation
  – atmospheric decanters
  – pressure decanters
  – filters (vacuum, pressure)
  – C-FLOC™, a dynamic settling analyser
Pressure Decanters
BEC - Capacity and Equipment

- 150 L/h of solution, 20 kg/h of bauxite ore
- Batch or continuous operation around the clock
- Grinder (wet and dry)
- Tanks with mixers
- Preheaters (steam, electric)
- Digestion
  - LT autoclaves
  - HT autoclaves
  - HHT tube autoclave
  - Flash vessels
- S/L separation
  - atmospheric decanters
  - pressure decanters
  - filters (vacuum, pressure)
  - C-FLOC™, a dynamic settling analyser
C-FLOC™- Settling Analyser
BEC - Equipment

> Precipitators

> Rotary calciner

> Positive displacement reciprocating metering pumps

> Flow-meters, density-meters

> Conductivity-meters, turbidity-meters

> Data acquisition system, fully integrated control system and supervisory control

> Programmable logic controller

> Services: laboratory, compressed air, water, low pressure steam, heating, ventilation, lifting equipment and drainage, control room.
Metering Pumps
BEC - Equipment

> Precipitators

> Rotary calciner

> Positive displacement reciprocating metering pumps

> flow-meters, density-meters

> conductivity-meters, turbidity-meters

> Data acquisition system, fully integrated control system and supervisory control

> Programmable logic controller

> Services: laboratory, compressed air, water, low pressure steam, heating, ventilation, lifting equipment and drainage, control room.
Control System Structure
Typical Control Page
BEC - Equipment

> Precipitators
> Rotary calciner
> Positive displacement reciprocating metering pumps
> flow-meters, density-meters
> conductivity-meters, turbidity-meters
> Data acquisition system, fully integrated control system and supervisory control
> Programmable logic controller

> **Services**: laboratory, compressed air, water, low pressure steam, heating, ventilation, lifting equipment and drainage, control room.
Control Room
BEC - EH&S

> Designed like a real plant

> Environment:
   – drainage pit, waste tank, no reject to the environment

> Health and safety:
   – ergonomical with various lifting and handling devices
   – showers with eye washers and PPE against the corrosive caustic solution
   – Monel alloy protecting against stress corrosion cracking or steel caustic embrittlement
   – Rupture disks, relief valves, pressure sensors for automatic shut-off, hydrostatic tests, audits against overpressure risks

> Documented risk assessment procedure, more than 100 assessments archived
BEC - EH&S

> Designed like a real plant

> Environment:
  – drainage pit, waste tank, no reject to the environment

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BEC - Industrial Applications

> **Patented Alcan Double Digestion Process to reduce energy consumption**

– This is a process by which gibbsite is extracted first at normal temperature, then the residue, containing boehmite, is digested again at lower than usual temperature to recover boehmite.

– Tested on two Jamaican bauxites for potential expansion of one former Alcan plant

– Tested on two Australian bauxites. Results are being used as design specifications for a brownfield expansion
BEC - Industrial Applications

Patented Alcan Pressure Decantation to reduce caustic consumption

- This is a decanter operating under pressure to separate residue from pregnant solution at the digestion conditions.

- Tested on two Jamaican muds. In one case, an industrial prototype was built in one former Alcan plant; in the second case, a full-scale industrial application is in operation in the United States of America. The plant performances are as predicted by the BEC tests.

- Tested also on two potential applications in Australia. In one case, again, the results are being used as design specifications for a brownfield expansion.
Industrial Pressure Decanters
Conclusions

> The alumina industry is facing significant challenges and the Alumina Technology Roadmap addresses the technology issues.

> To achieve significant technical improvements, Alcan has been running its R&D Centre in Québec for 58 years and the BEC was built 14 years ago as a development tool to increase the odds of successful scaling up and technology transfer.
Conclusions (cont.)

> The Alcan Bayer Experimental Centre has proven to be a reliable development tool to transfer key Alcan proprietary technologies. These technologies represent a partial answer to the roadmap as they reduce energy and caustic consumption in the Bayer refineries. It is also a tool that helps reducing investment costs as the equipment can be sized properly.

> The BEC also presents several challenges in EH&S and, at Alcan, EH&S is a journey of continuous improvement.
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