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THE NEED FOR EFFECTIVE RISK MITIGATION IN ALUMINIUM PLANTS

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The need for effective risk mitigation in Aluminium plants

Aluminium, the world's second most preferred metal after iron has a unique combination of qualities. It is lightweight; (approximately one-third the weight of steel for the same volume), has excellent corrosion resistance, and it is non-magnetic with high thermal and electrical conductivity. It is relatively soft but picks up considerable strength when alloyed with suitable metals. These distinctive qualities of Aluminium mean it is used widely in the manufacturing of a number of industrial and consumer products from packaging of food & beverages to building of aircraft, since the beginning of its commercial production around 150 years ago.

The metal is also abundantly available, around 8% of the Earth's crust has Aluminium signature mainly in oxide form. Global consumption of Aluminium is around 5 million metric tons per year and China alone produces almost half of this requirement. It is estimated that the demand for Aluminium will rise by 4% per year for the next five years.

The extraction of Aluminium is very power intensive. Aluminium producers have taken advantage of lower energy prices in the Middle East. As a result, Aluminium production has become one of the key economic drivers after Oil & Gas in this region. Today, the Middle East accounts for around 10% of the world's Aluminium production.

Raw material extraction process

Aluminium is produced in many forms according to various end use requirements including ingots, slabs, billets, sheets, foil, wire, rod, tube, powder etc. However, as a raw material it exists as a group of hydrated Aluminium oxides, Al $(OH)_3$ called bauxite (Aluminium ore) which is the main source for Aluminium production.

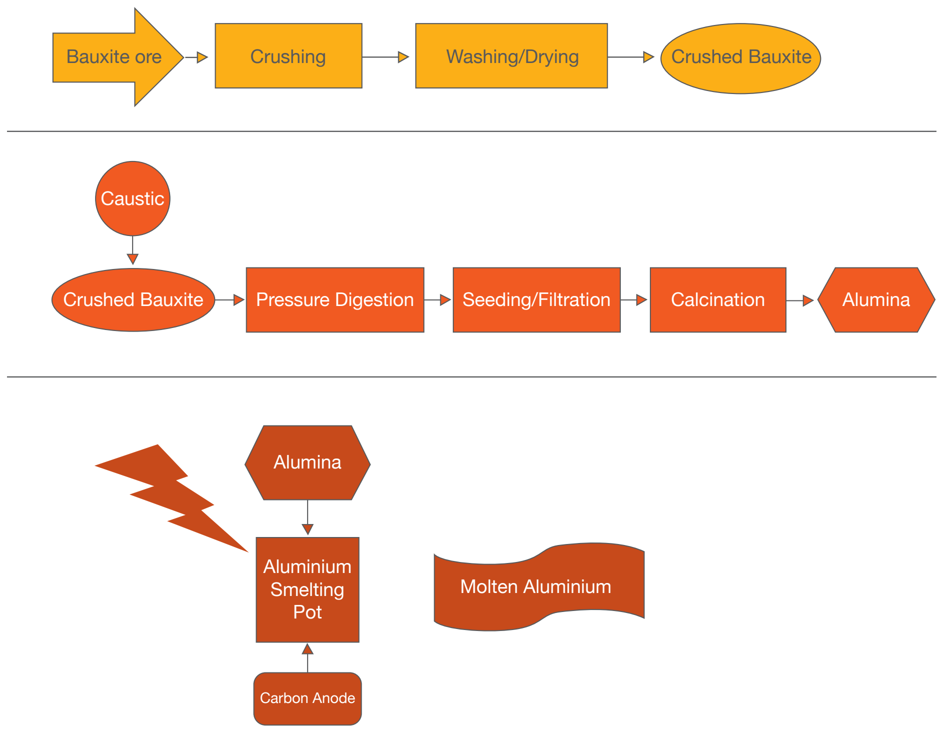
Since by nature Aluminium is positioned higher in the electrochemical series (reactivity series) compared to other common metals, it is not economical to extract it from its ore by using conventional carbon reduction technology.

Therefore Aluminium is extracted by electrolysis, which is the most effective, but also a rather energy intensive process.

The bauxite is first converted into aluminium oxide or 'Alumina' and then electrolyzed in a solution with molten cryolite (another aluminium compound used for controlling the temperature of the electrolysis). The process for producing Aluminium consists of three main phases:

- Mining of bauxite ore
- Alumina or Aluminium oxide (Al_2O_3) production from bauxite
- Aluminium Smelting or extraction of Aluminium metal from Alumina (Al_2O_3) by Electrolysis and casting of extracted molten Aluminium into ingots for further processing like rolling, extrusions etc.

Other raw materials used in Aluminium production include sodium hydroxide (caustic soda), petroleum coke, pitch, cryolite, Aluminium fluoride etc.



Flowsheet of Aluminium Production

Mining

Bauxite is generally mined from shallow open-cast type mines with typical overburden depths of one to three metres. The deposits' thickness in the mines generally range between 3 and 15 metres. However, there are underground bauxite mines in China with a depth ranging from 200 to 300 metres.

Open-cast mining operations typically involve rock blasting to loosen the bauxite; transportation requires the use of heavy mobile machinery such as power shovels, draglines, loaders, conveyors etc. Usually before the bauxite ore leaves the mines it is crushed to powder in ball mills and dried to remove organic material and water.

Operational hazard

Apart from blasting accidents, typical loss exposure in mining operations includes machinery breakdown and fire involving mobile equipment, hydraulic oil, conveyor belts, transformers, drive motors etc. Major untoward incidents involving these machines results in long downtime and disruption of operations.

Alumina Production

Crushed powdered bauxite is treated in a pressure vessel called a digester with a moderately concentrated caustic solution (sodium hydroxide) at 140°C to 240°C and at the pressure of around 35 bar for 2 to 9 hours, depending on the quality of the bauxite. Caustic solution reacts with hydrated aluminium oxide in bauxite to produce sodium tetra-hydroxo-aluminate solution which is then filtered, precipitated and seeded with Aluminium trihydrate crystals. It is then cooled to precipitate Aluminium hydroxide which is further calcined in a rotary kiln, heated by natural gas or oil, to produce white powder called Alumina or Aluminium oxide (Al_2O_3). The process is commonly known as Beyer's process. Impurities known as Red Mud settle down at the bottom of the digester and they are discarded carefully because of environmental sensitivities.

Operational hazard

The typical hazard associated with Alumina production is potential over pressurization of the digester while treating bauxite with caustic solution. This risk could be mitigated by ensuring proper maintenance of pressure relief safety systems. Other damage exposure in the alumina production includes mechanical breakdown of rotary kilns, conveyor systems, crushers, large motors etc., fire & explosion hazard of kilns' operation or fire exposures of the belt conveyors.

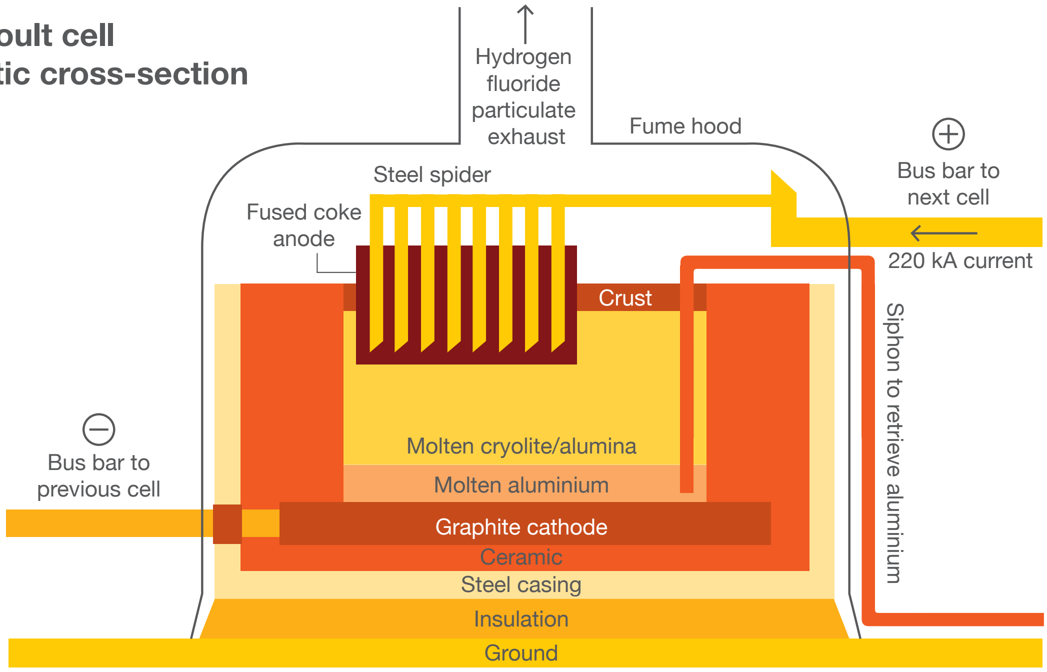
Aluminium Smelting

Aluminium is extracted from Alumina or aluminium oxide by electrolysis in a solution containing additives such as cryolite (Na_3AlF_6-another Aluminium ore), Aluminium fluoride added to maintain the electrolytic bath chemistry. The process is known as the Hall-Heroult process. The basic inputs of Aluminium production are alumina, electricity and carbon.

The production of Aluminium is very power intensive. As per an industry estimate, around 36 kWh of energy is required to produce 1 kg of Aluminium. Therefore, most Aluminium smelters have their own captive power generation system.

The electrolysis operation of Aluminium production is carried out in cells (also known as 'pots') that are long, shallow, steel shells lined with refractory bricks and carbon blocks; they are connected electrically in series with other pots. Each pot is filled with Alumina which serves as an electrolyte with a calculated amount of Cryolite and Aluminium fluoride added to maintain the electrolytic bath chemistry. The carbon lining of the cell acts as a cathode or negative electrode. The electric current flows into the cells through carbon anodes or positive electrodes installed at the centre of the pot which also act as the source of carbon required

Hall-Héroult cell
Schematic cross-section



https://upload.wikimedia.org/wikipedia/commons/f/fb/Hall-Heroult_cell_schematic.svg

for the reduction reaction. The typical arrangement of a pot is shown in the diagram above.

By the process of electrolysis, Alumina (Al_2O_3) separates into aluminium and oxygen. Aluminium is deposited at the cathode, while the oxygen reacts with the carbon anode and produces carbon dioxide, which is subsequently extracted and vented out. Alumina (Al_2O_3) is fed into the pots at regular intervals and the carbon anode is gradually lowered into the bath, in conjunction with the consumption of the carbon anode. Most modern Aluminium plants operate on a continuous basis and include an automatic anode adjustment and feeding systems, coupled with simultaneous carbon dioxide extraction facility from pots. The spent-up carbon anode known as ‘butt’ is eventually replaced and recycled.

The molten Aluminium deposits at the bottom of the cell are siphoned off and transported to the cast house in lined crucibles for further processing.

Since electrolysis is essentially a Direct Current (DC) based process which operates at extremely high amperage (typically around 250,000 amp) and very low voltage (5-6 Volts), Aluminium smelting facilities are fitted with a large transformer-rectifier system to reduce the supply voltage and to convert alternating current (AC) into direct current (DC).

In practice, Aluminium smelters generally have several pots electrically connected with each other in series called pot-lines, with several pot-lines in a smelting facility installed in a large hall known as a pot room. Each pot is generally provided with a hood so that the carbon dioxide generated in the process can be extracted effectively.

The pot to pot electrical connection is complicated and tends to be achieved by using specially designed Aluminium bus bars with large cross-sectional areas suitable for carrying a high quantum of amperage with minimum voltage drops. Since all the pots of one potline are connected in series, malfunctioning of one pot may disrupt the operation of the entire potline. Similarly, failure of power supply to a line may affect the entire potline.

Many Aluminium smelters are provided with carbon anodes production facilities where carbon anodes are produced using petroleum coke, coal tar pitch and recycled butts. The ingredients are ground together along with crushed butts and coal tar pitch to produce a paste which is pressed into moulds to produce green anode. It is baked at a high temperature then fitted with cast iron anode rods to facilitate maneuvering of the anode in pots while in operation.

Operational hazard (smelting)

The main operational hazard in Aluminium smelting is loss of electrical power while smelting pots are in operational mode. Generally the pots operate at a temperature of around 1,000°C. The loss of electrical power will eventually cool the pots down and a prolonged loss of power will result in solidification of Aluminium in the pots when the pot temperature goes below 700°C. This phenomenon is known as pot freezing. Once the pot freezes completely, it cannot be put back in service and must be discarded.

Occurrence of an electrical fault in one pot may render the entire potline frozen, if corrective actions are not taken in time. In case of occurrence of eventualities like 'tap out' (leakage of molten metal due to failure of shell of the pot), pots have to be bypassed, known as 'wedging out'. There are set ways to handle such a phenomenon; sufficient arrangements of gears like bus bar bridges, pot dis-connecters etc. must be available in smelting facilities, backed up by trained and experienced manpower who can mobilise heavy lifting equipment quickly. To be on the safe side, many facilities carry out regular drills. Experience shows that once a pot's power supply has been off for more than 3-4 hrs, recovery becomes difficult as loss of power cools the electrolyte and a restart of the potline becomes impossible, even if the power is restored. Restoration of the frozen pot is not only very expensive but also time consuming as solidified Aluminium and electrolyte need to be physically chiselled out of the pot for restoration. At the same time, the lifespan of the pot is also reduced considerably.

Modern Potline

Many costly losses on record are due to improper handling of such situations.

Handling molten Aluminium in the smelting area also involves considerable loss exposure as accidental spills of molten Aluminium coming in to contact with water can cause steam explosion. Similarly, chemicals like metal oxides or nitrates can cause a chemical explosion if molten aluminium comes in to contact with such chemicals.

Operational hazard (anode plant)

In anode plants, heavy to moderate machinery breakdown exposure exists due to usage of heavy presses, motors or gear sets etc. There are also fire hazards associated with the use of coal tar pitch. If natural gas is used as a fuel for anode baking, it can cause an explosion if it leaks. There is also the exposure to dust explosions due to the presence of a considerable amount of combustible carbon black powder.

Aspects of Loss Prevention

As per worldwide acknowledged norms, the following practices (not exhaustive) are generally recommended for loss prevention in different sections of the Aluminium extraction process.

Mining

Explosives for blasting need to be stored and handled as per the set norms of the country or as per NFPA (National Fire Protection Association USA) code no. 495.

It is advisable for the entire operational area to be protected by a hydrant system designed and maintained as per NFPA norms or as per country standards of the plant location.

Depending on the situation, installation of water spray or foam-water type sprinklers designed as per NFPA 13 & NFPA 15 or NFPA 16 respectively (or as per the countries' regulations) need to be considered as appropriate fire protection for the storage area, transformers, hydraulic and lube oil reservoirs of the crushers.

Alumina Production

Suitable portable fire extinguishers need to be provided for mobile mining equipment, oil systems, electrical and mechanical switchgear and equipment as per standard norms.
Digesters need to be provided with appropriate pressure-relief valves, as per statutory regulation of the country or as per ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Codes.

The alignment of the rotary kilns should be checked and adjusted at least once a year. The kiln should preferably be fitted with a deflection sensor to warn operators to take corrective action in advance.

Kiln firing systems should be equipped with BMS (Burner Management System), Flue Gas analyzer to provide early warning of incomplete combustion and formation of explosive CO (Carbon Monoxide) in the kiln.

It is best if only fire-resistant conveyor belts are used. The system needs to be earthed properly for quick dispersal of static charge accumulations which are formed due to rapid movement of conveyer belts over the idlers/ rollers. The condition of rollers/idlers should be properly monitored and taken care of.

Also here, it is desirable that the entire plant area is covered by a hydrant system designed as per NFPA norms or as per country standards of the plant location.

All the areas of the plant need to be equipped with the appropriate type and number of portable fire extinguishers as per standard norms.

Aluminium Smelting

It is essential to ensure redundancy of the power supply and distribution system, backed by proper electrical maintenance programmes. An Aluminium smelting plant should ideally have a well-designed captive power generation facility of adequate capacity.

It is very important to carry out regular drills to handle emergency situations such as 'wedging out' of pots in case eventualities such as 'tap out' (leakage of molten metal due to failure of shell of the pot) occur.

An adequate supply of spare bus bar bridges and pot dis-connecters needs to be maintained to ensure a quick turnaround time in case they need to be used. Developing safe procedures to empty molten Aluminium from pots in case of eventualities is essential to safeguard against pot solidification.

Availability of adequately trained and experienced manpower needs to be ensured round the clock to handle such situations.

Steel structural members of the plant areas exposed to molten Aluminium spills should be encased with cement concrete up to at least 2 metres above the floor.

As mentioned under the previous two subsections, the entire plant area should be covered by a hydrant system designed as per NFPA norms or as per the country standards of the plant's location.

All the areas of the plant need to be equipped with an appropriate type and number of portable fire extinguishers as per standard norms.

Since the transformer-rectifier is critical for continued operation of the plant, it needs to be protected with an automatic fire protection system designed as per NFPA or country standards.

Since electrical power is very critical to Aluminium smelting operations, proper condition monitoring systems should be established while maintaining electrical systems. This includes conducting DGA (Dissolved Gas Analysis), Furan and corrosive Sulphur tests for transformer oils at certain accepted intervals, performing partial discharge tests, thermographic analysis of electrical system etc.

For the other sections of the process

All the offices and cable trenches should be protected with automatic heat/smoke detection systems.

All unmanned electrical sub-stations and control rooms should be protected with an automatic gas-based fire protection system designed as per NFPA or country standard.

Hydrocarbon detectors should be placed in strategic locations in plants which use natural gas as kiln fuel.

All cables which pass through walls must be sealed with an intumescent material, or any other approved type of material, to restrict flames spreading through the cables in case of fire.

Underwriting considerations

Some of the technical issues which tend to be factored in (or considered) while developing insurance programmes for Aluminium processing facilities, are listed below.

Project Stage

In most large Aluminium smelting projects, potlines are tested and commissioned in phases. After commissioning of each potline, it continues to be in operational mode awaiting completion of all the projected potlines for integral testing. It is preferable that such operational potlines under the project policy should be excluded from the purview of

Advance Loss of Profit (ALoP) if such cover is part of an opted in policy.

Reputable EPC (Erection, Procurement & Construction) contractors should be in charge to handle projects with established technology as the operation of pots involves the very critical stabilization of electrolysis parametres, including electrolytic bath composition. Costly losses because of pot freezing have been known to occur while commissioning potlines.

Operational insurance (All risks)

Since the aluminium extraction process is very power intensive, plants with a reliable built in redundant power supply are to be preferred. Plants with a captive power generation facility capable of meeting the entire demand would be advantageous.

Adequate sub-limits for losses caused by pot freezing should be imposed. However, while deciding the sub limit, the configuration of the entire plant's potlines and their power supply systems must be considered.

Pots need to be relined periodically and discarded at the end of their designed lifespan; hence plants which have a proper system for relining and discarding pots, are preferred risks.

Underwriters should prefer plants which have well-rehearsed contingency plans to handle 'pot tap' out and 'power outage' situations, backed by trained manpower.

Technology which allows for long power-outages of pots might be eligible to receive preferential treatment.

Operational Loss of Profit insurance (Fire & Machinery)

Power supply transformers and rectifiers play a crucial role in the Aluminium smelting operation. This equipment is generally regarded as having a long lead time, being of high value and crucial from the business interruption point of view. Therefore, plants which deploy a proper condition monitoring system, such as conducting periodic Dissolved Gas Analysis, Furan & Corrosive Sulphur tests, to monitor the condition of the transformers' oils and which have an automatic fire protection system for transformer in place, are desirable.

Lessons Learnt from Past Loss Experiences

Experiences with large losses involving the Aluminium industry located in different parts of the world demonstrate that the majority of these incidents occurred due to power outages to the pot rooms of the plant. The reasons why such phenomenal losses occurred generally boils down to inefficient and inexperienced handling of power outage situations of pot rooms.

Recently, a couple of Aluminium smelting facilities in the Middle East have suffered colossal losses because of Pot Freezing. However, the biggest portion of these losses was the loss of revenue, or Loss of Profit, due to the prolonged shutdown of the plant after the pot freezing incidents.

The analysis of available documents related to the loss of the plant which suffered the highest loss, indicates that the deviation from standard 'wedging out' procedures of a 'tapped out' pot was likely caused by the lack of availability of adequate and experienced manpower. In turn, this led to massive arcing/flashover of the very high amperage electrical bus bar linkages which burnt down the permanent lifting gear needed for taking further steps to handle the power outage. It is possible that this forced the authority to resort to other non-standard makeshift arrangements which created further complications. Ultimately, all their attempts to restore normality failed and power supply had to be switched off completely for the sake of personnel safety. Therefore, there are reasons to believe that the loss was due to a lack of experience and lack of practice of emergency drills.

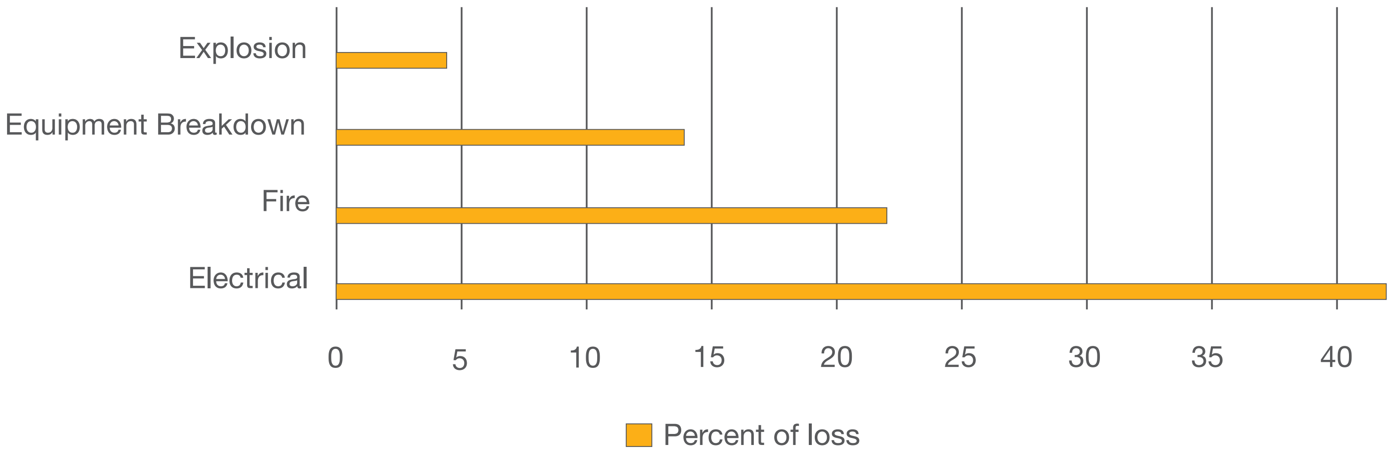
In another incident, human error presumably caused tripping of a critical transformer which led to a situation of total power outage for the pot rooms. This critical transformer was supplying power to the feed gas compressors used for boosting the gas feed supply pressure for the gas turbines of the captive power generation plant.

Stoppage of the feed gas compressors disrupted gas supply to all the captive power plant's gas turbines.

Unfortunately, simultaneous failure of the protection gear of other power systems (due to the sensitive setting of the power distribution system) led to a total collapse of the power supply system of the plant for a few hours. This happened even although there was an adequately designed power capacity redundancy. This incident eventually resulted in the freezing of several aluminium smelting pots in the plant. It serves as a reminder of the necessity to always evaluate power systems and to consider various failure modes.

Most of the fire losses in the Aluminium industry, however, occurred in connection with molten Aluminium spillage and fire in carbon plants and rolling mills.

The chart below shows the severe loss drivers for Aluminium plants, based on a large number of past loss records available to Trust Re.



Losses by Peril

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