

BAUXITE RESIDUE MANAGEMENT

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Abstract

With some two to four tonnes of bauxite residue arising for every tonne of aluminium produced, the management of bauxite residue (or Red Mud) has always been a significant issue for the aluminium industry. However, the tragic fatal incident in Ajka, Hungary in October 2010 has reinforced the need for safe and effective management of storage areas globally.

For the past five years the International Aluminium Institute has been involved in research into the management of bauxite residue and in 2011 created a set of voluntary objectives recommending that best practices are adopted to ensure that the Hungarian incident is never repeated elsewhere.

This paper will review the current and best practices of bauxite residue management.

Introduction

Bauxite residue has been continuously produced since the development of the alumina/aluminium industry in the late nineteenth century – and the global inventory is estimated to be around 3,000 million tonnes at the end of 2010 [Klauber, C., Grafe, M., and Power, G, 2009] – and growing at approximately 120 million tonnes per annum. This makes bauxite residue one of the largest industrial by-products in modern society – and highlights the importance of effective storage and remediation strategies.

The chemical and physical properties of the bauxite residues are determined by the nature of the bauxite and the processing conditions used during the Bayer process. This will be influenced by the technology and operating conditions at individual refineries, in particular, the temperature of digestion of the bauxite. The moisture content, pH value and particle size of the material being discharged from the production phase play a critical role in the future management of the residue material and the storage area.

Composition

The bauxite residue is mainly composed of iron oxides, titanium oxide, silicon oxide and un-dissolved alumina together with a wide range of other oxides which will vary according to the country of origin. The high concentration of iron compounds in the bauxite gives the by-product its characteristic red colour, and hence its common name 'red mud'.

A typical chemical composition is shown in Table I and a typical mineralogical composition is shown in Table II.

Table I – Chemical composition range of bauxite residue for main components

Component	Typical range (%)
Fe ₂ O ₃	5 - 60
Al ₂ O ₃	5 - 30
TiO ₂	0.3 - 15
CaO	2 - 14
SiO ₂	3 - 50
Na ₂ O	1 - 10

Table II – Mineralogical composition range for bauxite residues

Component	Typical range (%)
Sodalite (3Na ₂ O.3Al ₂ O ₃ .6SiO ₂ .Na ₂ SO ₄)	4 - 40
Goethite (FeOOH)	10 - 30
Hematite (Fe ₂ O ₃)	10 - 30
Magnetite (Fe ₃ O ₄)	0 - 8
Silica (SiO ₂) crystalline and amorphous	3 - 20
Calcium aluminate (3CaO.Al ₂ O ₃ .6H ₂ O)	2 - 20
Boehmite (AlOOH)	0 - 20
Titanium Dioxide (TiO ₂) anatase and rutile	2 - 15
Muscovite (K ₂ O.3Al ₂ O ₃ . 6SiO ₂ .2H ₂ O)	0 - 15
Calcite (CaCO ₃)	2 - 20
Kaolinite (Al ₂ O ₃ . 2SiO ₂ .2H ₂ O)	0 - 5
Gibbsite (Al(OH) ₃)	0 - 5
Perovskite (CaTiO ₃)	0 - 12
Cancrinite (Na ₆ [Al ₆ Si ₆ O ₂₄].2CaCO ₃)	0 - 50
Diaspore (AlOOH)	0 - 5

In addition there are various other minerals sometimes found including hydrogarnet, chantalite, hydroxycancrinite, and sodium titanate.

There are a wide range of other components present at trace levels in the bauxite, most especially metallic oxides such as those of arsenic, beryllium, cadmium, chromium, copper, gallium, lead, manganese, mercury, nickel, potassium, thorium, uranium, vanadium, and zinc.

Addressing the pH of Bauxite Residue

The high alkalinity of most bauxite residue stored in existing facilities and continuing/ongoing flow of residue material to storage facilities is the most important barrier to remediation, re-use and long term sustainability of bauxite residue management.

The alkalinity of bauxite residue is a result of the use of caustic soda during the alumina extracting process; despite all attempts to reduce the amount of caustic/sodium aluminate that is retained with the residue, small quantities will inevitably be retained when the residue stream is discharged.

Introduction of additional or improved caustic recovery systems prior to the discharge of the residue to the storage area brings considerable benefits in operating cost, health and safety and environmental terms but can be difficult and expensive to implement in existing facilities where retro-fitting could be complex.

pH Reduction of Bauxite Residue

A range of methods has been employed to reduce the pH of both residue and decant waters. The most established methods to date involve either mixing with sea water to precipitate hydroxide, carbonate and aluminate ions with magnesium and calcium, or with carbon dioxide to produce magnesium/calcium carbonate and calcium aluminocarbonates. Neutralisation with mineral acids has been less successful due to the influence of solid hydroxides in the residue and the harmful effects that this method of neutralisation has on the physical properties of the residue.

However, the use of mineral acids to reduce the pH of alkaline leachate streams is well established.

At some refineries in Japan and Europe a specific process has been utilised where bauxite residue is used to reduce sulfur dioxide emissions from the refinery and at the same time the pH of the bauxite residue is lowered.

CASE STUDY: 'Carbon Capture' system, Alcoa Technology Delivery Group (Kwinana, W.A.)

Alcoa's research and development group has set a new world benchmark for the alumina industry with the development of an innovative residue treatment process that delivers a range of sustainability benefits.

Known as residue carbonation, the process adds carbon dioxide to bauxite residue.

Mixing CO₂ into residue reduces its pH level to the levels found naturally in many alkaline soils, where it can potentially be re-used in road base, building materials or soil amendments. In addition, the residue drying process is further enhanced by the carbonation process – allowing faster deposition of a further layer of residue onto the storage area, reducing the area required to be available for storage at any time.

Carbonation's further sustainability benefit is that it locks up CO₂ which would otherwise be emitted to the atmosphere. The Kwinana carbonation plant will lock up 70,000 tonnes of CO₂ a year, the equivalent of taking over 17,500 cars off the road.

The CO₂ is a by-product from the nearby CSBP ammonia plant and would otherwise be emitted, making this an excellent example of how industry can form sustainability partnerships to re-use waste products.

Since January 2007 the Kwinana carbonation plant has been operating at full capacity, treating all residue produced by the refinery. Prior to this, the plant had been treating around 25% of the refinery's residue for the past two years, while awaiting the construction of a pipeline to deliver CO₂ direct from the CSBP ammonia plant.

Alcoa's Technology Delivery Group is conducting further research to support the deployment of carbonation in refineries that do not have a nearby CO₂ supply like the Kwinana refinery. This research is examining options for extracting CO₂ from powerhouse emissions and using it to carbonate residue.

Alcoa plans to deploy the technology across all three Western Australian refineries, leading to CO₂ savings of 300,000 tonnes each year – equivalent to taking 70,000 cars off the road.

The system has the potential to deliver significant global benefits by locking-up CO₂ in a greenhouse sink.

As part of its on-going commitment to reduce its global emissions, Alcoa plans to deploy the technology across its operations worldwide. The project – which is set to become a best practice benchmark for refinery residue treatment and storage in the industry worldwide - has been recognised by a number of prestigious awards including two Environmental Engineering Excellence Awards (one in WA and an Australia-wide award presented in Canberra in 2005).

Bauxite Residue Disposal and Storage Practices

A number of methods have been used for the storage of bauxite residues including lagooning, dry stacking and dry disposal.

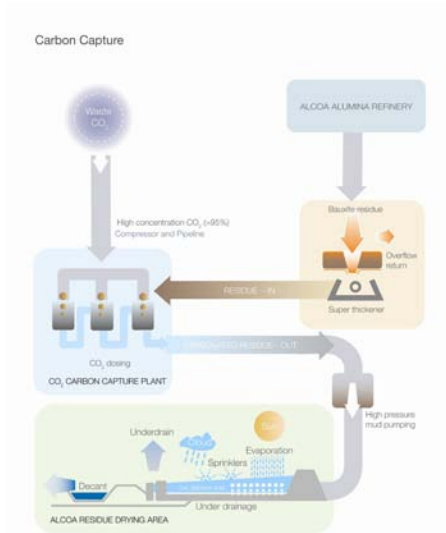
Prior to 1980s, most of the inventory of bauxite residue was held in lagoon-type impoundments, although some residue had been subject to discharge to deep-sea and (in very limited cases) river/estuary locations.

Since the mid-1980s, the trend has been towards dry stacking to reduce the potential for leakage of caustic liquor to the surrounding environment, reduce the land area required, and maximise the recoveries of soda and alumina. Improved methods for thickening and washing of the residues prior to storage, and recovery of decant water during storage, have been developed to increase the recovery of valuable soda and alumina to the Bayer process plants and to minimise the potential for leakage to the surrounding environment.

The current trend in residue storage practice is towards increasing use of dry stacking as the preferred technology, and further research to optimise this technology is appropriate.

River discharge is no longer undertaken at any alumina refining facilities and the historic practice of deep sea discharge is limited to some six plants and only a small share of total alumina production. Deep sea discharge is expected to be completely phased out within the next five years.

Image I: Carbon Capture Process Diagram



Lagooning (with/without neutralisation treatment)

Lagoon-based storage remains in use at some facilities both with and without neutralisation treatment.

The residue slurry from the mud washing circuit is pumped into land-based storage areas utilising dams and other earthworks for secure containment. The storage areas are normally sealed to minimise leakage to the underlying ground and ground water, with the sealing used covering a range of materials including compacted clay and/or the use of plastic and other membrane materials; drainage and seepage collection and monitoring systems are often incorporated into the design/construction of the facilities. Advantages include improved dust control and little/no thickening or filtration of the residue prior to storage. The disadvantages include the requirement of large areas of land for the establishment of storage areas.

If the residue material is not neutralised before discharge to the storage lagoon, it becomes a highly alkaline, poorly compacted mud area covered by a highly alkaline lake. This creates safety and environmental hazards including potentials for contact of humans and wildlife with alkaline liquor and mud, and contamination of surface and ground waters by leaching of caustic liquor and other contaminants can occur. Closure and rehabilitation costs are greatly increased.

Addressing the risk and to eliminate the potential for catastrophic failure of the dam/impoundment and consequent environmental hazard to the surrounding area/communities introduces high construction and maintenance costs. Under some circumstances, this creates the prospect of an indefinite legacy with expensive treatment and monitoring costs.

Mud/Dry Stacking

The residue is thickened prior to discharge to within a range of 45-55% solids allowing the material to flow and form layers of a uniform thickness over the storage site. The layer of residue is allowed to dewater and air-dry before being covered with the next

layer. The material consolidates as the solids settle and the liquor is removed by a combination of decantation and surface evaporation. A modern facility is likely to include a drainage system to facilitate the consolidation process and the subsequent stacking of additional layers of residue material, minimising the footprint of the storage area. Environmental and safety hazards are greatly reduced in comparison with the technique of lagooning – and further reduced by a lowering of the pH (through caustic recovery/neutralisation) and a management programme to minimise surface water. Dust management programmes are required to avoid airborne dust during windy conditions.

Dry Disposal

The residue slurry from the mud washing circuit is filtered to a dry cake (> 65 % solids), normally after being washed to recover soda and reduce the pH of the residue. The dry residue material is carried by truck or conveyor to the storage site and stored without further treatment. This method minimises the land area required for storage and the potential for leakage to groundwater – and environmental and safety hazards are avoided. Rehabilitation and closure costs are greatly reduced and the material is in a more readily usable form. Drum filters have been used since the 1930s but there is now increasing use of press filters capable of achieving 70 to 75% solids. For sites with a constrained space this approach can often present the best option.

Utilisation of Bauxite Residue

Hundreds of patents have been issued and thousands of trials have been undertaken on different uses for bauxite residue, some of these applications have been commercialised but matching the tonnage arising annually with possible commercial applications has been, and continues to be, a major challenge. However, in many cases the possible uses involve replacing another low cost raw material – so, whilst the concept may be technically feasible, the costs and risks of using bauxite residue are not justified. It is critical that all the costs are taken into account when consideration is given to utilising bauxite residue in a particular application; the ongoing costs of maintaining the site, security, HSE implications, risk of ongoing storage issues, rehabilitation and monitoring of closed sites must also be taken into account when considering the feasibility of particular applications.

The proposed uses fall into a number of different categories: extracting some of the components, e.g. iron or rare-earths; using it as a source of a particular component, eg. iron and alumina in cement; using the material for a specific characteristic, e.g. colour; as a construction material, e.g. bricks, tiles, aggregate blocks, wood substitute; or as bulk impermeable material for covering landfill. The majority of patents filed have involved bauxite residue being used in the construction, building or agricultural industries. It is estimated that some 2 million tonnes is at present used annually; the largest uses currently are in cement production, refractory use, soil amelioration and landfill covering. The Chinese Government have set an ambitious target of 20% utilisation by 2015.

Remediation & Rehabilitation

The most important barrier to remediation, use and long term sustainability of bauxite residue management is its high alkalinity.

Continuing research on residue pH reduction/remediation is being funded by the International Aluminium Institute under the co-ordination of the IAI Bauxite & Alumina Committee (BAC) and the Alumina Technical Panel (ATP).

Work in the remediation field has been underway for some time in both collaborative activities and individual company research efforts. The recently completed AMIRA project P1038 was a literature review with the aim to identify, on the basis of the open (public) literature, possible ways in which the “*in situ*” remediation of bauxite residues might be undertaken and in particular to define specific objectives for the industry in the context of the most promising research pathways. This review suggested that the most promising pathway for *in situ* rehabilitation would appear to be bioremediation based on strategies developed for saline-sodic soil, with a focus on enhanced surface rehabilitation techniques.

Following a review of AMIRA Project P1038, the IAI Board has accepted the recommendation of the BAC/ATP to fund further research by the University of Western Australia’s School of Earth and Environment on the *in situ* remediation of bauxite residue. Work already conducted by the School of Earth and Environment (where a professorial position is co-funded by Alcoa and BHP Billiton) has been working in this direction. The overall project is aimed at addressing the need for the development of methods for modifying the existing stored residue by a combination of neutralisation and concretion, without major disturbance to the bulk mass, with a view to improving the chemically and physically stability in the long term. This might be achieved by means of accelerated leaching, natural biological amelioration as an extension of surface rehabilitation, or concretion reactions if enough is known about the chemistry and geo-mechanics of the deposits. This project is expected to be completed by 2013.

CASE STUDY: From red to green – bauxite residue remediation in Jamaica. A case study of Kirkvine remediation activities

Alcan (now Rio Tinto Alcan) had a long history in Jamaica, constructing the first alumina plant (Kirkvine) there in 1952, and a second in 1959, (Ewarton). In 2001 Alcan sold its bauxite mining and alumina plants in Jamaica but kept responsibility for many of the bauxite residue sites with the intention of safely remediating them to an agreed standard and transferring ownership to the Government of Jamaica. The agreed objective was maximum biodiversity rather than housing or agricultural use.

At Kirkvine, the bauxite residue (typical concentration 47 % Fe₂O₃, 16 % Al₂O₃, 7 % CaO, 6 % TiO₂, 4 % SiO₂, 3 % Na₂O, 2 % P₂O₅, and 14 % water) had been deposited in depressions left after bauxite mining. When deposited, the residue had a solids content of approximately about 20 % but it was discharged in a way that in most cases, when full and aged, no residual pond water remained resulting in a relatively dry surface and the pH was about 11.

In 1996, trials were undertaken on a former pond; after working the surface to produce smaller nodules/particles, plots were treated with gypsum loadings of between 10 and 100 t/ha. Soil electrical conductivity and pH measurements showed that whilst there was a substantial improvement as the level was raised from 10 to 20 t/ha, there was only a modest improvement as the level

was increased to 40 t/ha and almost no improvement when the level was raised further to 60 t/ha. Just over a year after the gypsum was spread, poultry manure was spread at dosage levels of 4 and 2 t/ha on different areas; ammonium sulfate was spread at 0.062 t/ha. Three months later seeding was undertaken:

Cynodon dactylon (Bermuda Grass) 21 kg/ha
Brachiaria decumbens (Brachiaria) 31 kg/ha
Leucaena leucocephala (Leucaena) 10 kg/ha
Ricinus communis (Castor Bean) 4 kg/ha
Haematoxylum campechianum (Logwood) 1 kg/ha

In 2004 a study found 53 species belonging to 28 families, dominated by Lead Tree Christmas Bush and Guinea Grass; only Logwood and Lead Tree remained from the original species planted. The success of the Lead Tree is attributable to its nitrogen fixation ability. The growth form of the vegetation, slender trees, grasses, climbers and runners with rhizomes and stolons is typical of an early pioneer stage in succession and development.

In 2005 parts of the area were reinvigorated by the addition of additional gypsum and chicken manure and reseeded with *Brachiaria*, Bonavista Bean and Guinea Grass. By 2011 there had been a dramatic improvement in the growth across the entire area; 56 species were found which is comparable to a ‘dry limestone forest’ in Jamaica.

Photograph I: Kirkvine Pond 6 – 2005



Photograph II: Kirkvine Pond 6 - Feb 2011



Following this trial, Rio Tinto Alcan adopted the approach on the remaining ponds which still comprised bare bauxite residue.

References

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