Aluminium production

Molten salt electrolysis
Aluminium (aluminum) production

Alumina production
Aluminium production
Environmental impact

Molten salt electrolysis process

Electrochemical processes non realizable in water environment - thermodynamics reason (Al), product reaction with solvent (Alkali and Alkaline earth metals) must be done in solvent (water) free environment e.g. molten salt electrolysis

Usually high temperatures (over 500°C) – high energy consumption

Functions of electricity - electrolysis
- heating (another additional heating possible)

Cheap electric power is one of most limiting factor to perform electrolysis in molten salts. (Norway, Canada, ...)

Aluminium

Formula Al

the most abundant metallic element in the earth’s crust (combined with other elements)
elemental aluminum particles have been discovered in lunar soil
metallic aluminum was first made by H. C. Oersted in Copenhagen in 1825
today second in production to iron and steel.

Properties:
low density,
form strong alloys (alloying with relatively small percentages of Cu, Mn, Si, Mg or Zn)
high thermal and electrical conductivity,
non-magnetic
highly ductile
Aluminum and its alloys can be cast, rolled, extruded, forged, drawn, and machined.
Aluminium world production

Aluminium production

breakthrough - 1886 when Charles Martin Hall in Ohio and Paul L. T. Heroult of Paris independently applied for patents for the electrolytic process in molten salt for manufacturing aluminum. Both electrolyzed alumina (aluminum oxide) dissolved in molten Greenland cryolite (sodium-aluminum fluoride Na$_3$AlF$_6$) at about 1000°C (1832°F). - Hall-Heroult process

Bauxite ore - 40-60% alumina, combined with silica (silicon oxide), iron oxide, and titanium dioxide - mined in many places worldwide

The Bayer process for alumina production

alumina is dissolved in hot NaOH solution and the iron oxide and other oxides are removed as insoluble "red mud."

Aluminum hydroxide is precipitated from the clarified solution by cooling and seeding with aluminum hydroxide crystals.

The washed precipitate is calcined at up to 1200°C to produce anhydrous alumina. The particle size of the alumina is about 100 µm

Hall-Heroult process

produced from primary materials by the electrolytic reduction of aluminium oxide (alumina) dissolved in a molten bath of mainly sodium aluminium fluoride (cryolite Na$_3$AlF$_6$) at a temperature of approximately 980 °C

Anode – carbon (two types) “prebaked” or “Sødeberg” (produced from petroleum coke and coal-tar)

Cathode – molten Al (99%)  Electrolyte – molten Cryolite is significant to form electrolyte with low melting point (Al$_2$O$_3$ corundum mp 2053°C)

Overall reaction

$\text{Al}_2\text{O}_3 + \frac{3}{2}\text{C} \rightarrow 2\text{Al} + \frac{3}{2}\text{CO}_2$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical Range (g/l)</th>
<th>Alumina</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauxite</td>
<td>100 – 2250</td>
<td></td>
</tr>
<tr>
<td>NaOH (C/N)</td>
<td>35 – 140</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>57 – 119</td>
<td>0.000</td>
</tr>
<tr>
<td>Water</td>
<td>1000 – 8000</td>
<td>0.00</td>
</tr>
<tr>
<td>Oxygen (O2)</td>
<td>0.0 – 11.2</td>
<td></td>
</tr>
</tbody>
</table>
Hall-Heroult process

Two types of anodes
- Sødeberg – is formed continuously (lower quality of Al)
- Prebaked – must be replaced (better process control)

Environmental impact

Aluminium production - extremely energy consuming
- Necessity of sideproduct purification

Maximum recycling of aluminium – most optimal way to minimize negative impact to environment
## Alternative processes investigated for aluminum production

<table>
<thead>
<tr>
<th>Process</th>
<th>Features</th>
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</thead>
<tbody>
<tr>
<td>Drained-Cell Technology</td>
<td>By eliminating the metal pad, the anode-cathode gap could be halved to ~25 mm, enabling substantial voltage lowering. Other basics would remain the same as present technology (E° ~ 1.2 volts, electrolysis = 6.34 kWh/kg).</td>
</tr>
<tr>
<td>Inert Anode Cells</td>
<td>Eliminate consumable carbon anode by having an electrode material that evolves oxygen. Although the electrochemical potential would increase by 1 V (E° ~ 2.2 volts), the voltage increase would be (hopefully) less because of lower anode polarization (electrolysis = 9.26 kWh/kg). The superstructure of the existing cell could be refined, reducing capital costs. If drained-cell materials development were successful, further design options are possible.</td>
</tr>
<tr>
<td>Chloride Process</td>
<td>Aluminous material converted to (anhydrous) AlCl₃ of adequate purity. AlCl₃ electrochemically decomposed in a multi-electrode cell at ~700°C (E° ~ 1.8 volts, electrolysis = 6.34 kWh/kg). Electrochemically generated chlorine is recycled.</td>
</tr>
<tr>
<td>Sulfide Process</td>
<td>Aluminous material converted to (anhydrous) Al₂S₃ of adequate purity. Aluminum sulfide electrochemically decomposed to recyclable S₂ and aluminum (E° ~ 1.0 V) in a multipolar cell (electrolysis = 5.24 kWh/kg).</td>
</tr>
<tr>
<td>Carbothermal Reduction</td>
<td>Convert aluminous material to an intermediate Al₄C₃ (or oxycarbide) chemically at T &gt; 1,700°C. React carbide with further oxide to evolve CO and produce aluminum (or alloy) at T &gt; 2,000°C. Refine the metal quality to a usable grade (minimum = 9.0 kWh/kg).</td>
</tr>
</tbody>
</table>

* Substantial retrofits using cryolite-alumina electrolytes.
† Processing using intermediates derived from alumina.