# Aluminium Production Technology

The Hall- Heroult process is an example of Aluminium smelting process and is used industrially. Aluminium cannot be produced by an aqueous electrolytic process because hydrogen is electrochemically much nobler than aluminium. Thus, liquid aluminium is produced by the electrolytic reduction of alumina ($Al_2 O_3$) dissolved in an electrolyte (bath) mainly containing Cryolite (Na_3AlF_6). The overall chemical reaction can be written as:

**2 Al_2O_3 (dissolved) +3C (s) =4 Al (l) +3 CO_2 (g)** $\longrightarrow$ **(1)**

Aluminium production
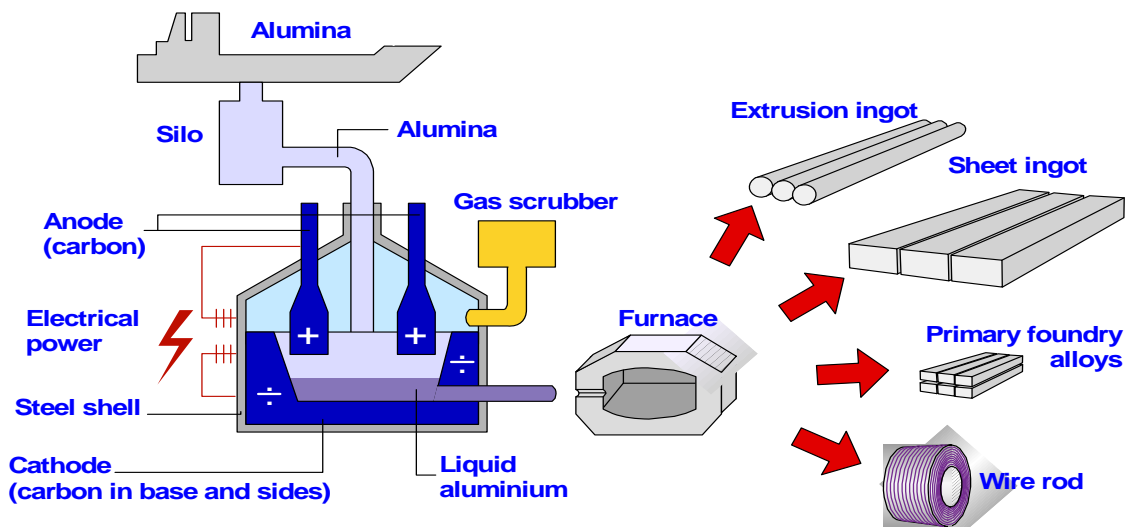
Aluminium is formed at about 900°C, but once formed has a melting point of only 660°C. In some smelters this spare heat is used to melt recycled metal, which is then blended with the new metal. Recycled metal requires only 5 percent of the energy required to make new metal. Blending recycled metal with new metal allows considerable energy savings, as well as the efficient use of the extra heat available. When it comes to quality, there is no difference between primary metal and recycled metal.

The smelting process required to produce aluminium from the alumina is continuous, the potline is usually kept in production for 24 hours a day year around. A smelter cannot be easily stopped and restarted. If production is interrupted by a power supply failure of more than four hours, the metal in the pots will solidify, often requiring an expensive rebuilding process.

There are two basic technology- **Prebaked Technology and Soderberg Technology.** In prebaked technology the anodes used are termed as prebaked anodes which are made from a mixture of petroleum coke, aggregate and coal tar pitch binder moulded into blocks and baked in separate anode baking furnace at about 1120 °C. An aluminium rod with iron studs is then cast or rammed into grooves in the top of the anode block in order to support the anode and conduct the electric current to the anode when it has been positioned in the cell.

Prebaked anodes have to be removed at regular intervals, when they have reacted down to one third or one fourth of their original size. These remaining anodes are termed as butts and are usually cleaned outside the cell in a separate cleaning station to be able to recirculate the adhering bath materials removed from the cell. The cleaned butts are then crushed and used as a raw material in the manufacturing of new anodes. A typical prebaked cell is shown below-
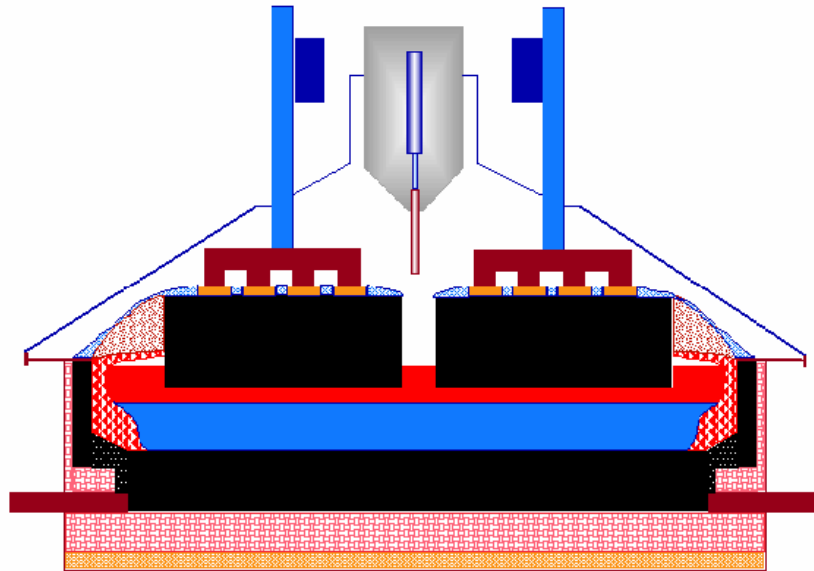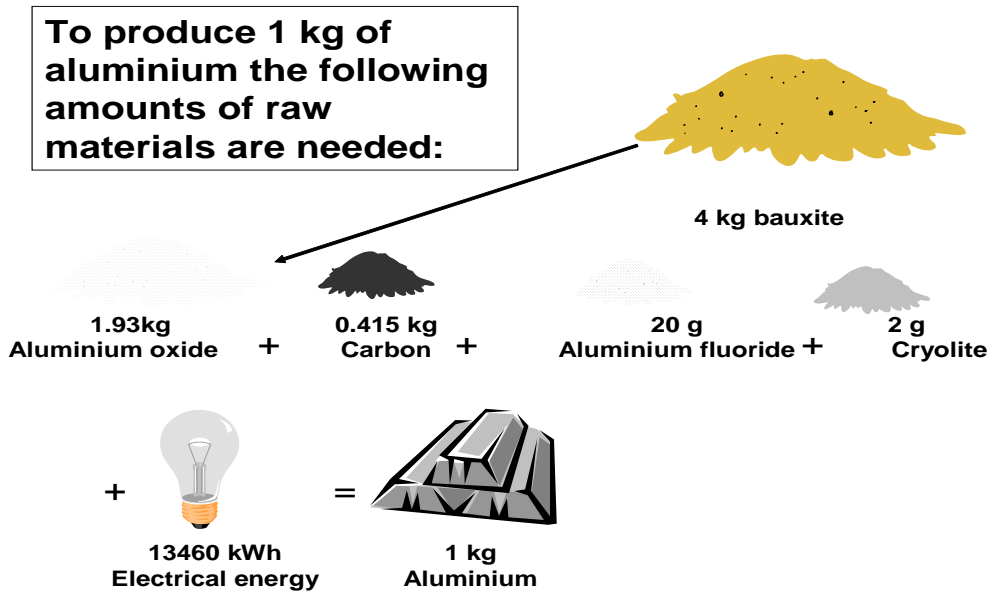

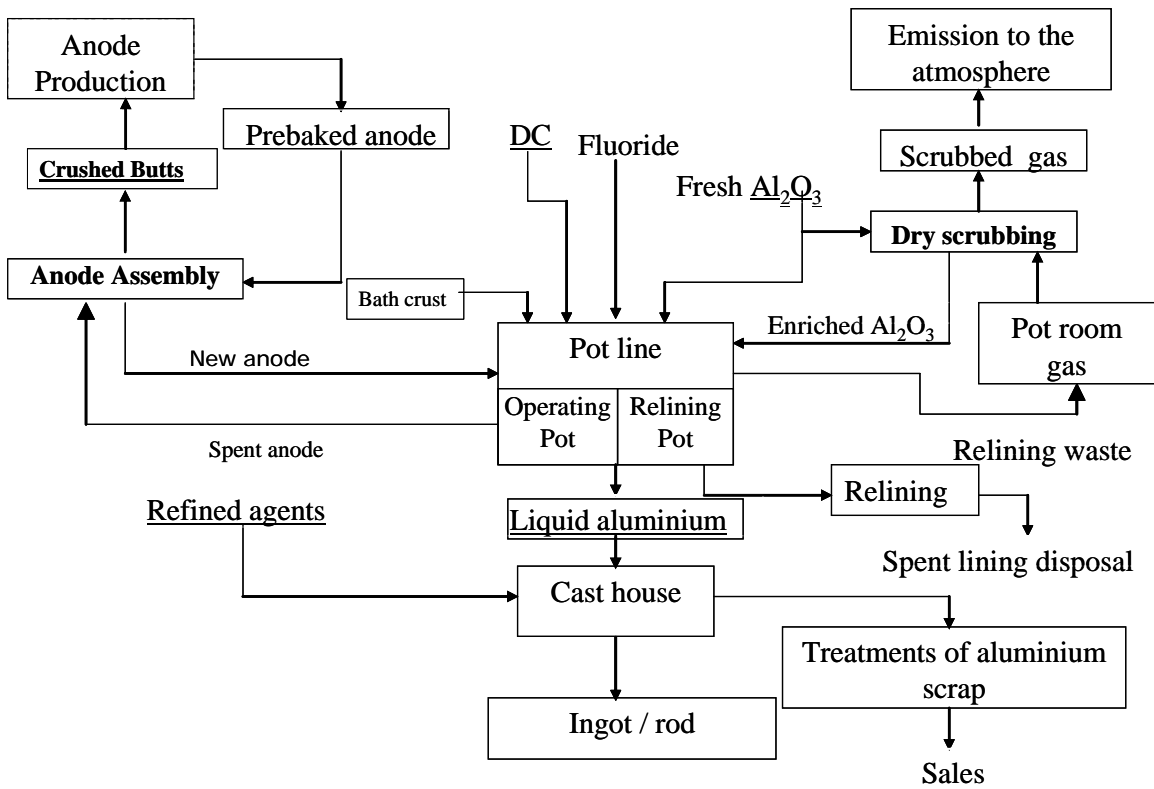## RAW MATERIAL FOR ALUMINIUM PRODUCTION

The major raw material required for aluminium production is alumina, carbon, power, aluminium fluoride and cryolite.

GAMI Specification

Raw Material	Alumina	Carbon	Cryolite	Aluminium Fluoride	Energy
Theoretical Consumption (Kg per Ton of Aluminium)	1930	415	2	20	13460 KWH/t-Al

To produce 1 kg of aluminium the following amounts of raw materials are needed:

4 kg bauxite

1.93kg
Aluminium oxide + 0.415 kg
Carbon + 20 g
Aluminium fluoride + 2 g
Cryolite

+ 13460 kWh
Electrical energy = 1 kg
Aluminium

Process of Aluminium Reduction

Description of Raw Materials used in Aluminium Production

I Alumina- Bauxite is the most important aluminous ore for the production of alumina. Bauxite occurs close to the surface in seams varying from one meter to nine meters, formed as small reddish pebbles (pisolites). Bauxite contains 40 to 60 mass% alumina combined with smaller amounts of silica, titania and iron oxide. Alumina is mainly extracted from bauxite using **Bayer Process.**

The Bayer process dissolves the aluminium component of bauxite ore in sodium hydroxide (caustic soda); removes impurities from the solution; and precipitates alumina tri hydrate, which is then calcined to aluminium oxide. A Bayer Process plant is principally a device for heating and cooling a large re circulating stream of caustic soda solution. Bauxite is added at the high temperature point, red mud is separated at an intermediate temperature, and alumina is precipitated at the low temperature point in the cycle. Alumina (aluminium oxide Al_2O_3) obtained is a fine white material similar in appearance to salt. Alumina is also used in abrasive, ceramics and refectory industries.

$$2NaOH + Al_2O_3.xH_2O = 2NaAlO_2 + (x+1)H_2O \longrightarrow \qquad (2)$$
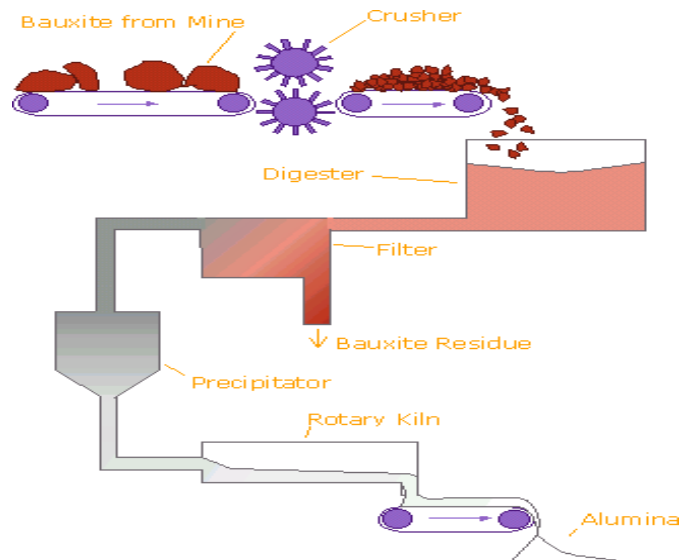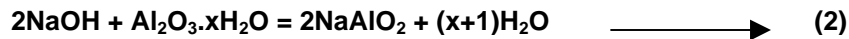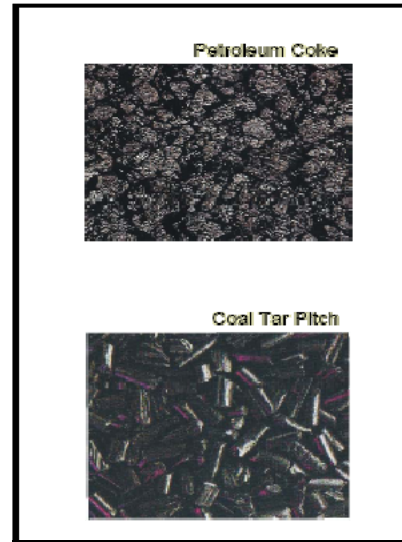
II Anodes

In the electrolytic production of aluminum the consumption of carbon is second only to the consumption of alumina in quantity. 415 KG of carbon is used for each MT of metal production.

Carbon quality is of great interest to the Potroom not only because it is an expensive operating supply but because of the effect poor quality can have on the on the pot operation

Anodes are made of carbon containing as few impurities as possible. Calcined petroleum coke and pitch as a binder are used for raw materials.

Filler, coke + butts, 0.1 – 16 mm

Binder matrix, pitch + dust
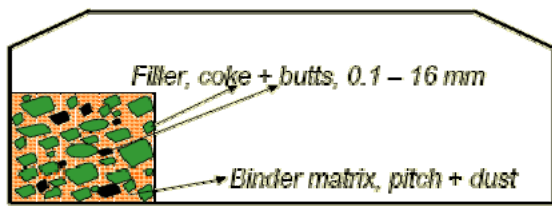
Material	Typical	Range
Coke	65%	50-85%
Butts	20%	0-32%
Pitch	15%	13-17%

Petroleum Coke

Coal Tar Pitch

1) Coke

- Coke is a by- product of petroleum refining, other gaseous and liquid products are optimized at the expanse of the coke.
- >50% of world's production from USA.
- Total requirement of aluminium industry is 8-11 million tonnes.
- Trend is towards increasing sulfur and other impurities content in coke

2) Pitch

- Pitches are used as a binder agent.
- Pitches are a complex mixture of aromatic and heterocyclic organic compounds, which carbonize on heat treatment.
- Coal tar pitches are used most commonly, due to its sustainability as a binder and economics

Function of pitch as a binder

- Good wetting of coke grains & mixing properties   *Paste Mixing*

- Gradual release of volatiles during anode baking
- High coking value

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- Strong bonding between coke & carbonized pitch   *Baking*
- Good mechanical properties of carbonized pitch

- Low ash and sulfur
- Low reactivity   *Electrolysis*
- High electrical conductivity
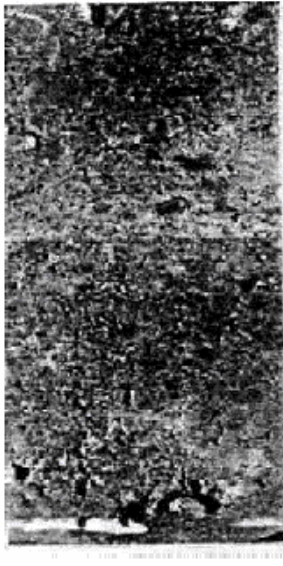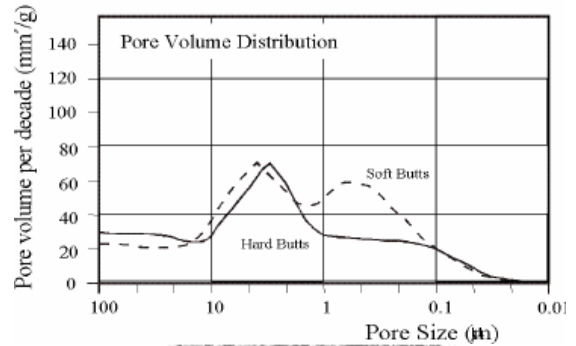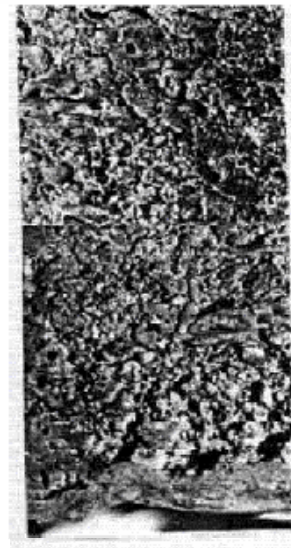
3) Butts

- Recycled anodes cleaned of adherent bath can be up to 35% (more typically 20%) of the new anode.
- In coarse fraction of recipe
- Hard butts – much like coke
- Soft butts – more porous, usually have experienced air or Carboxy burn, have negative impact on anode quality

1. **Aggregate**

   Calcined petroleum coke is received as a mixture of coke particles ranging from fine dust to pieces 2-3 cm in diameter.

   This coke is screened and sorted into 3-4 different sizes. The over size is passed through a impact crusher, screened again and classified into grain sizes.

   Measured quantities of each grain size are now drawn off to enter the dry mix. Quantities are taken from a recipe designed to give a dense mix voids between the coarse particles have to be filled with medium size particles and voids between these to be filled by small size particles, etc. An average recipe for dry mix is given below:-

Grain Size	Quantity
Coarse	30%
Medium	20%
fine	50%

2. Mixing

Pitch is added to the dry mix and every thing is well blended in a mixer at 160-180 degree centigrade. At this temperature the pitch becomes liquid and will coat the coke particles. The quantity of pitch added should just achieve that. If not enough pitch is added ' dry pockets' will result , too much pitch will give various problems during the next stages of anode making resulting in an inferior finished anode.

The exact quantity needed is related to be dry mix recipe. Smaller particles have a larger surface area to be coated with pitch hence more pitch is needed for the same weight of coke. Average quantities are 16-20% pitch.
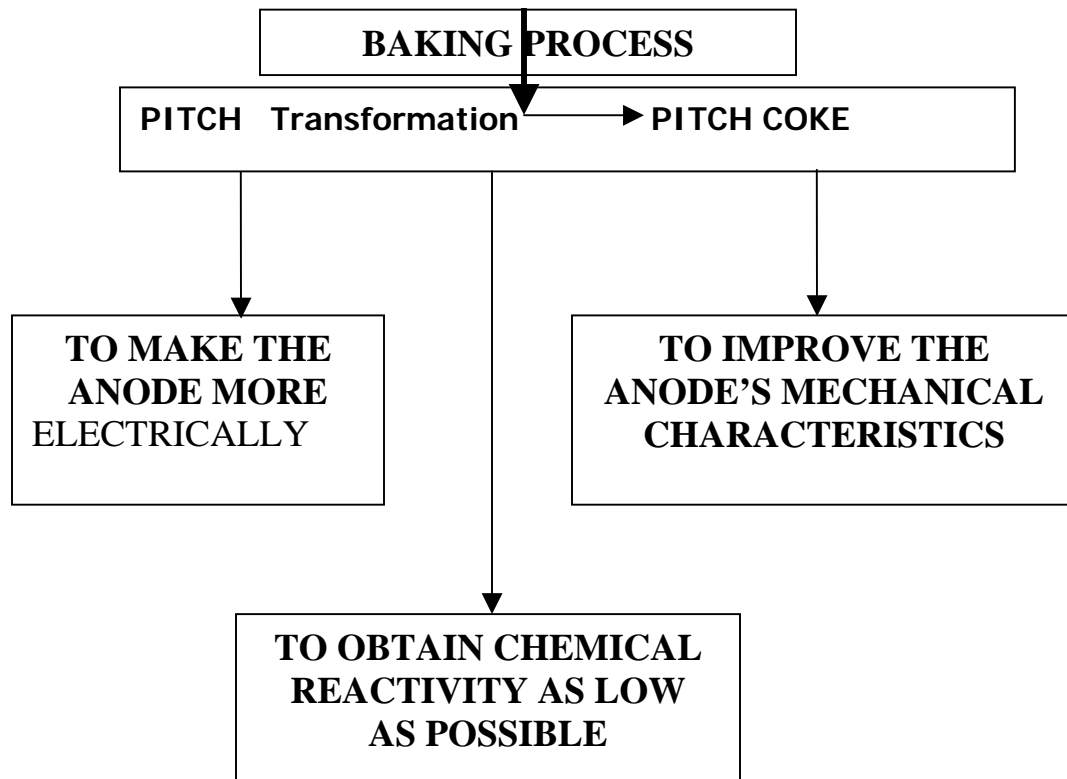
3. Block Forming

The hot green paste coming out of the mixer has to be cooled to about 110-120 degree Celsius before it is fed into the block press. This is so that the finished blocks retain their shape. By block forming processes the bulk density of the product mix is usually raised from $1.0 – 1.1$ g.cm^{-3} to $1.55 – 1.65$ g.cm$^{-3.}$

Inside the press blocks are formed either by pressure alone or by vibration and / or pressure. The green blocks are cooled further and put in the temporary storage until they are put into the furnace for baking.

4. Baking

In the furnace the green anodes are slowly heated up to the range of $1100 – 1120$ ^{0}C and slowly cooled down again. The total heating cycle may last $16 – 28$ day. The objective of green anode baking is to transform its binder pitch into pitch coke so as to produce baked anodes with the following characteristics:

- Sufficient mechanical strength to withstand the handling forces and thermal shock.

- High electrical conductivity for lower voltage drop and energy losses.

- Low chemical reactivity against the attack of carbon dioxide and ambient air.

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                    ┌─────────────────────────────┐
                    │      BAKING PROCESS         │
                    └──────────────┬──────────────┘
          ┌─────────────────────────▼──────────────────────────┐
          │  PITCH   Transformation ──►  PITCH COKE             │
          └────────┬──────────────────┬───────────────┬────────┘
                   │                  │               │
                   ▼                  │               ▼
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| TO MAKE THE ANODE MORE ELECTRICALLY | | TO IMPROVE THE ANODE'S MECHANICAL CHARACTERISTICS |

TO OBTAIN CHEMICAL REACTIVITY AS LOW AS POSSIBLE

To separate out the specific volatiles by the controlled temperature application is called Baking. It require to bake the green anodes above the 1000ºC because the operating temperature of electrolysis cell is around the 1000ºC. The under heating may cause to less strength and hardness, higher electrical resistively and chemical unbalance. The uniform baking up to high enough temperatures gives low carbon consumption per ton of metal produced. The baked anode is sent to rodding to produce rodded anode from where it is sent to potroom to be used in pots.

5. Anode Quality

To a certain extent we can judge the quality of baked anode by its physical appearance. It should have a light grey colour and show no deformation or cracks. Further it should give a ringing sound when stuck by a hammer while being suspended.

To gain further information on quality of anode, laboratory tests have to be made. This starts with examining the raw materials.

The petroleum coke used must be sufficiently calcined. This is tested by checking the electrical specific resistively. Another method of checking the degree of calcination is to determine the remaining H_2 content of the coke. Impurities must of course be at a minimum. A total amount of ash may be 20% of which iron and silicon compounds make up the bulk.

A good pitch will yield a good amount of graphitised carbon or coke when baked, this is called cocking value. If it is low not enough links will be established between the original coke grains. A too high value will produce such a dense "pitch coke" that the escaping pitch vapours will expand the anode during baking.

Another important property of pitch is its wetting power, i.e. how well the liquid pitch wets the coke particles. Wetting power is measured in terms of viscosity.

III Cryolite - Cryolite is the main constituent of the electrolyte used in alumina electrolysis. Chemically it is Na_3AlF_6, a double fluoride of sodium and aluminium. It is a white granular powder. Certain impurities may give it a grey or pink discoloration. The freezing point of cryolite is 1009°C.

Synthetic Cryolite is made from fluorspar (CaF_2), which is found as a natural mineral. Fluorspar is treated with sulphuric acid to produce hydrofluoric acid HF.

$CaF_2 + H_2SO_4 = 2HF (g) + CaSO_4 (s)$ ⟶   **(3)**
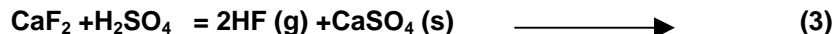
HF is then reacted with sodium oxide Na_2O and alumina to produce cryolite.

Cryolite ratio= Molar Ratio of NaF
                   Molar Ratio of Alf$_3$

CRYSTALINE CRYOLITE

IV Bath- The bath used in aluminium reduction has a number of unique properties, which make it the only suitable material for the purposes. The requirement of bath is as follows-
- Being molten at a high temperature, which can be reached without too much difficulty in reduction cells.
- Have a density low enough that it floats on top of aluminium metal in the cell to prevent the aluminium from oxidation.
- Used as a solvent for alumina.
- Ionize and conduct electricity so that current can flow.
- Have a low volatility such that losses are not excessive.

Bath ratio = Mass ratio of NaF
                  Mass ratio of Alf$_3$

V Aluminum Fluoride – Aluminum fluoride is added as an additive to the cryolite electrolyte used in the electrolysis. Its chemical formula is AlF_3. This chemical compound does not occur in nature. It is made from fluorspar in a similar process to cryolite. It is marked as a white powder but it may show shades of colour as a result of impurities.

Excess AlF$_3$%= Mass %AlF$_3$

Mass % Na₃AlF₆

VI Calcium Fluoride- Calcium Fluoride (CaF_2) is always present in the electrolyte because it occurs as calcium oxide impurity in the alumina feed. It reacts with aluminum fluoride dissolved in the electrolyte to form calcium fluoride. Eventually, it reaches steady state concentration of 3-7 mass%. CaF_2 in the electrolyte varies due to the type of alumina added. This concentration is stable because the rate of addition of CaO is balanced by the rate of the loss of calcium into the aluminum produced in the anode gases.

VII Sodium Carbonate or Soda Ash- Soda ash is used as an additive to the electrolyte in alumina electrolysis. It is used as a source of aluminum and is much cheaper alternative to sodium fluoride. The chemical formula is Na_2CO_3. It is a white granular material. When soda ash is added to the electrolyte, large quantities of gas will be produced as carbon dioxide. Great care has therefore to be taken during addition.

VIII Lithium Fluoride- It is superior to all other additives with respect to the physico- chemical properties of the electrolyte. It is added in the form of lithium carbonate (Li2Co3), which reacts with aluminium fluoride dissolved in the electrolyte to form dissolved lithium fluoride. Its consumption varies 2-3 Kgs of Li_2CO_3 per ton of aluminium to maintain a concentration of 1.5 – 3.0 mass% LiF.

IX Magnesium Fluoride-Magnesium Fluoride (MgF_2) is present in the electrolyte of some aluminium smelters, sometimes in connection with the use of lithium containing melts. The actual addition is made in the form of MgO or $MgCO_3$. Its consumption is 1kgs of MgO per ton of aluminium to maintain a concentration of 2.0– 4.0 mass% MgF.

X Power-Aluminium is a power intensive industry. The electrolysis process used to produce aluminium requires large quantities of electrical power. When the cost of producing one tonne of primary aluminium is broken down almost one third is devoted to electrical power. The DC power required depends on the total number of cells or pots installed & the potline DC current. For meeting this huge power requirement most aluminium smelters are equipped with their own Captive Power Plants. Balco Plant II is also powered by its own captive power plant CPP-II with a capacity of 540MW

Aluminium Reduction

A modern aluminum reduction cell, commonly called a pot, is made of a rectangular steel shell, (At Balco-**15.780**m long by **4.180** m wide by **1.372m** high), lined with refractory thermal insulation. Inside the shell there is an inner lining of SiC to contain the highly corrosive molten fluoride electrolyte (or bath, as it is commonly called) and liquid aluminum. Electric current enters the cell through 40 prebaked carbon anodes. A crust of frozen bath and alumina covers the molten bath. Alumina in the Cell is fed through point feeders. Thermal insulation is designed to provide sufficient heat loss to maintain a protective ledge of frozen electrolyte on the walls of cells, but not on the bottom under the anodes.
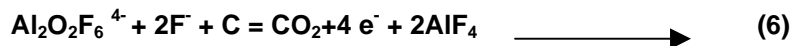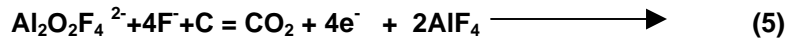
The ledge serves to stabilize the temperature of the bath by freezing to a greater thickness when heat generation is low and thinning when heat generation increases.

The anode-to-molten aluminium spacing, anode-cathode distance, ranges from 4.5-5 cm. Steel current-collector bars, joined into the carbon lining, carry the electric current from the cell. Aluminium is electro - chemically deposited from dissolved alumina into the molten aluminium pool. Oxygen of the dissolved alumina is discharged onto and consumes the cell's carbon anodes.
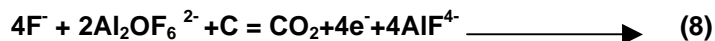
All pots are connected in series. Molten cryolite (Na_3ALF_6), having a high solubility for aluminium oxide, is the major component of the Hall-Heroult electrolyte or bath. Low operating temperatures improve efficiencies; hence, the liquidus temperature (where freezing starts) is lowered by various additives from 1011°C (for pure cryolite) to 930 - 960°C. Alumina, aluminum fluoride and calcium fluoride are the most common additives. Calcium enters the electrolyte as calcium oxide impurity present in the alumina and

reacts with aluminum fluoride to attain a steady state concentration of 4 to 6% CaF_2 from which it is co-deposited into the aluminum and lost at a rate equal to its introduction.
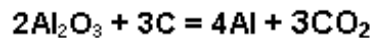
Anode Reactions- During the electrolysis reaction gaseous CO_2 evolved. The carbon is provided by the anode material, the oxygen is transported to the anode in the form of AL-O-F complex anions. At high alumina concentrations the species $Al_2O_2F_4^{2-}$ and $Al_2O_2F_6^{4-}$ may be discharged as suggested by the reactions-

$$Al_2O_2F_4{}^{2-}+4F^-+C = CO_2 + 4e^- + 2AlF_4 \longrightarrow \qquad (5)$$

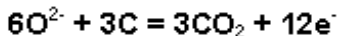$$Al_2O_2F_6{}^{4-} + 2F^- + C = CO_2+4e^- + 2AlF_4 \longrightarrow \qquad (6)$$

These reactions explain why the electrolyte becomes enriched in AlF3 or actually AlF^{4-} close to the anode during electrolysis. At low alumina concentrations, where the Al2OFx (4-x) species may dominate, the reactions may be written as-

$$2Al_2OF_8{}^{4-} + C = CO_2+4e^-+4AlF^{4-} \longrightarrow \qquad (7)$$

$$4F^- + 2Al_2OF_6{}^{2-} +C = CO_2+4e^-+4AlF^{4-} \longrightarrow \qquad (8)$$
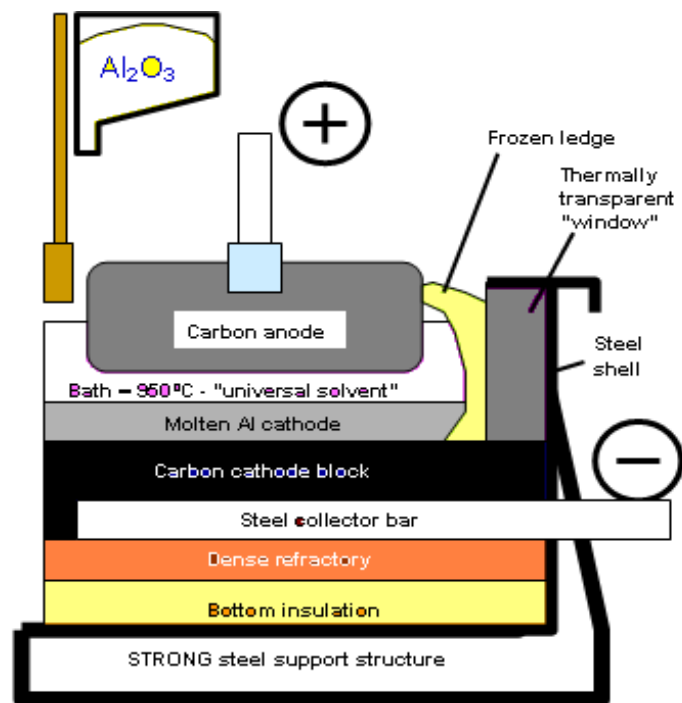
It has been suggested that the occurrence of the anode effect during electrolysis may be related to the nature of the Al-O-F complexes. Thus the anode effect could be caused by the depletion of the $Al_2O_2F_x^{(2-x)}$ ions in the melt at low alumina concentration. This would imply that the reactions (7) and (8) are kinematically slow compared to the reactions (5) and (6).

$$2Al_2O_3 + 3C = 4Al + 3CO_2$$

Anode:
$$6O^{2-} + 3C = 3CO_2 + 12e^-$$

Cathode:
$$4Al^{3+} + 12e^- = 4Al$$

Al₂O₃

(+)

Frozen ledge

Thermally transparent "window"

Carbon anode

Steel shell

Bath – 950°C - "universal solvent"

Molten Al cathode

Carbon cathode block

(–)

Steel collector bar

Dense refractory

Bottom insulation

STRONG steel support structure

Cathode Reactions - The only cation present in cryolite-alumina melts is Na+. Despite Na+ being the main current carrier, it has been showed that formation of aluminium is favored over sodium in the electrolyte compositions used industrially, since the reversible EMF is favorable. That is aluminium is the

thermodynamically preferred product. As there is no evidence that Al^{3+} ions are present, all of the aluminium in the melt is bound in different anionic complexes. Al-O-F takes part in the anode reactions so the most probable cathode reactions involve the remaining aluminium – containing ions AlF_6^{3-} and AlF_4^-. The overall reaction can be written as

$$AlF_6^{3-} + 3\ e^- = Al+6F^- \longrightarrow \quad \textbf{(9)}$$

$$AlF_4^- +3e^- =Al+4F^- \longrightarrow \quad \textbf{(10)}$$
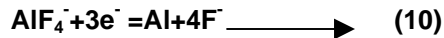
Reaction (9) may be less favored because of the stronger electrostatic repulsion of AlF_6^{3-} ions from the cathode. In any case, these reactions explain why the electrolyte close to the cathode contains a high concentration of F-ions.

Breakdown of Voltage Requirement- To drive current through a reduction cell a certain amount of voltage is required. The total amount required can be broken down into its single elements.

All bus-bar necessary to lead the current in and out of the cell plus the anode and the cell lining present a resistance to the current. To overcome this external resistance a certain amount of voltage is required. It depends on the type of material used for building a cell, its design and the quality of workmanship during erection. On an existing cell it is an almost rigid value.

Current going through an electrolyte has to accomplish two things. This requires a voltage related to the distance to be covered by the ions and the amount of current that is supposed to flow. Voltage related to this bath resistance will produce heat or energy according to the following formula-

$E= I*V*time$

A second of voltage is required to cause the electro- chemical to take place. This voltage can be considered the **reaction or decomposition voltage**. It is the voltage required to cause the aluminium making reaction to occur.

$2Al_2O_3+3C+Energy= 4Al+3CO_2$

Simply this is a conversion of electrical energy to chemical energy but it does not obey Ohm's Law, as ohm's law applies to resistance current flow rather than energy conversation reactions. This voltage is independent of the amperage.

Theoretically 1.2 volts is required to cause aluminium reduction to occur. Measurements have shown that this voltage is 0.5 Volts higher than the theoretical. This extra voltage is referred to as the over voltage or polarization potential. This simply means that we need extra voltage to push some part of the reaction fast enough to make it up with the rest. The over voltage is somewhat variable and is affected by the current density at which we operate the cell and the alumina concentration in the bath. For practical purposes 1.7 V is the average reaction voltage.

The total voltage needed to operate an aluminium reduction cell is therefore-
$V_{total}= (R_{external}*I)+(R_{bath}*I)+V_{electrochemical}$
$V_{total}= V_{external} + V_{bath} + V_{electrochemical}$

Current Efficiency- The amount of metal produced per unit time depends primarily on average current going through the cell during that time. In every technical electrolytic process there are losses, which mean that the output will be less than the theoretical amount given by faraday's law. To account for those losses or to measure the electrochemical efficiency, the concept of current efficiency is introduced to know how well the reduction process is conducted. The amount of aluminium actually produced as compared to the theoretical amount calculated as a percentage is called current efficiency. The current

efficiency is mainly influenced by backward reaction, bath chemistry, bath temperature, cell design, operational practices, etc.

Current Efficiency = **Actual Production**
Theoretical Production

Three electrons have to be supplied to one aluminium ion for it to be discharge at the cathode.

$Al_3+ +3e^- = Al$
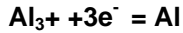
The amount of aluminum deposited therefore depends upon the number of electrons supplied to the cathode, i.e. the size of the electric current passing through the cell.

One mole of a substance contains $6.023*10^{23}$ atoms or molecules. Thus one mole or 26.98 g of Al^{3+} ions will contain $3*6.023*10^{23}$ positive charges or $18.069*10^{23}$ electrons have to be supplied to produce 26.98 g of aluminium metal.

One electron is equipped with a charge of $1.602*10^{-19}$ Amp-sec.
Hence $18.069*10^{23}*1.062*10^{-19}$ Amp.sec is the total charge needed to produce 26.98 g of aluminium or $2.895*10^5$ Amp.sec

Electric current is defined as charges passing per unit time. If these 26.98 g of metal were to be produced in 60 seconds, a current of-
  $I = 2.895*10^5/60$
  I= 4825 Amp would have to flow for that time.

One ampere would therefore produce in one hour
= 26.98*60/4825
**= .3355 g of Aluminium per hour per KA**

In More understandable terms, 1000 Ka flowing for 24 hours should produce 8.053 kg of aluminium.

If we are able to recover theoretical amount of Aluminium deposited at cathode, we would have a current efficiency of 100%. But because of insufficiencies in the process the current efficiency is always lower than 100%, in fact the best current efficiency which can be obtained are 93-97%.

The factors affecting current efficiency are-

    i)   Back reaction- Some aluminium is dissolved back into the bath and reacts with the anode products, producing alumina. The extent of this reaction depends on the relative cathode area, the temperature of the bath and the composition of the bath .The back reaction can be reduced by:

          •   Reducing metal solubility
          •   Increasing the electrolyte viscosity
          •   Increasing inter electrode distance
          •   Reducing metal/electrolyte velocity
          •   Reducing electrolyte density
          •   Reducing metal diffusivity in the electrolyte
          •   Reducing metal/electrolyte interfacial area

    ii)   Co-deposition of more noble impurities from raw materials- Some elements other than aluminium are deposited at the cathode. The current which was used in their deposition was not available to make aluminium. Iron and silicon tend to stay in the liquid metal wile

sodium goes into the bath where it may be re-oxidized, ionized again and discharged at the cathode, This sodium cycle is more likely to occur at higher operating temperatures.

iii) Shorting- Any current which doe s not flow through the bath will not produce metal. A kicking voltmeter shows this shorting is taking place thereby resulting in reduction in current efficiency.
iv) Electronic Conduction
v) Leakage currents.
vi) Vaporization and oxidation etc.
vii) Absorption and reaction with container materials.
viii) Physical losses.
ix) Anode effects.
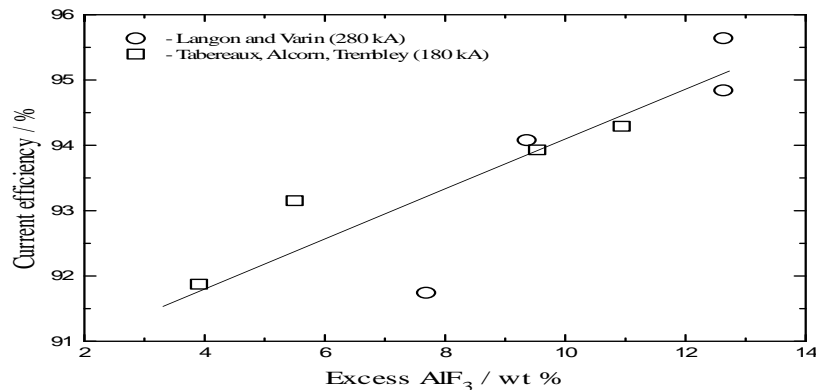
Current Efficiency increasing with increase in AIF3% in the electrolyte

Energy Consumption – energy is the product of voltage, current and time and it is energy that has to be paid for, not current. It is therefore desirable to operate at a high current efficiency and consume as little voltage as possible at the same time.

Pot voltage is linked via the bath resistance to the anode – cathode distance. A low pot voltage calls, therefore for a small anode – cathode distance, which in turn will result in more reoxidation and a lower current efficiency.

DC Energy Consumption= Gross Voltage (in V)
$\qquad$ CE%* Kg of Al prod./hr*KA

Carbon Consumption-The amount of carbon used electrolytic ally increases as the current efficiency decreases. Changes in carbon consumption due to this reason are however normally quite small. Anode quality, operating temperature of the pot and quality of alumina covering of anodes are much more important contributing factors.

As an anode stays in a pot its surface temperature will gradually increase. It will rise to the point where the anodes start slowly burning. The anodes are covered with anode covering material (Mixture of 40% alumina & 60% Crushed bath) to prevent oxidation of anodes.

Too high operating temperature of the pot may result in extreme cases in a much reduced crust formation. Such a pot would not hold sufficient alumina on its crust for protecting the anode and again air burn would result. Anode quality problems may increase anode consumption through dusting and preferential oxidation of the binder material.

$2 Al_2O_3$ (dissolved) $+3C$ (s) $=4 Al$ (l) $+3 CO_2$ (g)

108 gm of Al is produced from 36 gm of carbon
Therefore, 1 gm of Al is produced from =36/108 gm carbon
=0.333 gm carbon

2 Al$_2$O$_3$ (dissolved) +6C (s) =4 Al (l) +3 CO (g)

108 gm of Al is produced from 72 gm of carbon
Therefore, 1 gm of Al is produced from =72/108 gm carbon
=0.666 gm carbon

In actual practice during cell reaction 75%CO2 and 25 % CO is produced
Theoretically carbon required to produced 1 ton of Al = (0.333*.75)+(.666*.25)
=. 415 mt/mt of Al

Density
Resistivity
Strength
Permeability to oxidants
Specific reactive surface
Purity, catalyst content
Homogeneity towards CO$_2$/air

Anode quality

Anode temperature profile
Current efficiency
Electrolyte composition
Ore/bath covering
Anode setting routines
Crust breaking patterns
Anode gas outlets

Operation related

Anode consumption

Anode dimension and geometry
Contact resistance rod to carbon
Current distribution
Applied drought for fume cleaning
Anode covering
**Anode mantling**

Design related

Alumina Consumption- The amount of alumina used for the electrolysis is dependent on the amount on the metal produced. An increase can only be caused by handling losses up to the point where the alumina enters the bath. Theoretical alumina consumption in 1.88 kg Al_2O_3/kg Al.
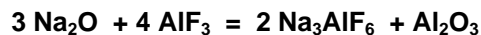
2 Al_2O_3 (dissolved) +3C (s) =4 Al (l) +3 CO_2 (g)

108 gm of Al is produced from 204 gm of Alumina
Therefore, 1 gm of Al is produced from =204/108 gm Alumina
$$=1.89 \text{ gm Alumina}$$

13Cryolite consumption- Cryolite has to be added to the pot to maintain the required liquid bath level. Losses occur mainly through metal tapping, anode changing, volatilization and absorption into the pot lining. Some of the bath material is reclaimed in the form of tapping ladle cleaning from the butt cleaning operation. However, a certain proportion of the losses are too difficult or too costly to recover.

Aluminum Fluoride Consumption- Aluminum Fluoride is lost through volatilization. Losses increase with temperature and with its own concentration in the bath. Alumina contains Na_2O as impurity. Soda dissolves and dissociates in the electrolyte to form sodium oxide:

Na_2CO_3 (s) = Na_2O (dissolved) + CO2 (g)
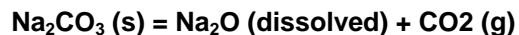
Sodium oxide then reacts chemically with aluminium fluoride in the bath and neutralises it:

3 Na_2O + 4 AlF_3 = 2 Na_3AlF_6 + Al_2O_3

Total reaction:

3 Na_2CO_3 + 4 AlF_3 = Al_2O_3 + 2 Na_3AlF_6 + 3 CO_2 (g)
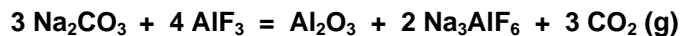
Weight ratio of Na_2CO_3/AlF_3= $(3x10^6)/(4x84)$ = 0.95
Thus, 1.0 kg of soda neutralises 1.0 kg of aluminium fluoride.

The sodium in this compound will constantly change the NaF/AlF3 ratio of a pot towards a larger value. To offset the effect of this impurity AlF3 is added continuously in small quantities to the cell. The lining in the pot absorbs sodium in large quantities. This absorption diminishes as the pot ages. By absorbing sodium in preference to other bath components the NaF/AlF3 ratio is shifted towards smaller numbers. A new pot therefore needs almost no addition of alF3 as sodium is absorbed in quantity into the lining. As aging increases, AlF3 will have to be added in increasing quantities. Pot age, Na2O impurity level in the alumina, NaF/AlF3 ratio target and actual operating temperature will determine the amount of raw materials consumed. About 45 kg of AlF3 is required for per ton of aluminum production