Guidelines for Handling and Management of Red Mud Generated from Alumina Plants

(May 2023)

Central Pollution Control Board
(Ministry of Environment, Forest and Climate Change)
Parivesh Bhawan, East Arjun Nagar, Delhi- 110032

PREFACE

The Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 (HOWM Rules, 2016) has classified Red Mud generated from Alumina plants as 'High Volume Low Effect Waste', which required to be managed in accordance with the guidelines of Central Pollution Control Board (CPCB).

There are six alumina plants in India with generating capacity of about 06 Million MT per Annum. The corresponding generation of Red Mud is about 1.5 to 2 times the alumina production. The major environmental issue in handling or disposal of Red Mud is the alkaline nature of waste that may pose risk of contamination due to seepage or over-flow. Historically, the Red Mud has been handled in slurry form and stored in ponds that have caused adverse impacts on the environment globally including in India.

The guidelines outline the process involved in alumina production, characteristics of Red Mud, possible impacts, the current practices and framework for the safe handling and management of Red Mud. The option of recovering material from Red Mud in line with the principles of resource efficiency is also addressed in these guidelines.

The contribution made by Ms. Deepti Kapil, Scientist D; Sh. B. Vinod Babu, Scientist-F and Sh. Nazimuddin, Scientist-F along with Late Dr R.S. Mahwar, Former Scientist-E, CPCB for preparing these guidelines are appreciated. Further, the inputs provided by the experts; researchers; and representatives of Industry; the Atomic Energy Regulatory Board; State Pollution Control Boards and Cement Manufacturers Association in finalising these guidelines are also gratefully acknowledged.

All the alumina refineries, Red Mud utilizers, environmental agencies, and concerned stakeholders are encouraged to embrace these guidelines and integrate them into their operational practices.

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1. INTRODUCTION

Red Mud is the waste generated in the Bayer process of alumina production from bauxite. It is also known as bauxite residue. Red Mud is defined as a "High Volume Low Effect Waste" under the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 (HOWM Rules 2016). The relevant provision given as note at the end of Schedule-I of the HOWM Rules 2016 is as follow:

"The high volume low effect wastes such as fly ash, Phosphogypsum, Red Mud, jarosite, Slags from pyrometallurgical operations, mine tailings and ore beneficiation rejects are excluded from the category of hazardous wastes. Separate guidelines on the management of these wastes shall be issued by Central Pollution Control Board."

In order to formulate the Guidelines on Handling and Management of Red-Mud, CPCB constituted a Technical Committee (TC) comprising of: (i) Dr Ranveer Singh Mahwar, Former Additional Director, CPCB, Delhi (ii) Mr Nazimmudin, Scientist E & Divisional Head, IPC-II Division, CPCB, Delhi and (iii) Ms Deepti Kapil, Scientist D, WM-II Division, CPCB Delhi. For preparation of these guidelines, the Committee carried out the survey on (i) manufacturing process and production scenarios (ii) generation and characteristic of the Red Mud (iii) current practices of handling, storage, Utilization and disposal of Red Mud, and the best practices for handling and management of this waste in the Aluminium metallurgical Industries in the country. The committee also visited the Red Mud generating industries as well as the legacy Red Mud storage sites for the assessment of the Red Mud generation, its handling and management and collection of samples of Red Mud and related environmental matrices for its analysis.

All possible support information/documents relating to the environmental permissions/ clearances issued were obtained by Pollution Control Boards of the concerned States and the Ministry of Environment, Forest and Climate Change (MoEF&CC). Details on handling and management of Red Mud were collected during the visits to Red Mud generating units and the results of the analysis of samples were reviewed and compiled for formulation of guidelines for handling and management of Red Mud.

These guidelines cover the national and international scenario on Alumina production, Red Mud characteristics and its generation including practices followed for handling, management and utilization of Red Mud. Issues related to failure of Red Mud Pond / accidents occurred in Hungary, Brazil, China and India have also been addressed alongwith possible causes of such failures and suggestive remedial measures.

Accordingly, the document deals with the guidelines for safe handling, transportation, storage, disposal and end use of Red Mud that may be encouraged to solve the problems associated with the disposal of Red Mud for its implementation by the Red Mud generating industries.

2. BAUXITE AND ALUMINA PRODUCTION

2.1 Bauxite Ores

Aluminium is a reactive metal and is not found in its elemental form in nature. There are a wide range of minerals containing aluminium almost exclusively as the oxide and often in combination with other oxides, especially silica and iron oxides.

The aluminium minerals present are gibbsite (Al(OH)3, often referred to in the industry as alumina trihydrate or hydrate, Al2O3.3H2O), boehmite (AlO(OH) or Al2O3.H2O, aluminium oxyhydroxide or monohydrate) and diaspore (the same chemical formula as boehmite). Bauxite is an aluminium ore and is recognised as one of the main sources of aluminium. It typically contains different minerals such as boehmite (γ-AlO(OH)), gibbsite (Al(OH)3) and diaspore (α-AlO(OH)) mixed with the kaolinite, goethite, hematite, and minor amounts of anatase (TiO2) and ilmenite (FeTiO3 or FeO.TiO2) (Liu et al., 2011). The crystal structures of these bauxite ores are very dissimilar to each other.

The availability of the bauxite ores in different areas is shown in ***Table 1***.

Table 1: Types of Bauxite Ores in different countries

Bauxite Ore	**Countries**
Gibbsite	Australia, Brazil, Guyana, India (Eastern Coast), Indonesia, Jamaica, Malaysia, Sierra, Leone, Suriname, Venezuela
Boehmite	Australia, Guinea, Hungary, USSR, Yugoslavia, India (Central part)
Diaspore	China, Greece, Guinea, Romania, Turkey

2.2 Locations of Bauxite Mining

The country with the highest amount of bauxite reserves worldwide in 2019 was Guinea. In that year, the reserves of bauxite in Guinea amounted to about 7.4 billion metric dry tons. Globally, bauxite reserves amounted to 30 billion dry metric tons.

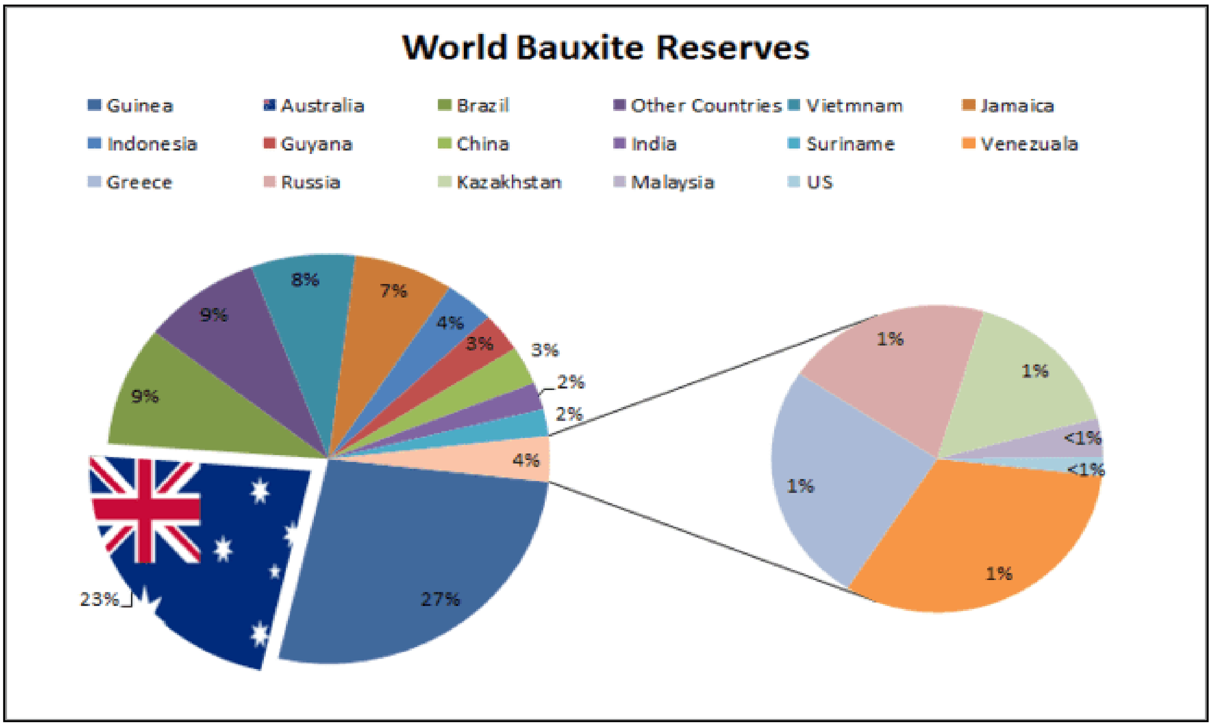


Figure 1: World Bauxite Reserves

2.3 Bauxite Production Worldwide from 2011 to 2019 (in 1,000 Metric Tons)

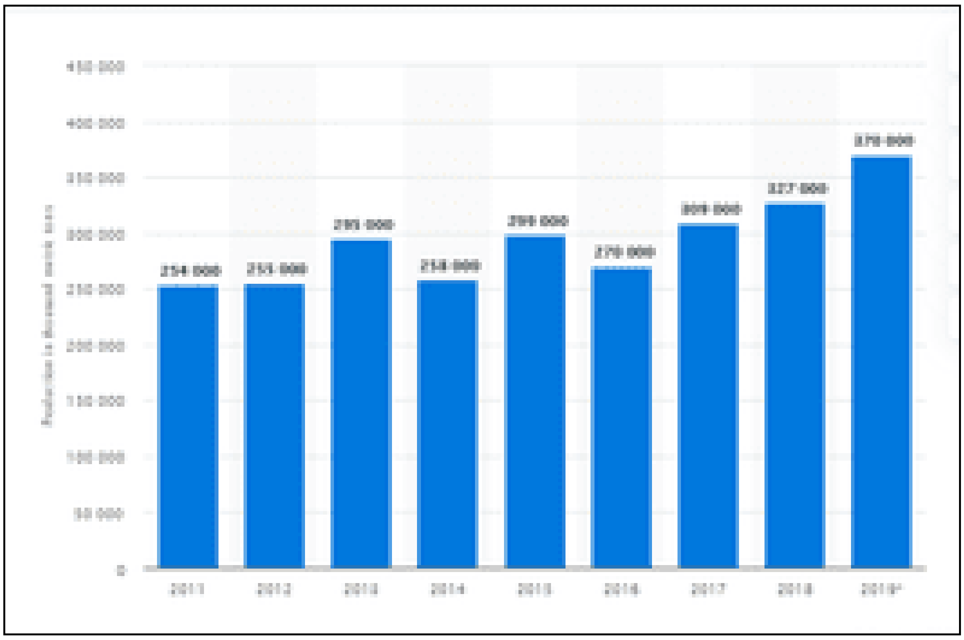


Figure 2: Bauxite Production Worldwide from 2011 to 2019

(Source: https://www.statista.com/statistics/799538/global-bauxite-production/#:~:text=In%202019%2C%20the%20global%20production,of%20the%20rate%20metal%20gallium.)

2.4 Bauxite Imports and Exports of Bauxite (Global & National)

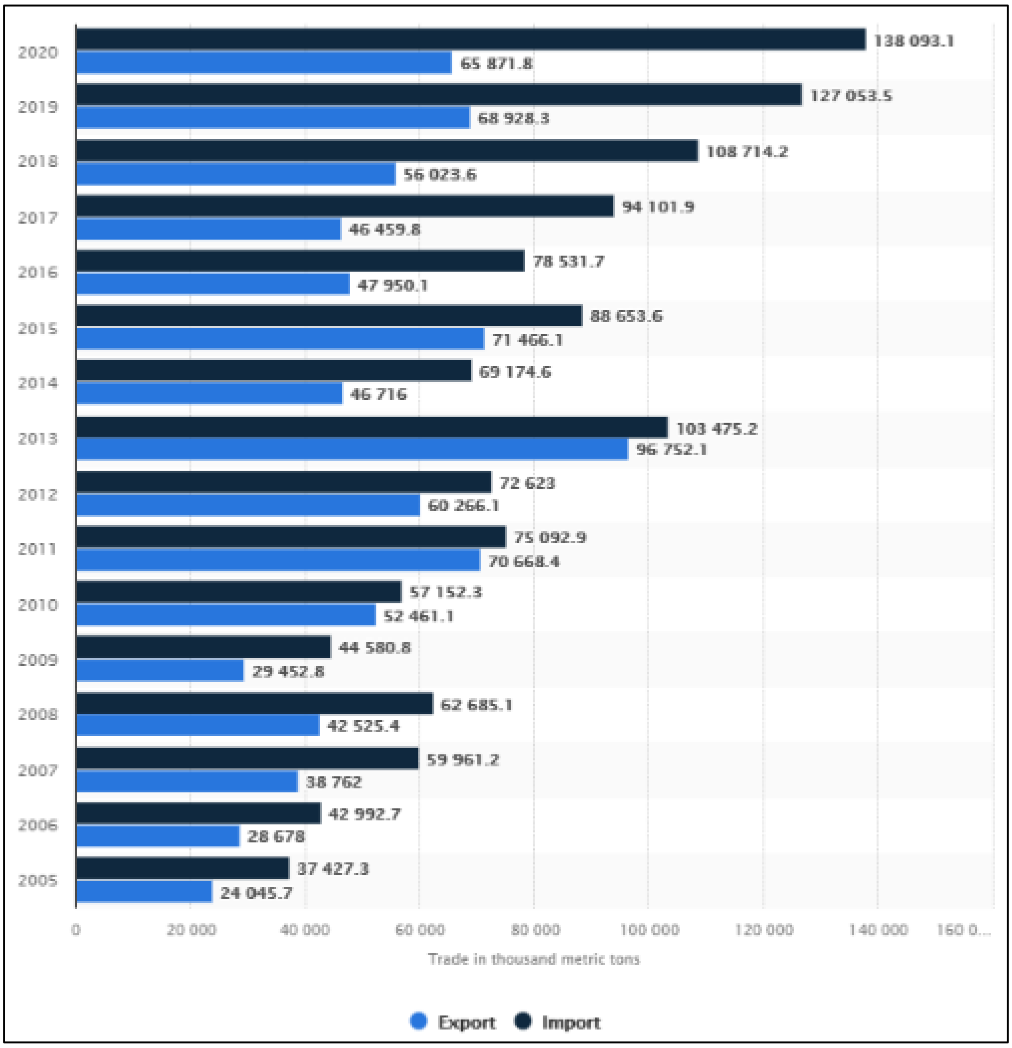


Figure 3: Global Import/Export of Bauxite

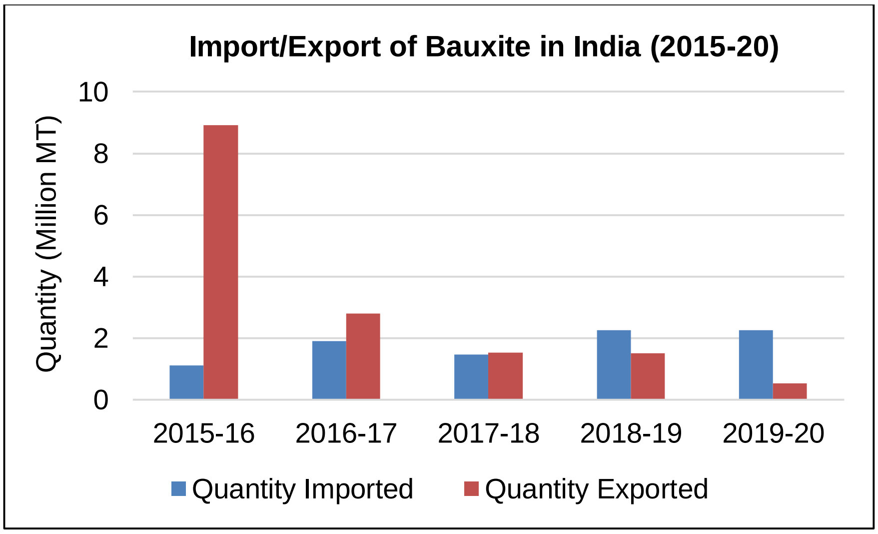


Figure 4: Bauxite Imports and Exports in India from 2015 to 2020

Bauxite is the primary mineral source of alumina for aluminium. Between four and seven tonnes bauxite ore are needed to make two tonnes of alumina, which subsequently produces around one tonne of aluminium.

2.5 Production of Aluminium from Bauxite

Unlike metals such as copper and gold, it is never found by itself, but always in combination with the most abundant element, oxygen, and often with the second and fourth most abundant elements, silicon and iron. Because of its lightness, resistance to corrosion and ability to be readily recycled, aluminium is extensively utilised in many applications. This requires a worldwide industry for its production, via the aluminium oxide (alumina) intermediate, and aided by the extensive deposits of aluminium ores.

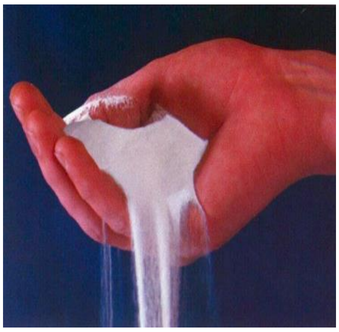
Besides aluminium production, the alumina produced from Bauxite ore is also used for non-metallurgical applications, which typically make up 10% of global end uses. These include water purification, refractory materials, pharmaceuticals, artificial marble, paper sizing, ceramics, abrasives, petroleum processing, plastic and flame retardants. In addition to alumina, bauxite itself is used in Portland cement, refractory material, abrasives, mineral fibres, steel and calcium aluminate cements.

Bauxite is the most widely distributed ore used for alumina production. It contains 30-54% alumina, Al_2O_3, the rest being a mixture of silica, various iron oxides, and titanium dioxide. The alumina must be purified before it can be refined to aluminium metal. Though alumina can be produced from bauxite by other chemical processes, the Bayer process is the main industrial route for alumina production, as it is the most economical process for purification of bauxite. The alumina produced through Bayer process is deemed metallurgical or smelter grade alumina (SGA).

2.5.1 Bayer Process

The Bayer process developed and patented in 1888 by Karl Josef Bayer is for production of the smelting grade alumina (the precursor to aluminium) from bauxite. The consumption of bauxite to produce 1 tonne of alumina varies between 1.9 to 3.6 tonnes depending upon the quality of the bauxite ore.

Bauxite Ore



Alumina Product

The production of aluminium from bauxite involves production of the intermediate alumina (Al_2O_3) through combination of hydrometallurgy and pyrometallurgical processes. The alumina so produced is subsequently smelted to aluminium via a pyrometallurgical process.

a) Process Flow sheet and Raw Materials and Liquor Properties

The basis of a hydrometallurgical process is addition of a solid ore to a solution, usually water-based (aqueous), containing the reagent which attacks that ore and dissolves the valuable component. The hydrometallurgical process involves continuous circulation of the aqueous medium around a circuit, dissolving ore at the "front" end and removing the dissolved metal as the "back" end. This is the essence of the continuous Bayer Process used by the industry today.

Caustic liquor (a strong caustic soda solution) is the medium moving around the circuit. When bauxite is added, the aluminium dissolves and "green" or pregnant liquor richer in aluminium is formed. As the circuit goes around, the aluminium concentration is decreased in the precipitation (or crystallisation) step, and ends up with a "spent" liquor. The spent liquor completes the circuit to treat more bauxite. The essence of the Bayer Process therefore is the dissolution of aluminium from its ore in the early part of the circuit followed by deposition of (pure) aluminium hydroxide in the later part. The circuit is comprised of a number of unit operations shown in the diagram:

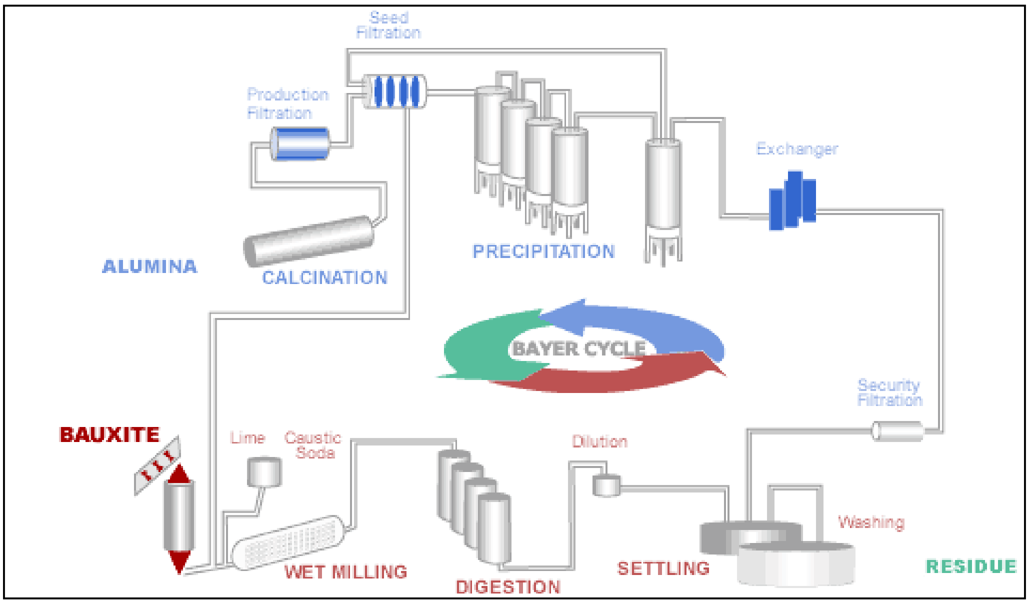


Figure 5: Flow Chart of Bayer's Process

(Source: http://redmud.org/red-mud/production/)

A part of caustic soda is lost in the circuit, to residue and to calcinations. So to maintain optimal concentration caustic soda in liquid form is added to the circuit. Typically, 100kg of caustic is consumed for each tonne of alumina produced.

Bauxite ores are usually found as near-surface deposits and hence they contain significant traces of humic (soil) matter, tree roots etc. In the aggressive caustic environment these high molecular weight humic compounds break down into carbon dioxide and a range of low molecular weight compounds. The CO_2 reacts with the caustic soda to produce sodium carbonate.

$2NaOH + CO_2 \rightarrow Na_2CO_3$

The effective caustic soda concentration therefore gets reduced and the process becomes less efficient. To avoid adding excess amounts of fresh caustic soda, lime is added in appropriate proportions with the bauxite. The lime reacts with the sodium carbonate to regenerate sodium hydroxide and this step is known as causticisation:

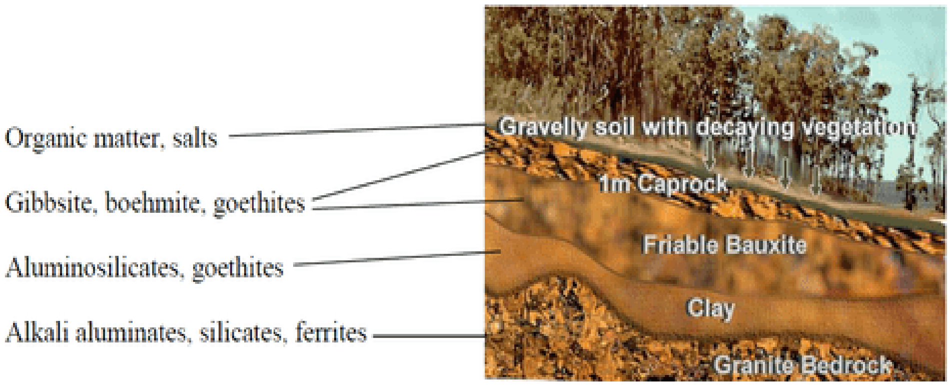
$Na_2CO_3 + CaO \rightarrow 2NaOH + CaCO_3$

The calcium carbonate exits the circuit as part of the residue.

The calcium carbonate thus formed becomes part of the residue. The humic materials reacting with the caustic liquor are responsible for the colour of the liquor a deep olive brown with a characteristic odour.

b) Ore Preparation and Grinding

Bauxite ores being a material mined from the near-surface deposits, are typically covered with a hard cap rock which is overlaid by soil and vegetation, including trees. The ore is formed by weathering of the base rock. The weathering process first produces aluminosilicate clays, which underlie the younger weathering product, the bauxite. Bauxite is formed as the silicate fraction of the clays is leached out. Mining of bauxite therefore typically occurs as an open-cut operation, with the cut-off at the clay horizon. A schematic representation of a bauxite profile typical of many commercial deposits around the world is shown below:



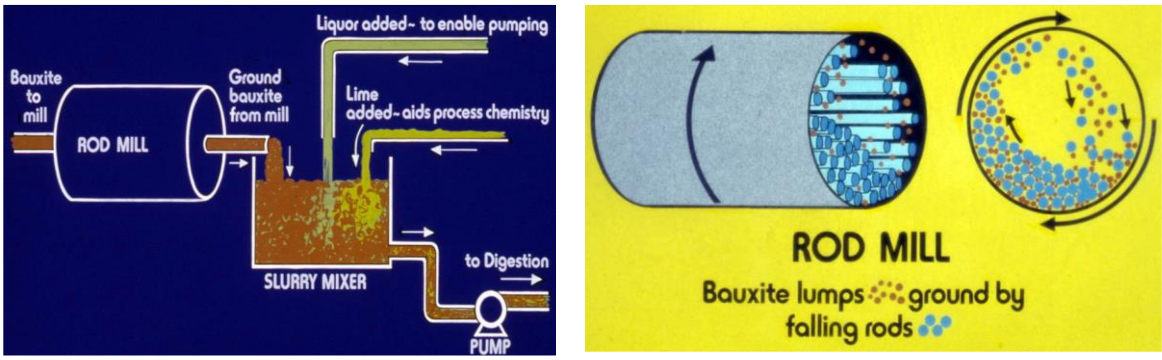
The preparation of the ore starts from its primary crushing which is usually carried out at the mine site. A primary crusher at the minesite reduces the bauxite to less than 150 mm diameter lumps.

Primary Crusher

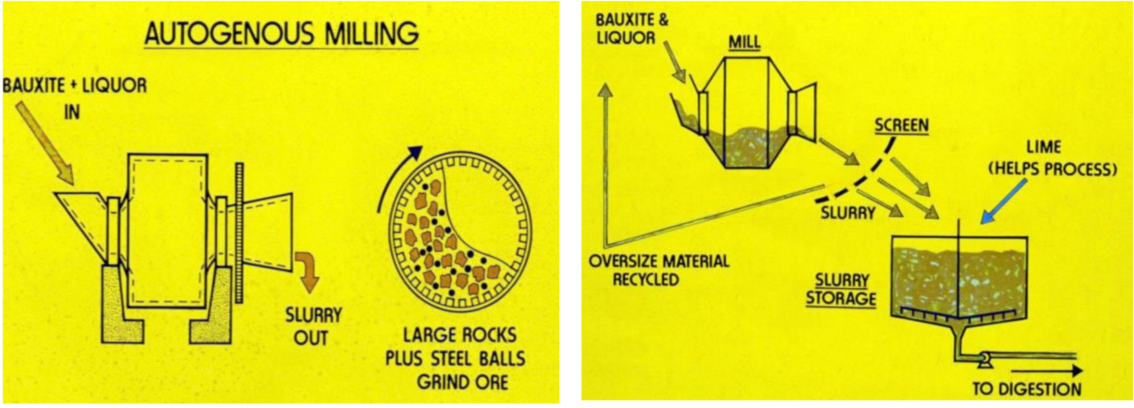
The ore is then transported by conveyor, pipeline or trucks /railway wagons to the alumina refinery or to a shipping point (if the refinery is located overseas.

The first step in the Bayer circuit is grinding: the ore must be reduced in size to less than 150 μm (0.15 mm) particles for efficient extraction of the aluminium. The ore is added to the mill together with spent liquor and lime. Three types of mill are used:

- Rod mills, holding a charge of steel rods which crush the ore by impact (now being phased out);
- Ball mills, holding a charge of steel balls for crushing; and
- Autogenous mills, which utilise the larger lumps of ore to crush the smaller ones; in some cases steel balls are also added for semi-autogenous milling



ROD MILLS



AUTOGENOUS MILLS

SEMI-AUTOGENOUS MILLS

c) Desilication

Bauxites contain some clays which are termed reactive in the Bayer Process, and they react with the caustic liquor and get dissolves in it. The most common reactive clay is kaolinite $Al_2O_3.2SiO_2.2H_2O$ and under Bayer conditions it dissolves:

$Al_2O_3.2SiO_2.2H_2O + 6OH^- \rightarrow 2Al(OH)_4^- + SiO_3^{2-} + H_2O$

The aluminate and silicate ions then react to form a complex ion

$Al(OH)_4^- + SiO_3^{2-} \rightarrow [SiO_2.O.Al(OH)_3]^{2-} + OH^-$

The complex ions in the above reaction further gets converted into an insoluble *Desilication Product* (DSP) in the presence of caustic soda:

$6[SiO_2.O.Al(OH)_3]^{2-} + 6Na+ \rightarrow 3Na_2O.3Al_2O_3.6SiO_2.2H_2O + 6OH^- + 4H_2O$

This DSP exits the circuit with the residue. About 0.8 tonne of caustic soda is typically lost for every tonne of kaolinite in the bauxite as well as almost one tonne of alumina which is unavailable. As caustic soda is an expensive reagent, its loss should be minimised which implies that the kaolinite content of the bauxite should be minimised. Whilst this is a worthy target, it has its dangers: if too little kaolinite is present, the silica formed in solution from its dissolution is inadequate to form the insoluble DSP: the silica remains in solution and contaminates the final alumina produced from the circuit. Optimum kaolinite content in bauxite is 2-5%.

To ensure that formation of the DSP is as complete as possible, the liquor slurry containing the milled bauxite is kept in holding tanks at about 90°C for at least 8 hours before proceeding to Digestion.

d) Digestion

The slurry from the desilication tank is pumped into the train of digester vessels where it is held for an appropriate time.

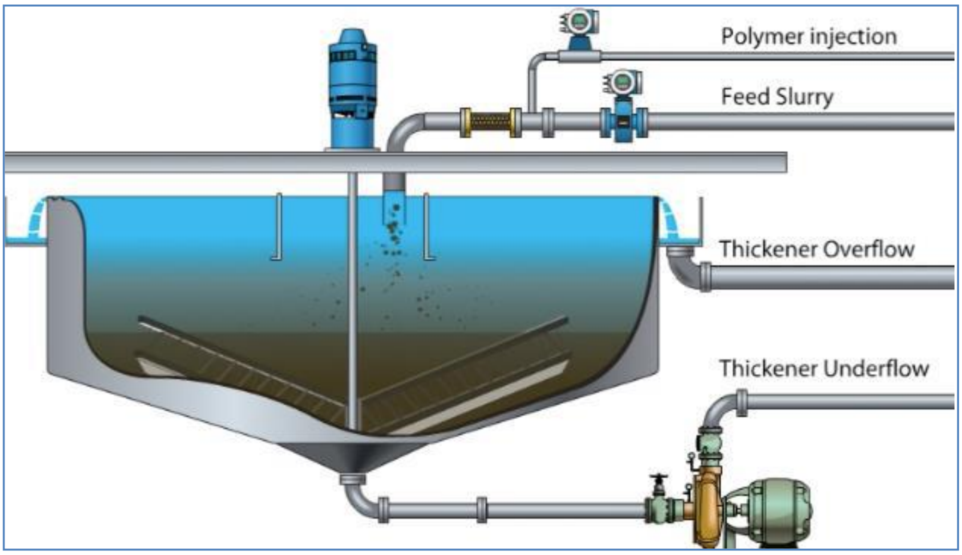
The extraction of aluminium from the bauxite into the caustic solution is dependent on the particular aluminium mineral present. Gibbsite is most readily attacked; the digestion temperature is usually in the range 140-150°C for 20 minutes. Whilst dissolution of the gibbsite occurs in about 5 minutes, the extra time in digestion allows completion of the desilication reaction, forming DSP. Boehmite is less readily attacked and temperatures in the vicinity of 250°C for 10 minutes are required. Diaspore is the least reactive mineral and temperatures up to 280°C may be required. All these digestion temperatures are above the boiling point of the caustic liquor so the digester is held under pressure; dependent on the mineral the pumps and digester vessel must be able to handle the pressure. The temperature for digestion is achieved by injecting high pressure steam into the slurry. After digestion the slurry is flashed down to atmospheric pressure and the steam and heat evolved are collected. In simple terms the aluminum dissolves to form the aluminate ion $Al(OH)_4^-$.

The concentration of aluminum in solution is well above its equilibrium value (the liquor is supersaturated); this presents a number of challenges to prevent the aluminium precipitating (crystallising) out of solution before the Precipitation step.

e) Solid-Liquid Separation

The solids remaining in the slurry leaving digestion is removed to the best possible extent before the aluminium in the pregnant/green liquor is crystallised (termed *precipitation* in Bayer parlance) out as aluminium hydroxide (*hydrate or trihydrate*). It is essential that the hydrate is as pure as possible to ensure the final alumina product meets the quality requirements of the smelter customer.

To this end the first stage of solid/liquid separation in large vessels is called thickeners.



These are 40 m diameter tanks with a cone base; the slurry is injected at the top on the periphery and flocculants (coagulant – a specially designed polymer formulation) is added (to assist in smaller particles aggregating into larger ones). A large rake in the vessel rotates around, and the solids settle to the base and exit at the bottom of the cone (thickener underflow). The clarified pregnant/green liquor exits at an overflow weir at the top (thickener overflow). Typically a train of 5 thickeners in series is used in each unit. The solids, in a dense slurry, exiting the last thickener are pumped to the washers.

f) Filtration

The liquor from the thickeners still contains low levels of fine solids and must be subject to polish filtration before the Precipitation step. Pressure filters force the liquor through specially designed polymer cloths.

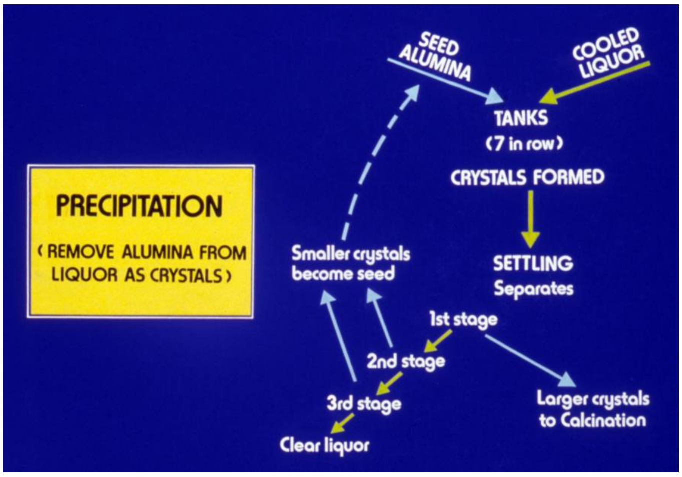
g) Heat Interchange

The liquor exiting filtration is at temperatures around 95°C; this must be cooled to about 80°C before entering the Precipitation vessels. The liquor is passed through heat exchangers and the evolved heat captured.

h) Precipitation and Equilibrium Considerations

The crystallisation of aluminium hydroxide $Al(OH)_3$ (*hydrate*) from the supersaturated green liquor with dissolved aluminium is the slowest part of the Bayer cycle. The kinetics of the overall reaction are controlled by chemical steps. This requires long holding times and it is also necessary to provide a large recalculating mass of hydrate seed to accelerate the reaction. The seed provides a catalytic surface to encourage the formation of aluminium hydroxide, and a surface on which it can grow.

It is very important that the crystals produced are of the right form and structure to ensure that they pass through the calcinations stage (to form alumina) and shipping to arrive at the aluminium smelter meeting all quality criteria.



Hydrate seed (fine crystals) screened from the precipitation step, is added to the first precipitator; the aluminium hydroxide crystallises onto these seeds in a controlled way. The precipitator is a large vertical tank (typical dimensions 30 m high and 15 m diameter with volume about 4.5 ML) with some form of agitation to maintain suspension of the solids in the liquor.

Modern refineries have flat-bottomed precipitation tanks with agitation via a stirred propeller to maintain suspension of the solids in the liquor.

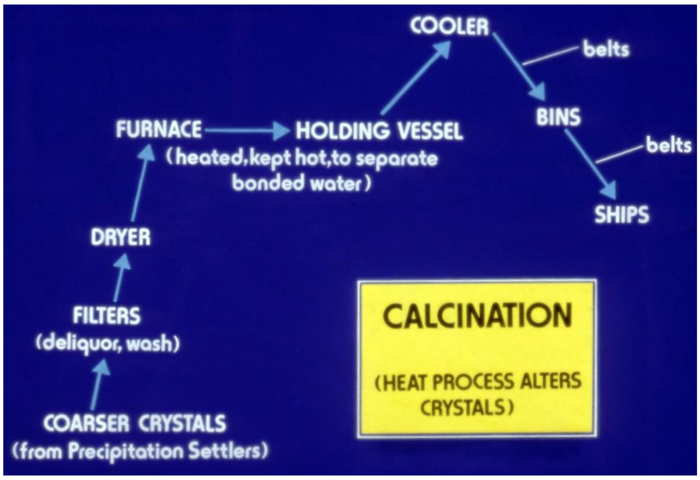
Precipitation takes place over at least 24 hours as the hydrate slurry passes through up to 10 precipitators in a train. The number and size of the vessels are necessary to accommodate the slow Precipitation step in the Bayer cycle; all other unit operations are much faster.

As the hydrate slurry (typically 500 g solids/L) passes down a precipitator bank the temperature is carefully reduced to provide a greater driving force for crystallization. The liquor (termed spent) leaving Precipitation is still somewhat saturated in dissolved aluminium. The yield of hydrate through the precipitator train is an important efficiency parameter. The greater the yield the more efficient the refinery.

i) Calcination

The aluminium hydroxide (hydrate, often expressed as $Al_2O_3.3H_2O$ rather than more correctly as $Al(OH)_3$) from Precipitation is required to be heated in some suitable fashion to remove the three molecules of “water” to produce anhydrous alumina (Al_2O_3) which is the desired smelter feedstock. The hydrate is in fact a genuine hydroxide and does not contain any water of crystallisation at all. Nevertheless, upon heating it does decompose with the release of three molecules of water per molecule of alumina produced, just as if it were a trihydrate.

$$2Al(OH)_3 \xrightarrow{\text{Heat}} Al_2O_3 + 3H_2O$$



In earlier times long rotary kilns were used for this Calcination; however, they are energy-intensive and have been superseded by Calciners using natural gas fuel. These calciners utilise the fluid-bed principle whereby the injected gas suspends the hydrate particles as they are carried through the Calcining profile over a period of seconds. The temperature applied is important, to ensure the right alumina product quality.

Gas Suspension (Fluid Bed) Calciners

The decomposition of the hydrate to alumina is by no means as simple as might be implied by the above equation. The ultimate product of calcination is the most stable phase of alumina, corundum or alpha alumina. This is, however, not desirable for smelting, because alpha-alumina is slow to dissolve in the bath. For the formation of Smelting Grade Alumina (SGA), calcination is carried out at around 950°C. At this temperature, the alpha-alumina content of SGA is generally kept at around 1%. The remainder is a complex mixture of anhydrous alumina phases.

Some fine alumina (less than 20 μm in size) is produced as a result of the vigorous treatment of the hydrate particles in calcination; for example, edges of crystals are broken off as the particles become more rounded. This fine alumina dust (ESP dust) is collected in electrostatic precipitators adjacent to the calciners.

The calcination of aluminium hydroxide (hydrate) to alumina is an endothermic reaction (that is, heat is absorbed). This aspect is put to good use as hydrate is applied as a fire retardant in the manufacture of, for example, carpets, textiles and building materials.

j) Scale Formation

The concentration of aluminium in the caustic liquor is well above its equilibrium value. Hence there is a driving force for hydrate to precipitate from solution in a less controlled way than that desired in the precipitation step. The result is that hydrate scale can form in pipes and vessels, including the precipitators. This leads to loss of hydrate yield in the Bayer process as well as inefficiencies due to reduced flows in pipe work and volume in tanks.

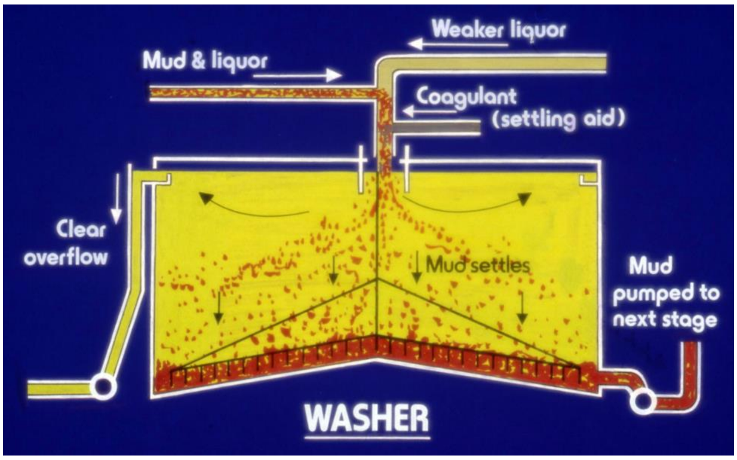
Maintenance programs ensure that the hydrate scale is removed on a regular basis, adding to the overall cost of operation. But the hydrate scale can be returned to digestion, ensuring the valuable alumina is recovered.

Other scales can form in various locations, for example Desilication scale in heat exchangers. This scale, which can form very hard deposits, cannot be removed by caustic attack; it is soluble in acids, so on a regular basis heat exchangers are taken off line and washed with sulfuric acid.

k) Mud Washing

The mud exiting the thickeners is comprised mainly of iron oxides and silica-based minerals, including quartz (SiO_2), as well as DSP and various calcium-based elements resulting from the addition of lime for causticisation.

Depending on the quality of the bauxite, the amount of mud can be between 1-2 times the amount of alumina produced. To minimise loss of alumina and caustic soda in the liquor associated with the mud exiting the thickeners, it is directed to a series of washers (usually 5 to 6 in a train for each unit). The wash water (lowest liquor concentration) entering the last washer exits at the top (overflow) and then is used as the wash water in the preceding washer; the underflow from the preceding washer enters the last washer. The underflow from the last washer is pumped to disposal areas. This process is termed counter current decantation and at each of the washing step the liquor concentrations are reduced and the overflow liquor from the first washer is concentrated by evaporation and returned to the Bayer circuit.



l) Red Mud Generation

An alumina refinery of, say, 4 million tonnes per year production could produce around 8 million tonnes of mud (termed residue), dependent on the quality of the bauxite ore. Such an amount, and its special properties, requires stringent conditions on its proper disposal. The residue is caustic (alkaline) in nature, due to:

- Some residual entrained caustic liquor, which is a combination of sodium hydroxide and sodium carbonate (formed from sodium hydroxide by carbonation with CO2); and
- The DSP which decomposes in less alkaline environments to release sodium hydroxide.

The residue is so fine grained in size (significant proportions are less than 45 µm and some less than 20 µm) that when it dries it can result in caustic dusts forming.

m) Impurity Balances and Removal including Liquor Purification

The organic materials such as soil and tree roots within the bauxite which as mentioned earlier in this report, enter the Bayer circuit are attacked by the high caustic concentration and temperature in digestion. The high molecular weight (up to a million) of the humic material breaks down to a complex mixture of lower molecular weight compounds. Some of these are quite simple, such as the sodium salts of formic (HCOOH) and acetic (CH_3COOH) acids. The most prevalent is sodium oxalate, $Na_2(COO)_2$. The sodium oxalate concentration in the liquor builds up to a saturation level where, if not reduced, it will contaminate the hydrate being crystallised in Precipitation. Therefore, steps are taken to reduce the oxalate by treating a side stream of the spent liquor. In one process the sodium oxalate is crystallised from solution, filtered off, washed and put through a kiln or calciner where it decomposes to sodium carbonate:

$Na_2(COO)_2 \rightarrow Na_2CO_3 + CO$

The sodium carbonate is then converted back to sodium hydroxide by the lime addition in grinding.

A newer process utilises the ability of “bugs” (naturally occurring microorganism or bacterium) which selectively “consume” the oxalate and produce sodium carbonate.

The oxalate is seen as a detrimental impurity in the liquor as it can affect the quality of the hydrate product. However, there are other organic impurities in the liquor stream that are beneficial: they aid in maintaining the hydrate concentration in liquor well above the equilibrium value (the liquor is supersaturated with hydrate) and so enable controlled crystallisation in the Precipitation step rather than random crystallisation in other unit operations.

Depending on the origin and nature of the bauxite ore, the amount of organic material can range from 0.01% to 0.35% by weight, expressed as organic carbon. This organic mass can build up to substantial levels in the liquor (total organic carbon contents of up to 30 g/L). This can affect the viscosity of the liquor, requiring more energy in pumping and other side effects. So a process called *liquor burning* has been implemented in some plants: a small side stream of the spent liquor is mixed with fine alumina dust (ESP dust produced in Calcination) and treated in a kiln. The organics are burned off to carbon dioxide. The product is solid sodium aluminate which is dissolved back into the spent liquor.

Inorganic anions such as chloride and sulfate enter the Bayer circuit from within the bauxite and in process water added. These species build up to equilibrium levels and exit the circuit entrained in the DSP cage structure.

n) Water Usage and Balance

Maintaining the optimal water balance in a refinery is challenging. Inputs and outputs include:

Water In:	**Water Out:**
Free moisture in bauxite	Moisture in hydrate
“Water” in gibbsite & boehmite	Hydrate to calcination
Injected stream	Evaporation
Caustic soda	Heat interchange flashing
Residue washing	Water in residue
Hydrate washing	
Rain	

At the residue storage area, which has a significant footprint, rainfall may add to the water balance and the supernatant liquor formed returned to the refinery. Alternatively, evaporation (in a hot climate) may exceed rainfall and make-up water may need to be added to the refinery circuit. Water is a valuable resource, so any addition (from scheme water or more usually from bores or groundwater) should be minimised. Up to 4 kL of water are required for each tonne of alumina produced.

2.5.2 Smelting to Aluminium

The Hall-Heroult Process, currently used worldwide for the production of aluminium from alumina, is two years older than the Bayer Process! In 1886, Charles Martin Hall in the USA and Paul Heroult in France independently discovered that alumina, dissolved in a molten bath of sodium aluminium fluoride (cryolite, Na3AlF6), could be successfully electrolysed to aluminium metal. The overall reaction is:

$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2$ (Just about 2 tonnes of alumina are needed to produce one tonne of metal).

The alumina is fed into the top of the pot and dissolves in the molten cryolite at temperatures around 900°C. The cryolite is contained in a carbon cathode (the base of the pot); electrolysis occurs in conjunction with the carbon anodes. The molten aluminium (melting point 660°C) collects on top of the cathode and is occasionally siphoned off; carbon dioxide is emitted from the pot.

Since the smelting environment involves fluorine in various salts, reaction with moisture can form hydrogen fluoride gas. The alumina delivered to a smelter is first used as an adsorbent to scrub out this HF in the gas streams exiting the pots; this is why the alumina should have an adequate surface area.

Smelting of alumina to produce aluminium is energy-intensive: about 51 Gigajoules per tonne of metal (more than four times the energy needed to produce the alumina and sufficient to operate a 1 kW electric heater for a year!). This is why aluminium is sometimes referred to as canned electricity (as so much metal goes into making drink cans!). However, the positive side is that aluminium can be recycled, and producing new metal from recycled stock takes less than 5GJ per tonne (compared to the 51GJ for primary metal). And recycling rates are steadily increasing; in some counties it is greater than 70%. The components of a typical smelting cell (termed *pot*) are shown below:

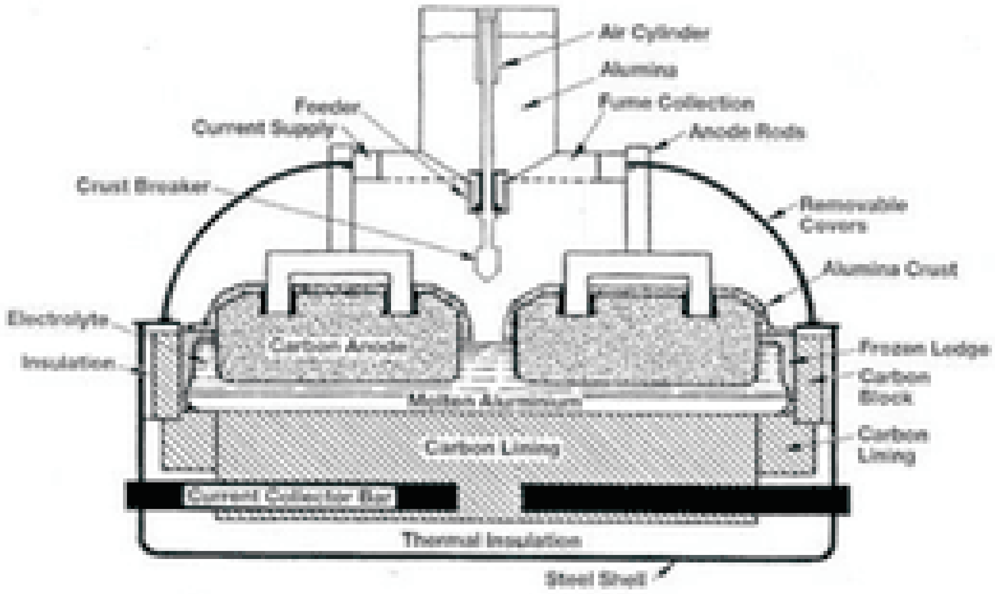


Figure 6: The components of a typical smelting cell (termed pot)

In this overview of an alumina refinery notice the predominant colours: white in the foreground and red behind. This reflects what is happening in the unit operations: the "white" side involves mainly handling hydrate and alumina, whereas the "red" side involves mainly bauxite and residue which exhibit the ruddy colouration of iron oxides.

2.5.3 Other Bauxite Refining Processes

Historically, the Alumina manufacturing processes in China and Russia have been very different from the rest of the world due to the nature of the naturally occurring bauxite minerals there. They adopted lime sintering process for production of alumina from boehmite and diaspore bauxites for producing alumina from low grade bauxite in these countries. The process involves a pyro-metallurgical sinter approach, which produces aluminium while "locking up" the silica as clinker, thus preventing it from contaminating the alumina. The clinker residue left behind in the sintering processes is known as white mud or bellite (dicalcium silicate, Ca2SiO4) and it can be used for manufacturing cement (as opposed to Red Mud, which requires landfilling). These methods enabled recovery of the residue components to produce cement, soda, potash, alumina, and hydroxide. At some refineries in Russia, nepheline (instead of bauxite) is sintered with limestone to produce alumina.

The lime sintering process was once a mainstay of the Chinese alumina industry. However, the capital and operational costs are significantly higher with lime sintering than the Bayer process. China has also become more dependent on imported bauxite ore, which has significantly altered the characteristics and composition of the residues produced. Thus, the sinter process has gradually been replaced by the Bayer process.

In Russia, UC Rusal Engineering and Technology Centre has studied and performed mini-plant tests for using the sinter process to produce superfine alumina precipitated trihydrate (ATH).The process deficiencies in limestone sintering for metallurgical alumina production (high thermal energy and electrical power consumption) allows for production of chemical grade ATH with a high quality and low production cost. This could offset the added costs of the limestone sintering process.

An alternative technology for alumina production is under development in Russia for production of alumina from local non-bauxite ores. This is known as a hydrochloric acid technology for smelter grade alumina production from kaolin to level of 94.5% and the extraction of aluminium chloride from the solution of 92%.

2.5.4 Alumina Refineries and its Production

There are over 80 alumina refineries across the world (2019 data) producing alumina from bauxite ore. The global annual production of alumina in 2017 was approximately 130 million tonnes. The figure below shows the world's leading producers of Alumina and aluminium.

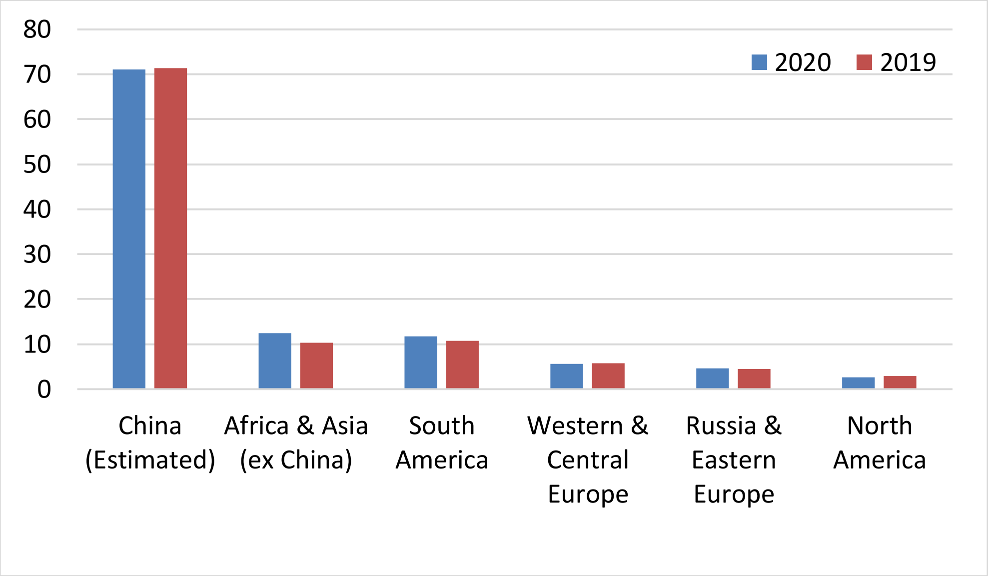


Figure 7: World's leading producers of Alumina

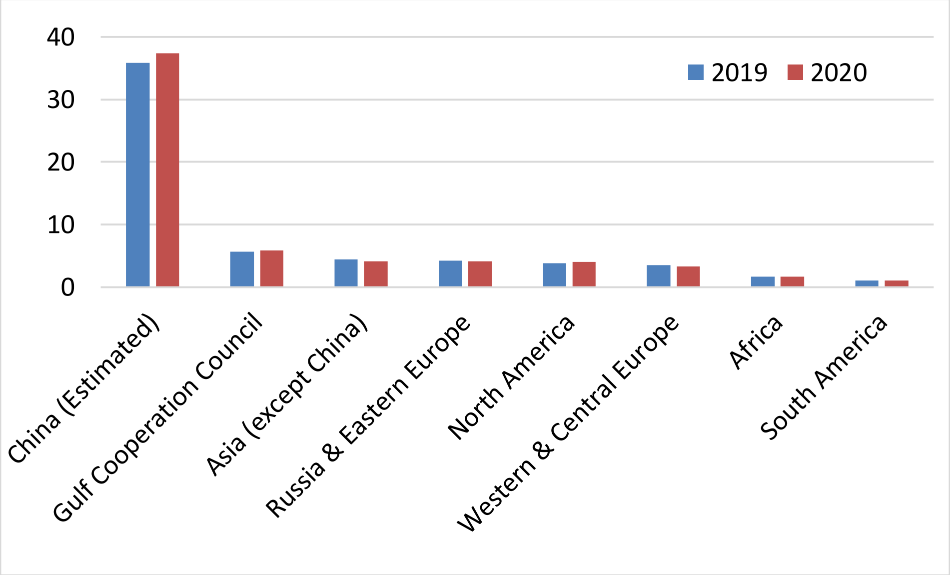


Figure 8: World's leading producers of aluminium

In India, there are six operating and two closed alumina industries which are/were generating Red Mud. The list of these industries and the data on their annual alumina production vis- vis bauxite consumption are given below:

1. **Name of the Industry** Hindalco Industries Ltd, Muri, Jharkhand

   Year of Establishment 1948

S.No.	Year	Bauxite Consumption (MT)	Annual Alumina Production (MT)
1.	2015-2016	1013954	299119
2.	2016-2017	1158369	348038
3.	2017-2018	1188599	339400
4.	2018-2019	1067527	305100
5.	2019-2020	294496	91600

2. **Name of the Industry** Hindalco Industries Ltd, Renukoot, Uttar Pradesh

   Year of Establishment 1962

S.No.	Year	Bauxite Consumption (MT)	Annual Alumina Production (MT)
1.	2015-16	2054249	708357
2.	2016-17	2006550	709992
3.	2017-18	2000767	684296
4.	2018-19	1990374	685885
5.	2019-20	1991493	690611

3. **Name of the Industry** Hindalco Industries Ltd, Belgaum, Karnataka

   Year of Establishment 1969

S.No.	Year	Bauxite Consumption (MT)	Annual Alumina Production (MT)
1.	2015-16	791209	128818
2.	2016-17	934714	151650
3.	2017-18	987524	185401
4.	2018-19	1003222	189062
5.	2019-20	906825	168156

4. **Name of the Industry** Vedanta Limited. Lanjigarh, Odisha

   Year of Establishment 2007

S.No.	Year	Bauxite Consumption (MT)	Annual Alumina Production (MT)
1.	2015-16	3108800	970893
2.	2016-17	3727600	1207957
3.	2017-18	3739000	1209436
4.	2018-19	4404500	1500670

5. **Name of the Industry** National Aluminum Company Ltd (NALCO), Damanjodi, Odisha

Year of Establishment 1981

S.No.	Year	Bauxite Consumption (MT)	Annual Alumina Production (MT)
1.	2015-16	6285119	1910000
2.	2016-17	6929194	2032500
3.	2017-18	6918511	2111000
4.	2018-19	7086477	2107000
5.	2019-20	7873244	2089500

6. **Name of the Industry** Utkal Alumina International Ltd, Rayagada, Odisha

Year of Establishment 2013

S.No.	Year	Bauxite Consumption (MT)	Annual Alumina Production (MT)
1.	2015-16	4528000	1402100
2.	2016-17	4729000	1499600
3.	2017-18	4790000	1499700
4.	2018-19	4927000	1553600

7. **Name of the Industry** Bharat Aluminum Company Ltd (BALCO), Korba, Chhattisgarh

The plant was commissioned in 1973 and was operational upto September 2009.

8. **Name of the Industry** Madras Aluminum Company Ltd (MALCO), Mettur Dam, Tamil Nadu

The industry started its commercial production in the year 1965 and operations were closed in 2008.

3. GENERATION AND PROPERTIES OF RED MUD (RM)

a) Generation

The specific generation of RM per tonne of alumina from the plants (more than 95%) which using the Bayer process ranges between 1 and 1.5 tonnes globally, though the amounts from different plants are much broader. It is estimated that about 140 million tonnes of RM is produced annually. The Global (country wise) generation of Red Mud for the year 2019 (India data from April 2018 to March 2019) is given in Figure below.

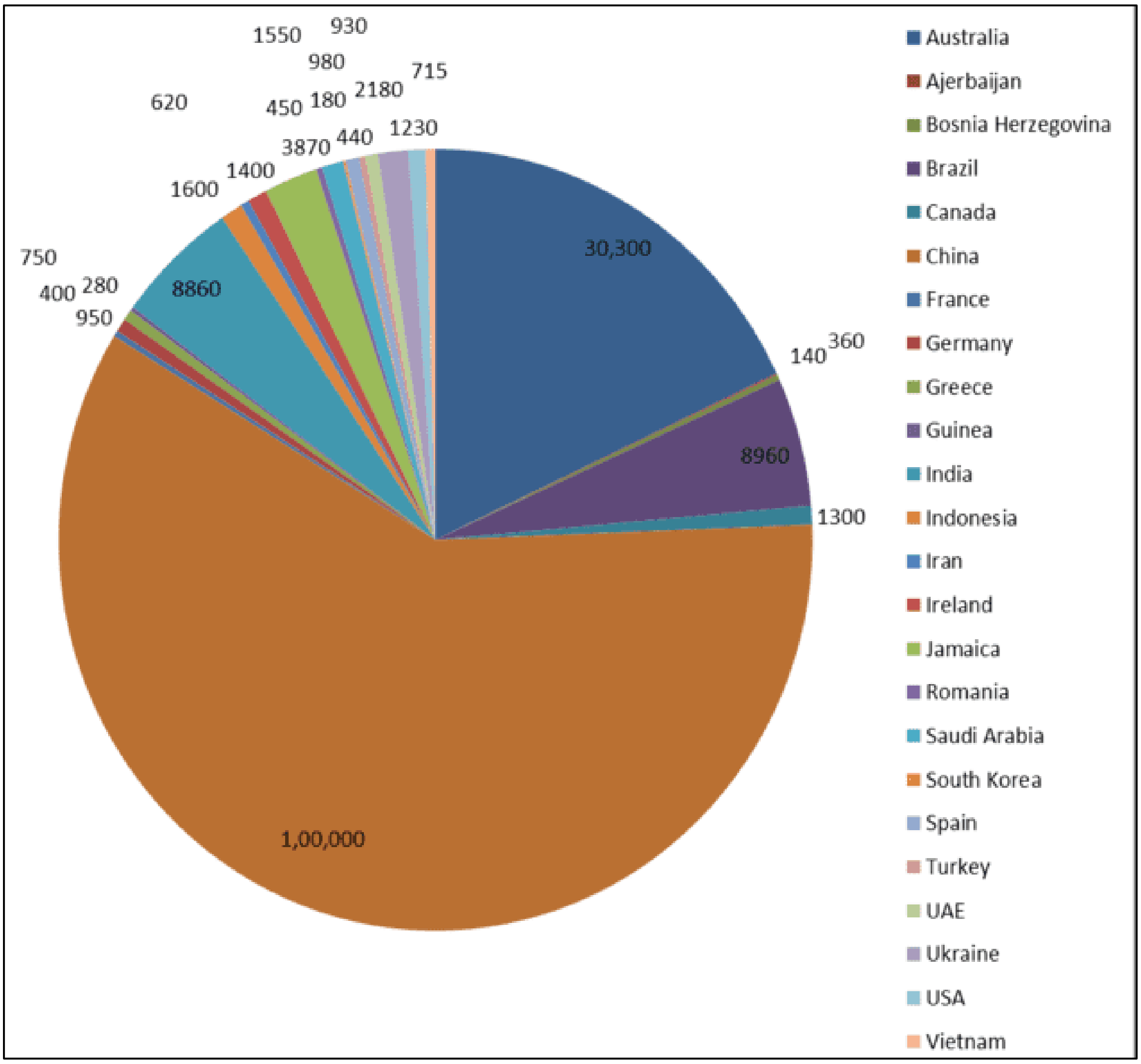


Figure 9: Global generation of Red Mud

In India, there are 06 Red Mud generating units and the details on the quantity of Red Mud generated annually by each of the industry is given below:

Table 2: Red Mud Generation in India

S.No	↓Name of units Years →	Quantity of Red Mud Generated (MT)						
		2015-16	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
1.	M/s Hindalco Industries Ltd, Jharkhand	525332	590959	610020	542855	143368	533595	715833
2.	M/s Utkal Alumina International Ltd., Odisha	1914000	1974000	2049000	2082000	2232705	5044648	2408246
3.	M/s Vedanta Limited. Odisha	1497733	1626194	1694693	1758462	2112688	2272953	2506121
4.	M/s NALCO Ltd., Odisha	2789160	3137853	3096637	3057509	3351021	3234786	3241446
5.	M/s Hindalco Industries Ltd., Uttar Pradesh	928515	972319	968029	946208	1438701	991249	1044645
6.	M/s Hindalco Industries Ltd, Belgaum	356878	434358	443910	468399	580092	438539	513786

INA: Information Not Available

b) Composition of Red Mud

The typical composition of the RM from the metallurgical and mineralogical point ad its properties are given below:

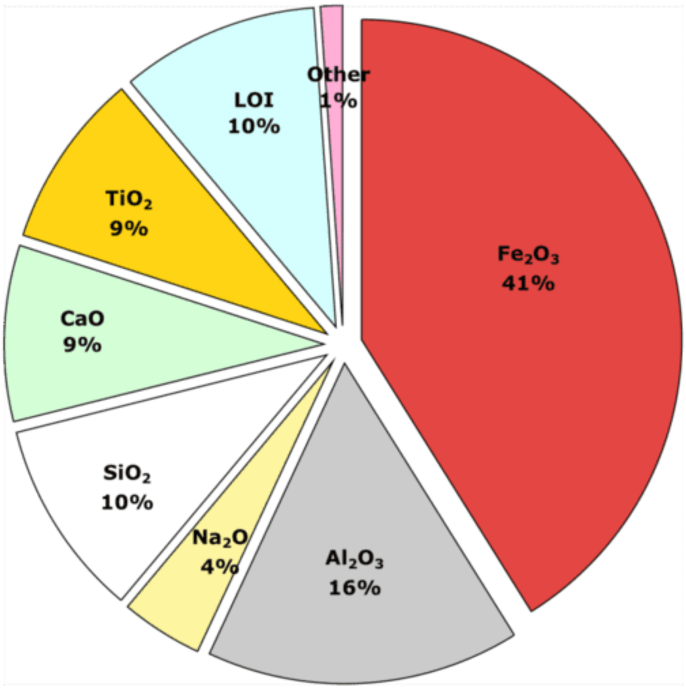


Figure 10: Composition of Bauxite Residue: Metallurgical View

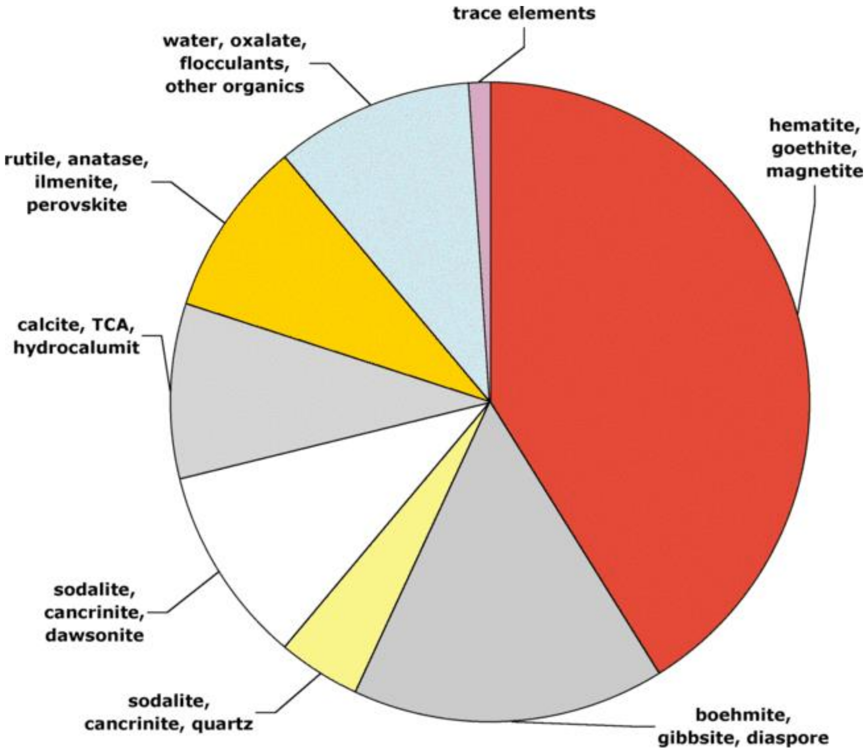
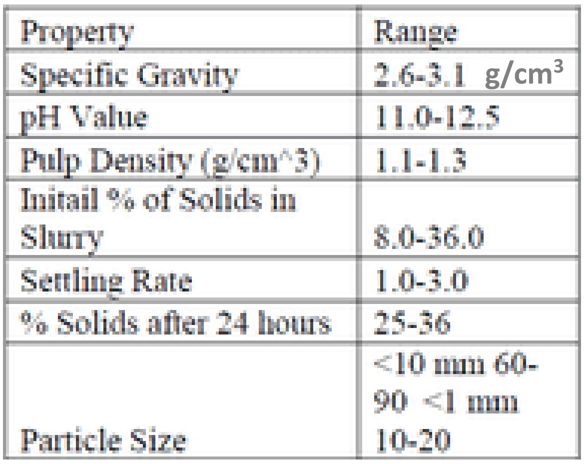


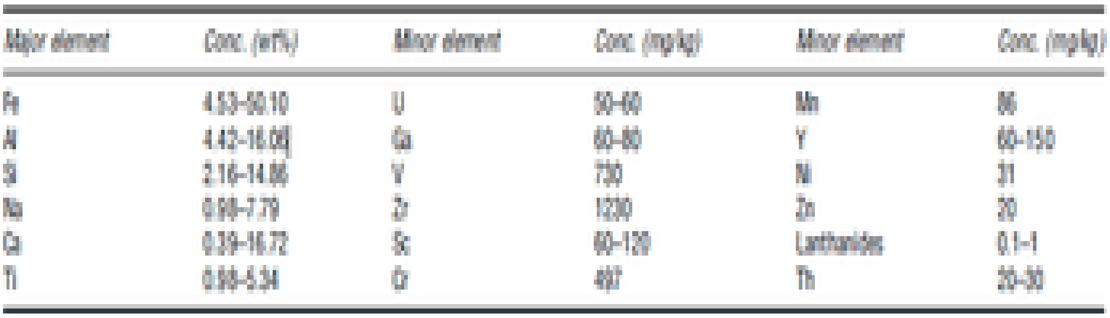
Figure 11: Composition of Bauxite Residue: Mineralogical View

General Properties of Red Mud

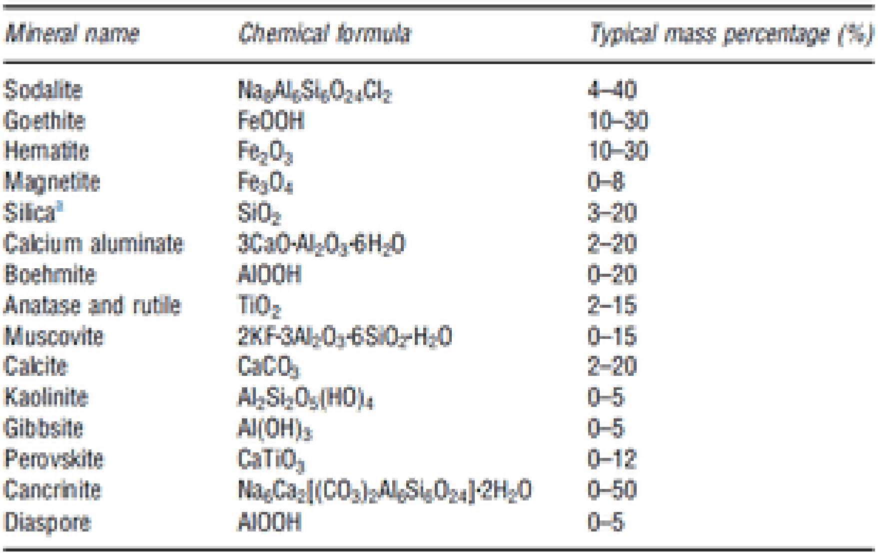


Property	Range
Specific Gravity	2.6-3.1 g/cm³
pH Value	11.0-12.5
Pulp Density (g/cm^3)	1.1-1.3
Initail % of Solids in Slurry	8.0-36.0
Settling Rate	1.0-3.0
% Solids after 24 hours	25-36
Particle Size	<10 mm 60-90 <1 mm 10-20

Typical Chemical Composition of Red Mud



Major element	Conc. (wt%)	Minor element	Conc. (mg/kg)	Minor element	Conc. (mg/kg)
Fe	4.53–50.10	U	50–60	Mn	86
Al	4.42–16.08	Ga	60–80	Y	60–150
Si	2.16–14.86	V	730	Ni	31
Na	0.98–7.79	Zr	1230	Zn	20
Ca	0.39–16.72	Sc	60–120	Lanthanides	0.1–1
Ti	0.88–6.34	Cr	497	Th	20–30



Mineral name	*Chemical formula*	*Typical mass percentage (%)*
Sodalite	$Na_8Al_6Si_6O_{24}Cl_2$	4–40
Goethite	$FeOOH$	10–30
Hematite	Fe_2O_3	10–30
Magnetite	Fe_3O_4	0–8
Silica[a]	SiO_2	3–20
Calcium aluminate	$3CaO{\cdot}Al_2O_3{\cdot}6H_2O$	2–20
Boehmite	$AlOOH$	0–20
Anatase and rutile	TiO_2	2–15
Muscovite	$2KF{\cdot}3Al_2O_3{\cdot}6SiO_2{\cdot}H_2O$	0–15
Calcite	$CaCO_3$	2–20
Kaolinite	$Al_2Si_2O_5(HO)_4$	0–5
Gibbsite	$Al(OH)_3$	0–5
Perovskite	$CaTiO_3$	0–12
Cancrinite	$Na_6Ca_2[(CO_3)_2Al_6Si_6O_{24}]{\cdot}2H_2O$	0–50
Diaspore	$AlOOH$	0–5

Figure 12: The general properties and typical chemical and mineralogical compositions of the Red Mud (a - Crystalline and Amorphous).

A wide range of other components may be present at lower levels; these will invariably be as metallic oxides, e.g., arsenic, beryllium, cadmium, chromium, copper, gallium, lead, manganese, mercury, nickel, potassium, scandium, thorium, uranium, vanadium, zinc, zirconium, and rare earth elements (REEs). Non-metallic elements that may occur in the bauxite residue are phosphorus, carbon, and sulfur.

The minerals present are complex and comprise some which are present in the bauxite and others that are produced during the autoclaving and desilication processes. In addition, there are various other minerals sometimes found at low levels including brookite (an orthorhombic variant of TiO2), ilmenite (FeTiO3), carnegieite (Si4Al4 Na4O16), dolomite (CaMg(CO3)2), hydrogarnet (Ca3Al2 (O4H4)3), various hydroxycancrinite/cancrinite (Na6Ca2 (Al6Si6O24)(CO3)2_2H2O), (Na,Ca)8(Al,Si)12O24(CO3)- 4H2O), cancrinite-NO3 (Na7.92Si6Al6O31.56N1.74), cancrisilite- CO3 (Na7.86(AlSiO4)6(CO3)(H2O)3.3), katoite-Si (Ca3Al2(SiO4)(OH)8), lawsonite (CaAl2Si2O7(OH)2_H2O), nepheline (Na2KAl4Si4O16), nosean (Na8Al6Si6O24(SO4)), portlandite (Ca(OH)2), schaeferite ((Na0.7Ca.2.3)(Mg1.85 Mn0.15)(VO4)2.88(PO4)0.12)), sodium titanate (Na2TiO3), and zircon (ZrSiO4) .

Sodium is the only element not found in the bauxite itself. Some of the elements are soluble in the Bayer process and either build up in the Bayer liquor or precipitate along with the aluminium hydroxide. Depending on their solubility and the temperature used in the extraction process, some elements will increase in concentration in the RM relative to the bauxite while others will be lower in the RM. Other than caustic soda, lime is normally the only other inorganic compound introduced during the Bayer process. The sodium in bauxite residue may be present in a sparingly soluble form, called the desilication product (DSP) or a very soluble form. The small quantities of some of the soluble sodium compounds resulting from the sodium hydroxide used in the extraction process will remain depending on the dewatering and washing systems used. ***All Bayer alumina refineries try to maximize the recovery of the valuable caustic soda from the residues in order to reuse it during the extraction process. The residual soluble sodium, predominantly a mixture of sodium aluminate and sodium carbonate, give rise to an elevated pH for bauxite residue slurries. Over time, the***

***residual sodium is partially neutralized by carbon dioxide from air to form sodium carbonate and other metal carbonate that may result in a lower pH for the RM*.** The desilication product (3Na2O_Al2O2_2SiO2_0-2H2 O_2NaX where X could be CO3 2-, Cl-, OH-, SO42-, or Al(OH)4 -) arises from the reaction between sodium aluminate and soluble sodium silicates.

c) Leaching Characteristics of Red Mud

The Leaching assessment of Red Mud is based on combined evaluation of results from pH dependence, percolation and mass transfer tests and reportedly provides a robust framework for evaluation of a wide range of disposal, treatment and utilisation scenarios for Red Mud.

The most important aspects of RM in the context of its leaching characteristics reported are as follows:

- Total elemental content does not correctly represent the leaching behaviour of most elements and therefore is not recommended as the basis for assessing environmental compatibility.
- Leaching behaviour of Red Mud is consistent within a defined bandwidth for many elements and samples from several sources. The impacts of neutralization, carbonation and redox conditions on Red Mud leaching are evident through the leaching assessment testing.
- Geochemical speciation modelling provides additional insights into the chemistry controlling observed leaching behaviour and facilitates estimating the leaching behaviour of a material under different conditions and exposure times. Verification testing is needed to confirm geochemical speciation modelling results.
- Establishment of a database for leaching characteristics of Red Mud samples from a variety of sources will provide a basis for comparison and an understanding of disposal, treatment and use options. It will also serve as the reference basis for ongoing quality control during Red Mud production, use and disposal.
- Statistical quality control of Red Mud as a product is possible using reduced testing at a frequency linked to the probability of exceeding a specified threshold value, focusing on key quality control parameters.
- There is promising evidence that eco-toxicity testing results can be linked to results from leaching assessment and geochemical speciation, suggesting a pathway to more integrated testing and evaluation in different contexts.

Use of leaching assessment based on the pH dependence, percolation and mass transfer tests is in the process of being adopted as part of regulatory frameworks in the European Union and the United States, and is under consideration in other countries.

LeachXS Lite is a free data management and visualization tool developed with support from USEPA that provides a clear overview and facilitates interpretation of the results from leaching tests, including the Leaching Environmental Assessment Framework (LEAF) test methods (USEPA SW846 Methods 1313, 1314, 1315 and 1316). The details of this software are available at (http://leachxs.vueinnovations.com/licensing/leachxslite). The software facilitates (i) maintaining a Red Mud leaching assessment database, (ii) geochemical speciation modelling of a range of Red Mud testing, use, treatment and disposal scenarios, and

(iii) statistical quality control of Red Mud production. Databases can be tailored to the aluminium industry user community.

The pH of the material is crucial in determining the release of many constituents. This is valid for all sorts of materials (monolith, granular, cements, soil, waste, sediment etc.). The pH value of the surrounding environment determines the maximum water phase concentration at that pH value, and each material has its own pH-dependent release curve. Release curves are similar and systematic for different groups of elements, only the absolute level may differ between different materials. This implies that the solubility controlling phases are the same; only the relative importance of the influencing factors may differ from one material to another (Fe oxides, Mn oxides, Al oxides, clay and organic matter). The strong influence of pH on release is because the dissolution of most minerals, is pH dependent. That means that the release of virtually all contaminants that are solubility controlled show pH dependent release. The general shape of the release curves is shown below:

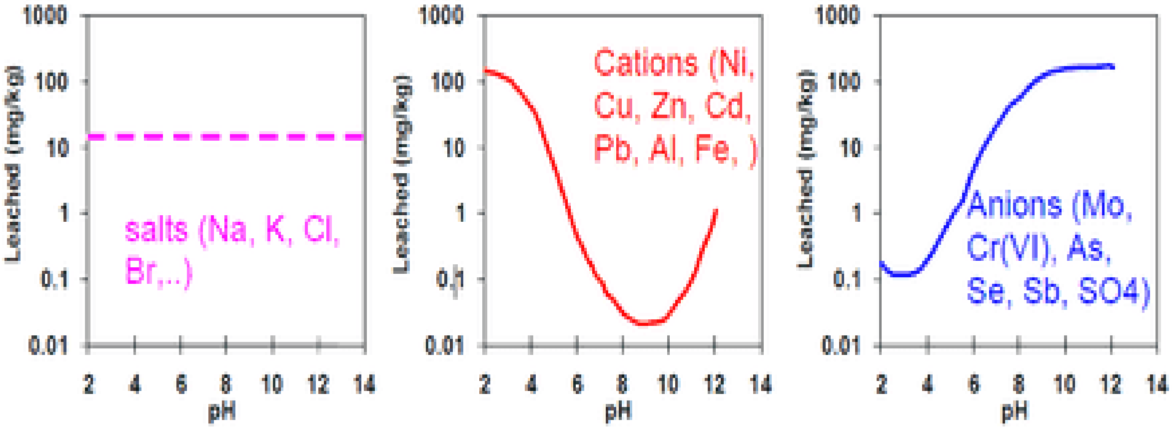


***Figure 13:* General leaching behaviour of three groups of constituents as a function of pH**

The leachability of metals at various Red Mud generating units in India in terms of Toxicity Characteristic Leaching Procedure (TCLP) and Soluble Threshold Limit Concentration (STLC) are given below:

Table 3: Leaching Analysis of Red Mud

S.No.	Sample	STLC					TCLP			
		Co (mg/l)	Ni (mg/l)	Sb (mg/l)	V (mg/l)	Zn (mg/l)	As (mg/l)	Cr (mg/l)	Pb (mg/l)	Se (mg/l)
1.	M/s Hindalco Industries Ltd., Muri, Jharkhand	0.03-0.1	0.03-0.26	BDL	8.48-14.21	0.05-0.33	BDL	0.02-0.31	BDL	BDL-0.01
2.	M/s Vedanta Ltd., Lanjigarh, Odisha	BDL-0.04	BDL-0.13	BDL	0.32-3.62	0.07-0.12	BDL	0.01-0.63	BDL	BDL
3.	M/s Utkal Aluminium Ltd.,	BDL-0.01	0.03-0.04	BDL	1.01-1.42	0.12-0.13	BDL	0.75-0.80	BDL	BDL

S.No.	Sample	STLC					TCLP			
		Co (mg/l)	Ni (mg/l)	Sb (mg/l)	V (mg/l)	Zn (mg/l)	As (mg/l)	Cr (mg/l)	Pb (mg/l)	Se (mg/l)
	Rayagada, Odisha									
4.	M/s NALCO Ltd., Damanjodi, Odisha	BDL-0.01	0.04-0.06	BDL	1.23-1.77	0.14-0.43	BDL	0.61-1.00	BDL	BDL
5.	M/s Hindalco Industries Ltd., Renukoot, Uttar Pradesh	BDL-0.04	BSl-0.03	BDL	0.79-2.52	0.17-0.45	BDL-0.01	0.02-0.26	BDL	BDL-0.02

d) Alkalinity and Buffering Capacity of Red Mud

The main contribution to pH buffering is the ability of the solids to maintain the concentration of the alkaline anions in solution. This is known as the ***buffering capacity*** of the RM and entails alkaline anions that are present in both soluble and solid forms. In order to buffer, the solids need to be soluble to some degree, and some degree of H^+-acceptance by the alkaline anion in solution is required. Above pH 10.2 and in the absence of excess Ca^{2+}, Na_2CO_3 controls the concentration of HCO_3^-/CO_3^{2-} in solution, because calcite ($CaCO_3$) is virtually insoluble. Hence, Na_2CO_3 and other alkaline solids which are more soluble at pH > 10 buffer the solution pH.

In the RM, the main alkaline anions buffering the solution are HCO_3^-/CO_3^{2-}, $Al(OH)_4^-$ and OH^-. Other, less concentrated anions, which may help to buffer the solution pH as well, are $H_2SiO_4^{2-}H_3SiO_4^-/H_4SiO_4$, VO_4^{3-}/HVO_4^{2-} and $PO\ ^{3-}/HPO_4^{2-}\ /H_2PO_4^-$.

It may therefore be summarised that the chemistry of RM is dominated by the presence of multiple alkaline solids, which impart significant acid neutralising capacity. The pH in RM solutions is 11.3±1.0 and ranges between 9.7 and 12.85. Thus RMs are highly alkaline and will not support plant life. The alkaline pH of RMs is strongly buffered by the presence of alkaline solids (hydroxides, carbonates and aluminates) that are formed by the action of caustic soda on bauxite in the Bayer process refinery, leading, among other, to the formation of Bayer process characteristic solids (BPCSs). The buffering action of multiple BPCSs causes the acid neutralisation reactions of the RMs to be highly complex. While it is impractical to remove the alkalinity from RM by washing with water or mineral acids, the alkalinity of RMs needs to be abated because it has profound implications for all aspects of Red Mud, including: storage requirements, raw materials usages and recoveries, neutralisation, sedimentation rates, bulk density, compaction, hydraulic conductivity, drying rates, dusting behaviour, and physical strength after drying.

e) Radioactivity of Red Mud

CPCB conducted a meeting with Department of Atomic Energy (DAE) and Atomic Energy Regulatory Board (AERB) to discuss the aspects of handling, utilization and disposal of Red Mud in respect to its radioactivity. ARB informed that the trigger value for any naturally occurring radionuclides of 238U or 232 Th decay series is 1Bq/gm and for 40K is 10 Bq/gm may be incorporated in the guidelines for radioactivity analysis of bauxite and Red Mud.

Further, M/s Hindalco Industries Ltd., carried out radioactivity analysis of Red Mud and the measurement values are below the trigger values stipulated by AERB. The analysis report is placed at Fig below:

ULR-TC66651900000 2372F

[redacted]

NO. 474 A 47372

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रेडियोसक्रियता परीक्षण प्रमाण-पत्र / RADIOACTIVITY TEST CERTIFICATE

Page 1 of 1

RADIOANALYTICAL LABORATORY

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NAVI MUMBAI 410208
MAHARASHTRA, INDIA

This is regarding the **RED MUD/BAUXITE SAMPLES** sent for radioactivity testing vide your letter dated 29.11.2019, with the following details:

NAME OF FIRM/COMPANY : HINDALCO INDUSTRIES LIMITED
PLOT NO.2, MIDC TALOJA AV,
NAVI MUMBAI, 410208
MAHARASHTRA, INDIA

The samples were analysed for U-238,Th-232, Ra-226 and K-40 radioactivity content and the values obtained are as follows:

SL. NO.	DETAILS OF SAMPLE	U-238 (Bq/Kg)	Th-232 (Bq/Kg)	Ra 226 (Bq/Kg)	K-40 (Bq/Kg)
1	HICA-RM-1 BELGAUM DMS	71.7 ± 8.5	135.8 ± 12.6	MDL 1.23	32 ± 2.6
2	HICA-RM-2 UTKAL DMS	53.2 ± 7.3	470 ± 27.4	3.5 ± 2.6	30.6 ± 2.4
3	HICA-RM-3 MURI DMS	89.6 ± 9.5	144 ± 12.8	87.5 ± 9.5	MDL 6.1
4	HICA-RM-4 RENUKOOT DMS	90.1 ± 9.6	164.5 ± 13.6	11.1 ± 3.3	5.8 ± 0.5
5	HICA-BXT-1 GMC-BXT-BELGAUM	70.9 ± 8.5	81.4 ± 9.5	24.2 ± 4.9	MDL 6.1
6	HICA-BXT-2 PAKHAR-BXT-MURI	37.7 ± 6.2	73.6 ± 9.0	40.9 ± 6.4	MDL 6.1
7	HICA-BXT-3 RICHIGUTA-BXT-RENUKOOT	47 ± 6.9	81.4 ± 9.5	MDL 1.23	MDL 6.1
8	HICA-BXT-4 UTKAL-BXT	20.8 ± 4.6	243 ± 27.8	MDL 1.23	MDL 6.1

Date of receipt of sample : 29.11.2019 *Date of completion of test : 17.12.2019*

The measurement values are below the clearance level for radionuclides of natural origin in bulk solid materials, as per AERB directive 01/2010 (table-3) dated 26/11/2010.

NOTE : (i) This report pertains to the given sample only. (ii)The sample will be retained in this laboratory for a period of one month from certificate date and thereafter it will be disposed off. (ii) The sampling is not done by this laboratory.

Checked by:
(AJAY·N·THAMKE)

Authorised Signatory:
20/12/2019

एन. जयचंद्रन / N. Jayachandran
प्रभारी अधिकारी / Officer-In-Charge
Radioanalytical Laboratory
Board of Radiation & Isotope Technology
सेक्टर / Sector-20, वाशी संकुल / Vashi Complex
नवी मुंबई / Navi Mumbai - 400 703

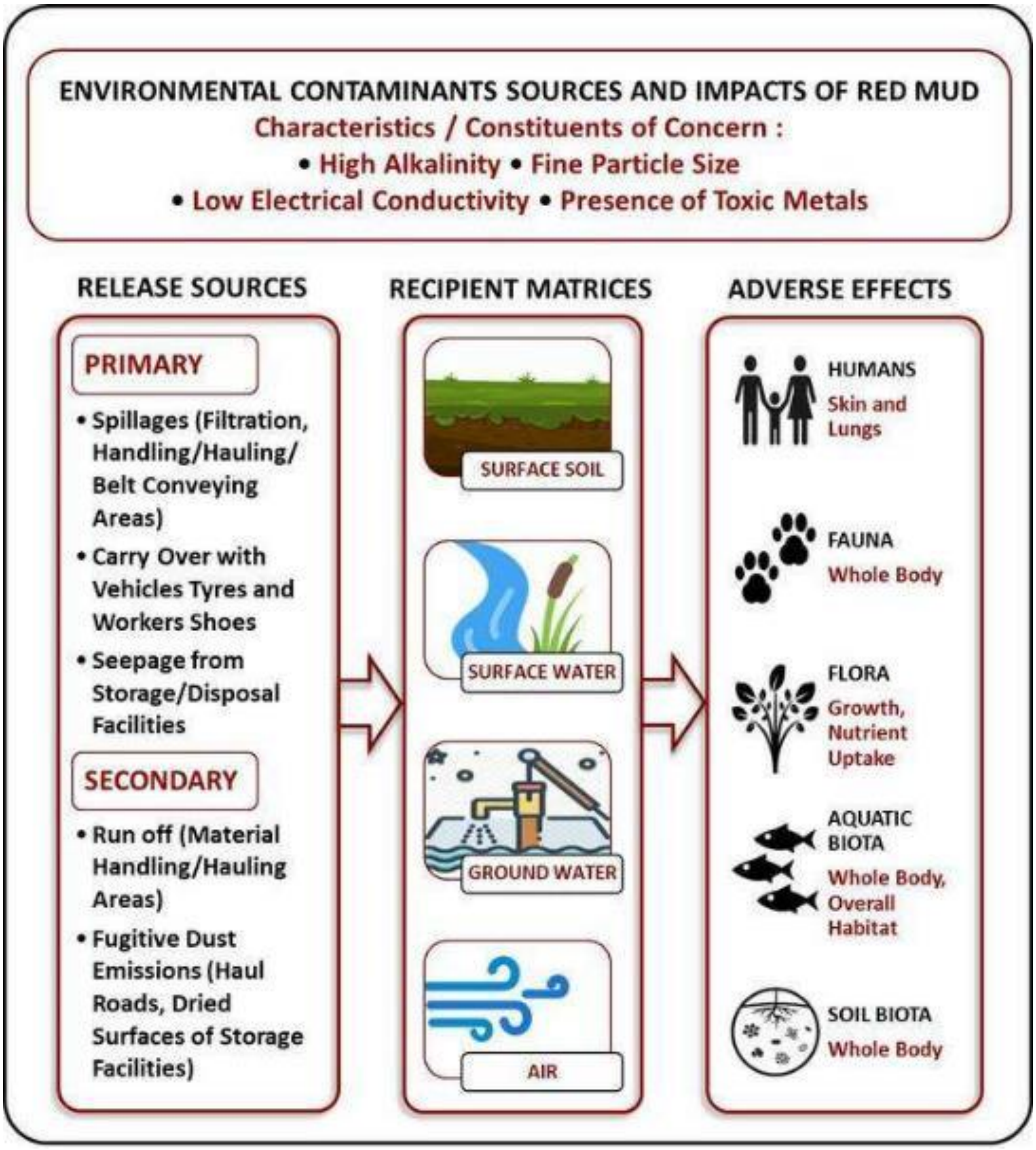
****End of Report****

Figure 14: Red Mud Radioactivity Analysis Report

4. ENVIRONMENTAL CONTAMINANTS SOURCES AND IMPACTS OF RED MUD

4.1 Contaminants Release to Impacts Cycle

The cycle of Red Mud contaminants release, the recipient systems, the receptors and impacts is depicted in the figure given below:



4.2 Characterisitcs and Constituents of Concern

Red Mud which is also known as Bauxite Residue and Alumina Refinery Residue, has been classified into diffeerent categories namely, hazardous waste, by product, non - hazarodus industrial waste etc under the regualtions of different countires. The Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 (HOWM Rules 2016) notified by the Govt. of India under the Environment (Protection)

Act, 1986, exempts Red Mud from the scheduled category of hazardous waste and instead classifies it as a “High Volume Low Effect Waste”.

Red Mud is a highly alkaline waste with a pH of about 12-13 containing traces of toxic heavy metals (Chromium, Arsenic, Cadmium etc.) and radionuclides. The information submitted by the industries in India includes an alkali level in the Red Mud as high as 1.5%. The average particle size of the Red Mud ranges between 2 to 100 µm which means from silt to a fine sand textural class and easy to be blown with wind as fine dust. The high alkalinity, fine particle size and presence of heavy metals are therefore a matter of concern in dealing with this waste.

4.3 Sources of Release to Environment

4.3.1 Primary Sources

a) *Spillages (Filtration, Handling/Hauling/Belt Conveying Areas)*

The waste has been seen (images given below) getting spilled while handling Red Mud. A visible layer of red colour on all the open to sky areas outside the covered filtration system including the haul roads, belt conveying system. This gets released though all movement activities on it, run off, dust emission etc. into water, air, soil with change in the weather conditions (rains, hot and dry summer etc.).

b) *Carry Over with Vehicles Tyres and Workers Shoes*

The waste Red Mud sticks (images given below) to the vehicles/workers in all the areas which include the activities indicated under section 2.1 above as well as the entry and exit of the waste storage/disposal areas. This waste therefore gets carried to the road between the filtration system and disposal facilities and even to the administrative blocks and other buildings.

c) *Seepage from the Storage/Disposal Facilities*

Leachate (images given below) from the Red Mud storage/disposal areas to the areas not connected to its collection and recycle system are also among the significant sources of release of this waste.

4.3.2 Secondary Sources

a) Run off (Material Handling/Hauling Areas)

The Red Mud that gets spilled (images below) in the open to sky handling areas and haul roads is carried with the rain water into the nearby environmental matrix depending upon the natural drainage contours of the area.

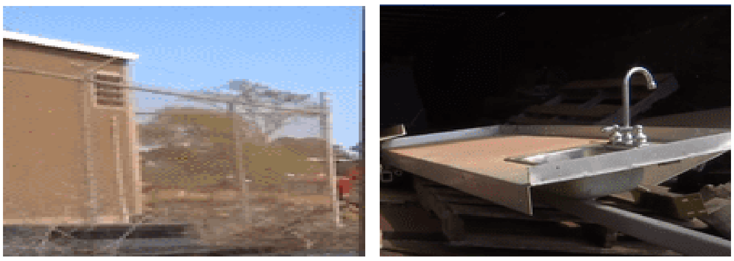
b) Fugitive Dust Emissions (Haul Roads, Dried Surfaces of Storage Ponds/Yards)

Once the Red Mud is dry it is blown by wind as fine dust. The wind can transport the dust particles at several kms distance. The movement of vehicles on dry stacks of red material also leads to emission of its fugitive dust. This can be seen in the images given below.

(Source: https://301-joweb.newscyclecloud.com/news/political-reps-say-yes-to-jisco-dust-control-project_191124?profile=1431&template=MobileArticle)

4.4 Receptors

The receptors cover all kinds of living species from humans to aquatic/soil biota in all environmental matrices that receives Red Mud. This is self-explanatory from the images (with source links) given below.



(Source: https://www.wbrz.com/news/red-dust-flying-through-neighborhood-concerning-some-residents/)

(Sources: http://redmud.org/category/introduction/ and https://www.wwf.eu/?195511/Toxic-plume-reaches-Danube-raises-questions-about-safety-in-multitude-of-other-sites)

4.5 Adverse Impacts

The adverse impacts due to mishandling and poor management of Red Mud affects not only human life but also aquatic life, soil quality, plant growth, etc. these adverse effects are listed below in table below:

Table 4: Adverse impacts due to release of Red Mud in the Environment

S.No.	Impacts	Probable effects
1.	Humans	Inhalation - burning effect, dust effect, toxic substances; Skin - irritation, corrosion; Eyes - irritation, corrosion
2.	Fish	Effect of alkalinity, suspended solids - deposition on whole body and gill, deaths

3.	Freshwater Zoobenthos	Effect of alkalinity - whole body, habitat loss
4.	Aquatic Biota	Effect of toxic substances: whole body and nutrition, deaths, habitat loss
5.	Soil Biota	Effect of alkalinity - whole body, deaths, habitat loss
6.	Plants	Limited nutrient uptake.
7.	Soil	Toxic substances - whole soil and nutrition

5. RED MUD DISPOSAL METHODS

5.1 Past Practices

Methodology for bauxite residue (i.e. Red Mud) storage have advanced continuously over the decades. Earlier, in the Bayer alumina plants, the residue generated was often just piled up on site or in the adjoining area of the alumina plant. Sometimes, exhausted mines and quarry sites were used for disposal of Red Mud.

Prior to 1980, most of the inventory of bauxite residue was stored in lagoon type impoundments and the practice is still carried out at a few facilities. In this method, the bauxite residue slurry from the mud washing circuit is pumped with a solids content of 18 to 30 % into storage areas created by dams and other earthworks for secure containment.

Another disposal technique adopted by some plants was sea or river disposal particularly in the 1940s to 1960s. Red Mud was being discharged into the sea, oceans, rivers, estuaries or tidal lagoons. However, these practices are no longer being followed by any of the Red Mud generating industry. River/sea/ocean discharge is no longer undertaken with any alumina refining facilities and sea discharge ceased by the end of 2015. The disposal of Red Mud in Estuaries and exhausted mine are shown in figures below:

Figure 15: Bauxite Disposal into an Estuary to Recover Land, Burntisland, Scotland

Figure 16: Bauxite Residue Disposal into a Former Oil Shale Mine, Whinnyhall, Scotland

In many instances, valleys were dammed, for example, Ewarton (Jamaica), see Figs.14 and Gardanne, Salindres, Saint Cyr (France), Ouro Preto (Brazil). In addition to Bergheim and Burntisland, other examples of old mine storage sites were former bauxite mines at Kirkvine (Jamaica) and the former refineries at Bauxite, Arkansas (USA). For the sites constructed in the last three or four decades, the storage areas have commonly been sealed to reduce leakage to the underlying ground and prevent contamination of ground water, however, this was not practiced in earlier years. Sealing methodologies consider a range of materials including compacted or impermeable clays and/or the use of plastic and other membrane materials.

Figure 17: Bauxite Residue Disposal into A Dammed Valley to Create a Lagoon

The supernatant liquor above the bauxite residue was generally returned to the plant for reuse leading to recovery of most of the caustic soda, thus, avoiding contamination of the environmentnt. Various drainage and seepage collection systems have been incorporated into the design and construction of the facilities. The construction of the storage area was mostly determined by the type of bauxite residue and differed for clay-like muds in comparison to sandy residues. At Gramercy (USA), sand-bed filtration and ‘‘French Drains’’ were used with drainage pipes and layers of sand of different size and gravel to provide permeability at the base of the lake. This was termed the DREW (Decantation, Drainage and Evaporation of Water) system.

The neutralization of the RM was not carried out before its discharge in the storage lagoon and the later it turned into a poorly compacted mud area covered by a highly alkaline lake, which had a pH of 12 and a soda level in excess of 2000 mg/L many years after bauxite residue slurry pumping was stopped. This left high risks of safety and environmental hazards including the potential 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. Unfortunately, in some cases, these early ponds have proved of limited effectiveness as caustic liquor and other contaminants have seeped into the surrounding environment. The remediation of these situations can prove to be an expensive exercise. Considering the risks and eliminating the potential for catastrophic failure of the dam/impoundment and consequent environmental hazard to the surrounding area/communities demands high monitoring, maintenance, and remediation costs. Under some circumstances, this has created the prospect of an indefinite legacy.

As lagoons started to exhaust for many plants, ‘‘Dry stacking’’ methods were initiated. Since the 1980s, the method has been actively used to reduce the potential for leakage of caustic liquor to the surrounding environment, reduce the land area required, and maximize the recoveries of soda and alumina. Further, to minimize the possibility of contamination, 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.

5.2 Current Practices

The current practices for storage of Red Mud around the world include dry stacking. Many plants now use equipment such as Amphirols to aid dewatering of the mud in order to compact and consolidate the residue, see Figure 15 and 16. Partial neutralization using seawater is practised at a number of Australian plants close to the sea (Yarwun and QAL); carbonation using waste carbon dioxide from ammonia production at Kwinana (Australia); and accelerated carbonation using intensive farming methods at Aughinish (Ireland), Kwinana, Worsley (Australia), have shown considerable benefits.

In order to reduce the moisture content, filtration using drum filters and plate and frame filter presses to recover caustic soda produces more manageable bauxite residue. Figure17 shows a typical press filter used for Red Mud.

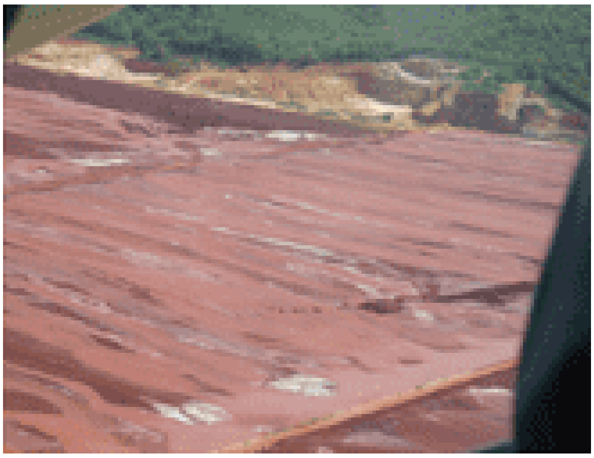


Figure 18: Mud Dewatering & Compaction

Figure 19: Dry Mud Stacking

Figure 20: Plate and Filter Press

In addition to recovery of caustic soda, this method is beneficial in terms of moisture reduction leading to ease and reduced cost of transportation. The producers, via organizations such as European Aluminium and the International Aluminium Institute (IAI), have worked collaboratively to look for improved solutions and propose best practice guidelines for environmentally sound disposal of Red Mud. The IAI continues to encourage collaborative effort on improving storage, monitoring, safety standards, looking at improved remediation techniques, and reuse opportunities and in 2011 issued a set of guidelines for members to work toward. Key messages coming out of the best practice reviews have been the drive to dispose of and store bauxite residue in a safer way with lower caustic and higher solids content. These moves will encourage the utilization of residue as the material produced will be in a more acceptable form for transport, handling, and reuse. Over the last two decades, the changes in the aluminum industry has led to ceased operation in case of many small plants and there has been an unavoidable shift to much larger alumina refineries in countries such as Australia, Brazil, and India.

Red Mud Disposal Practices in India

The Red Mud generated is mixed with lime in order to achieve stabilization and thereafter, it is filtered to reduce the moisture content. Drum filters and filter press are used to cater the need for moisture reduction to enable further utilization of Red Mud, however, Red Mud is being disposed in the form of slurry at one of the Red Mud generating units and installation of filter press is under process.

Further, drum filters were also used at one of the unit (now, non-operational) in order to reduce moisture of Red Mud before disposal of Red Mud into the pond. Remaining units use "Filter Press" to increase the solid content of Red Mud from the earlier 65% (conventional drum filter Technology) to 75% (filter press technology). The filter press is installed in the plant premises. The filer cake i.e. the Red Mud from the filter press is collected into trucks through hoppers and disposed in the Red Mud Stacking yards.

Filter Press

Hoppers for Red Mud dumping into Trucks

The details on Red Mud disposal practices followed by Indian Alumina industries are given in table below:

Table 5: Red Mud disposal practices in India

S.No.	Name of the Industry	Management and Disposal Practices
1.	M/s Hindalco Industries Ltd, Muri Jharkhand	Dry stacking of Red Mud stared in June, 2002. Filter Press is used to increase solid content up to 75%. The filer cake i.e. the Red Mud from the filter press is collected into trucks through hoppers and hauled to the Red Mud disposal ponds. There are 4 Red Mud disposal ponds, of which 03 are exhausted.
2.	M/s Hindalco Industries Ltd., Renukoot, Uttar Pradesh	Red Mud is filtered using filter press. There are 11 Red Mud disposal Ponds.

S.No.	Name of the Industry	Management and Disposal Practices
3.	M/s Hindalco Industries Ltd, Belgaum, Karnataka	Filter Press are used to reduce moisture content. Part of this Red Mud is sent to Cement industries for utilization and remaining is stored in Red Mud Ponds. There are 02 Red Mud disposal ponds available with the unit designed for wet ponding and the same got started used for the dry mud stacking.
4.	M/s Utkal Alumina International Ltd., Odisha	There are only 2 ponds for red mud disposal. The 3rd and 4th ponds are SP and SNLP ponds, which are not used for disposal. Only 1 pond is operational for red mud disposal as of now.
5.	M/s Vedanta Limited, Lanjigarh, Odisha	High concentration slurry disposal of red was followed till 2013. After 2013, High Pressure Membrane Filtration Technology is being used for dry stacking of Red Mud. The filter-cake Red Mud is transferred to the pond via truck, spread in lifts to dry with a dozer and compacted with a sheep roller.
6.	M/s NALCO Ltd., Damanjodi, Odisha	Thickened Tailing Disposal (TTD) System are used wherein the Red Mud is discharged into a pond (RMP) at solid consistency varying between 54% - 60% at one point for having a sloped deposit. Installation of Filter Press is under Process.
7.	M/s MALCO Ltd., Tamil Nadu	The unit is non-operational since November, 2008. However, during its operational days, moisture of Red Mud was reduced using drum filters and hauled through trucks and stacked in the Red Mud pond.
8.	M/s BALCO Ltd., Korba, Madhya Pradesh	The unit is non-operational since September, 2009. There are 07 Red Mud disposal ponds. One of the ponds has been reclaimed and plantation has been done. The remaining have been converted to ash dykes.

Red Mud Slurry Discharge Point

Dried Portion of Red Mud Disposal Pond

Red Mud Disposal Pond

The Red Mud utilization in India is primarily limited to co-processing in cement plants, however trial studies are being carried out to explore the utilization in road construction, building materials, etc. the details on quantity of Red Mud sent for utilized by various industries in India is as below:

Table 6: Red Mud Utilization in India

S.No	↓Name of units Years →	Quantity of Red Mud Utilized (MT)						
		2015-16	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
1.	M/s Hindalco Industries Ltd, Jharkhand	29599	31398	27613	27613	303935	624743	717228
2.	M/s Utkal Alumina International Ltd., Odisha	Nil	Nil	Nil	Nil	300	700000	60603
3.	M/s Vedanta Limited. Odisha*	12336	139870	241182	78842	138644	128973	519776
4.	M/s NALCO Ltd., Odisha	Nil	Nil	Nil	Nil	Nil	Nil	Nil
5.	M/s Hindalco Industries Ltd., Uttar Pradesh	53000	60000	72973	96981	362736	975058	1123459
6.	M/s Hindalco Industries Ltd, Belgaum	169904	205380	198451	219983	377731	361452	484367

***Strengthening of Dyke = 156489 MT; Sell to cement industries = 646706 MT**

6. RED MUD STORAGE FACILITY FAILURE/SPILL ACCIDENTS

In view of the extremely alkaline nature and characteristics of Red Mud as mentioned at section 3, it is important to consider a highly maneuvered and environmentally sound management of Red Mud. This can evidently be backed by the accidents/spillage occurred in the past due to failure of Red Mud storage facilities.

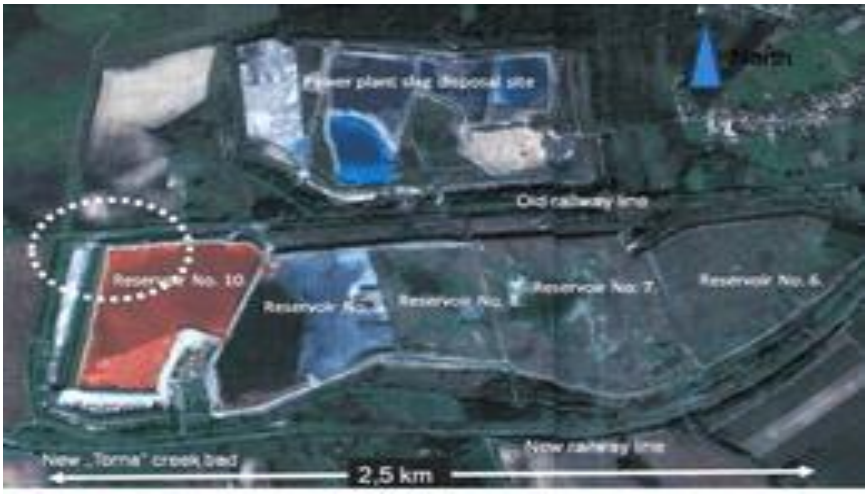
6.1 Akja, Hungary Red Mud Disaster 2010

a) Location and Description

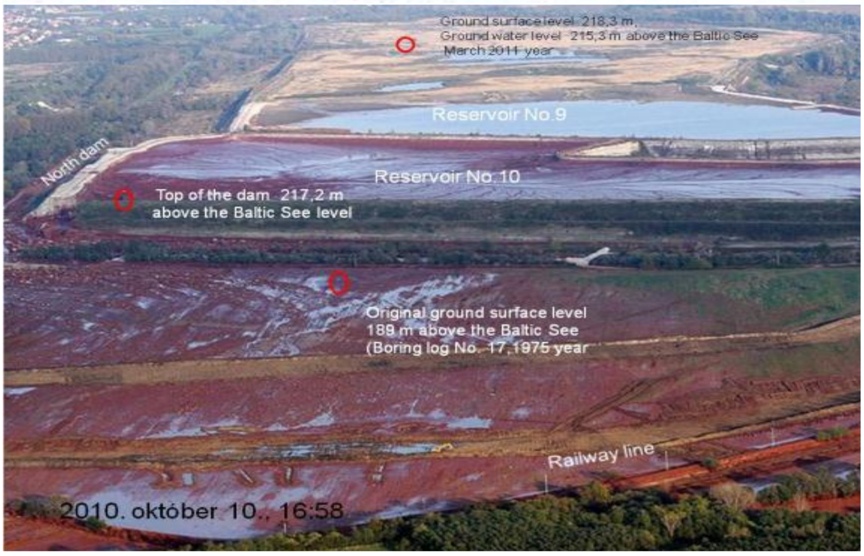
The accident occurred on 4 October 2010 around mid-day when the dam wall of the Red Mud containment Reservoir 10 of the MAL Inc. located in the vicinity of Ajka ruptured resulting into flow of about an estimated 1 million m^3 of alkaline Red Mud that even reached river Danube which is about 160 Kms from the accident site, causing some extent of destruction in all the affected waters. The disaster left 10 people dead and almost 150 slightly or severely injured, including local residents and the participants in the rescue operations. The red sludge also flooded around 400 hectares of agricultural land.

b) The Accident in Pictures

Before Accident:



After Accident:



Source: (http://redsludge.bm.hu)

An Aerial View of Chamber 10 before and after the Accident

The West and the North Dam after the failure

Source : https://upload.wikimedia.org/wikipedia/commons/e/e4/Ajka_accident_d38e36f0e9_b.jpg

The affected area of 10km^2

Source : http://redsludge.bm.hu/wp-content/uploads/2010/10/image002.jpg

Aerial photo of the affected area

(Source: http://www.hacusa.org/en/red-sludge-disaster-relief/red-sludge-disaster-relief
https://xpatloop.com/channels/2019/02/court-rules-ten-guilty-for-red-sludge-disaster-in-hungary.html)

c) Identified Causes of the Accident

(i) The foundation of the embankment was inappropriate. The soil below the embankment was highly heterogeneous and a rigid embankment was constructed.

(ii) The design calculations did not take into account the strength loss of the clay due to the caustic content of the liquid phase, nor the strength loss of the lower third of the embankment (constructed out of fly ash) due to the permanent load of water.

(iii) The cross section of the embankment was not satisfactory, the bank slopes were steep and the tension of the embankment toe was high. Also, he design did not cover the effects of the uneven sagging.

(iv) The material of the embankment is largely heterogeneous both in horizontal and vertical directions and this facilitated the formation of fractures.

(v) The embankment was not properly sealed, an inner water sealing wall] was not applied

(vi) The filling of the Red Mud slurry was not consistent; the Red Mud was randomly distributed at certain places. The safety of the embankment having a height of 25 m should not have been based on such a process technology.

(vii) The embankment integrity checks were substantially defective.

(viii) Inadequate monitoring and remediation for the seepage apparent on the north dike for the last two years.

The detailed investigation report of the accident is given at ***Annexure-I.***

The Triggering Effect

(i) The seepage area located about 300 meters east of the north-western corner of the impoundment, due to increased pore water pressures

(ii) Separation of the north dike at the north-western corner of the impoundment and tensile fracturing in the easterly displaced north dike segment,

(iii) Incremental eastern movement of the dike segment (west of the shear zone) where the fractured blocks in the north-western corner of the dike were pushed out by the water in the impoundment causing the ultimate structural failure.

d) Major environmental disaster management actions

(1) Air spreading of gypsum to reduce the alkali effect in the affected villages and river stretch.

(2) Containing the flood plume to the best possible through construction of barriers. This was done by creating temporary obstacles in the river bed.

(3) Direct addition of gypsum in the affected settlements areas.

(4) Intensive exercise for neutralisation of the river water using gypsum (23,500 tonnes) and acetic acid (cc. 1,800 m3) to reduce water pH levels. The mixing of gypsum was aided by the use of high-pressure fire-hoses. aeration equipment etc.

(5) Constriction of defence dams to for sealing of the failed reservoir.

(6) Construction of ring dam like cascade basins for safe release of the alkaline water from the failed reservoir while holding back the red sludge.

6.2 Red Mud Pond Burst In China – 2016

a) Location and Description

This alumina refinery was established in 2005 by Xinjiang Group Co. Ltd and Luoyang Xinan Power Grid Group Co. Ltd. With annual capacity of 1.2 million tonnes of alumina production. The Xiangjiang Wanji Aluminium's Red Mud storage is reported to have got busted in the form of a mud landslide around 7 PM on August 8. The Red Mud storage which had the accident is located in Dahegou Village, in Luoyang, Henan province. The waste containment wall is reported to have suddenly broke and the silt mixed with stones from the mountainside rushed out. This accident has caused huge harm on the village farmland because of its high alkalinity. It has been reported that the dam had held about 2 million cubic meters of Red Mud and was about 1.5 km in length."

Figure 21:Location of the Red Mud Pond Failure Site - Dahegou Village

b) The Accident in Pictures

Before the Accident

(Google image, June 29, 2016 showing the Red Mud pond, the village and surroundings)

After the Accident

(Google image, September 9, 2016 covering the Red Mud pond, the village & surroundings)

Surrounding Village Before the Accident

Surrounding Village submerged in Red Mud after the Accident

6.3 Red Mud Over Spill At Alunorte 2018, Barcarena, Brazil

a) Location and Description:

Alunorte - Alumina do Norte do Brasil S.A is located in Barcarena, a municipality situated 123 km from Belém in the state of Para. The location and overall layout of the production facilities, Red Mud disposal facilities, effluent treatment etc. are shown in the **figure 19 and 20**.

Figure 22: Location Map of Alunorte, Barcarena, Brazil

The Red Mud storage is named as the “Disposal of Residual Solids (DRS)”. The industry has two such facilities namely DRS1 and DRS 2. The DRS1 is in place since the start of the industry. It has been receiving the cake (through pipe conveyor) resulting from the drum filtration of the Red Mud generated in the alumina hydrate production process. The use of DRS2 was started in 2017 after the installation of the filter press technology by the industry in 2016. The design of both the DRS includes collection of the run off from the stacked material into control basins (2 in series) for sedimentation of suspensions. The alkaline water from the second basin is sent to the effluent treatment plant (ETP). The storm water generated in the industry’s premises gets collected into underground sump from where it is pumped to a chamber called “Mixing Box”. The mixed liquor from this box is then lead to the same ETP mentioned above. The effluent discharge permission given to the industry requires discharge its treated effluent into the Canal Novo. The Canal Novo is connected to the river Para which is the ultimate recipient water body for all the drainage from the industry and the settlements in its catchment.

Figure 23: Satellite view of Alunorte and the Pará River with illustration of production and associated facilities (1. Refinery area; 2. Bauxite Residue Storage Area DRS1; 3. Bauxite Residue Storage Area DRS2; 4. Licensed discharge to Pará River; 5. Wastewater treatment plant)

b) Accident Description

The information given in the industry's report as well as in reports of two outside agencies hired by the industry covers flooding of the certain areas including the ETP in the plant due to heavy rains (231mm in 12h and 239 in 24th) on February 16th and 17th 2018. It is also been reported that there was a lightening around the midnight of February 16th which struck the power sub-station feeding to ETP which resulted into tripping of pumps and disrupting the its operation. There was a dip in the voltage in the power supply to industry on February 17th which resulted into power failure/problems and thereby disrupting the functioning of the entire storm water and waste water collection and management systems. The volume of the water resulting from the combined effect of the heavy rains and disruption in the water management systems was extremely high compared to the holding capacity of the sumps, ETPs etc. The heavy rains resulted into reduction of the freeboard level in DRS1 from 3.25 meter to 1 meter in DRS1 and from 4.1 meter to 1.4 meter in DRS2. It may be recalled here that the contaminated water so collected in the two DRS is also required to be treated in the common ETP mentioned above and disposed into Canal Vevo as per the requirements of the effluent discharge permission. The power failure in the production facilities also resulted in over flowing of the spent caustic liquor storage tanks. The extent of the flooding in the industry could not be cleared in six days may be seen from the images given in figures below:

(Source: https://twitter.com/PersonalEscrito/status/967605864155828224/photo/2)

Figure 24: Image of the mixing box and area around during the flood situation

(Source:https://agenciabrasil.ebc.com.br/en/geral/noticia/2018-03/mining-giant-fined-toxic-spill-amazon-rainforest)

The industry had to therefore discharge all the flood water, the treatment of which was not possible under such circumstances through another canal viz Canal Velho. In -fact the company accused of causing environmental damage in northern Brazil, later in March 2018 apologized* for the unauthorized discharge of untreated water into the Para river.

(*https://agenciabrasil.ebc.com.br/en/geral/noticia/2018-03/norway-mining-giant-apologizes-toxic-leak#:~:text=Norwegian%20mining%20company%20Hydro%20Alunorte,mining%20giant%20was%20once%20again)

c) Environmental Impacts

The media and the other reports had reported adverse effect on the quality of the municipal water supply in the town. It may be however mentioned here that the industry was ordered closure and later permitted to start again at 50% of the production capacity with conditions of taking many improvement measures including increase in the capacity of ETP. Holding ponds etc.

6.4 Red Mud Pond Failure in 2019 at Muri, India.

a) Industry Location and Description

The plant is located on the banks of Subarnarekha River at Chota Muri, 65km from Ranchi, the capital city of Jharkhand state. The area on other side of the river stretch along this site falls under the state West Bengal. A "Filter Press" was commissioned in March, 2014 which increased the solid content of Red Mud from the earlier 65% (conventional drum filter Technology) to 75% (filter press technology). The Red Mud generated before 1991 was stored in Red Mud Pond (RMP)-1 & RMP-2 (36 acres) and RMP-3 (41 acres), which have been decommissioned and reclaimed by plantation. At Muri, the dry stacking of Red Mud started in June, 2002.

Figure 25: Location of Hindalco Industries, Muri

b) Accident Description

On 09.04.2019, there was a breach the western and south western portion of RMP-4 retaining gabion wall. This accident resulted into spreading of the Red Mud in nearby agricultural land located on southern side and the Muri-Jamshedpur Railway track located on western side of RMP-4. As per information given in the report of the Fact-Finding Committee (FFC) Constituted by the Jharkhand State Pollution Control Board vide its order dated April12, 2019), about 600 meters gabion wall breached on the west side RMP around 01 P.M. on 09.04.2019. The Red Mud and its slurry spread all over the land on western side of RMP which is mostly agricultural land and also on the railway track. The said railway track is part of Muri-Jamshedpur Railway track resulting in disruption of rail movement.

The panoramic views of the Red Mud ponds storage area before and after accident as given in the FFC report are shown below in Fig 22.

Figure 26 : Sateliite images of the area before and afther the accident

c) The probable causes of the accident as identified by the FFC are as follows:

(i) Excessive overburden on the base of RMP: The Red Mud has bulk density of 1.8 T/m3 (minimum). At major portion of RMP, the overburden pressure (with 42m height dump on base) is 42 x 1.8 = 75.6 T/m2. This implies that to sustain an overburden of 42m height above base, the bearing capacity of the base soil must be more than 75.6 T/m2. Any document substantiating such bearing capacity values of soil at base level of RMP could not be made available to the Committee. The CBRI report no. GE(S)/0182 indicate that the total height of the fill should be restricted to 22m above ground.

(ii) The Factor of Safety (FoS) in the south chainage 330 of the Red Mud dump as found by CMPDIL through conducting of the slope stability analysis study, was found to be 1.08 against the requirement of FoS to be more than 1.10.

(iii) Build-up of hydrostatic pressure and low bearing capacity of base/foundation of the pond.

(iv) The breach portion of the RMP-4 was mostly under water during the period from May 2005 to 28th March 2014. This was also the major location of the RMP-4 where the Red Mud was filled in a very short period of time between 28th March 2014 to

10th April 2014. Also, the boundary portion which breached is the same which was impounding the area covered with water until 28th March 2014 and was filled up with red-mud within a very short time. It appears that the area of breach and the boundary portion under water until 28th March 2014 were weak resulting into the breached due to excessive moisture content in the Red Mud filled at the bottom.

(v) The Red Mud is highly corrosive material and it might have corroded some weak portion of the Gabion wires where the coating might have got damaged during gabion transportation or execution of work. In such cases the Gabion wall becomes weak and the pressure of the Red Mud fill material may have got released from the wall causing the entire failure.

Further, the explicit reason for failure of RMP are under examination.

6.5 Key Aspects Needing Attention

(1) The need of conducting Risk and Environmental Impact Assessments and preparation of the DMP and EMP for siting of the Red Mud storage/disposal facilities.

(2) Sites for the storage of Red Mud are to be permitted at locations not having any human settlements and surface water bodies in the post facility failure impact zone.

(3) The site not be developed at locations having high ground water table and history of water logged areas in the past.

(4) Timely Identification of the risks and taking of preventive measures.

(5) Recycle of the alkaline run off from the Red Mud storage facilities to the Bayer.

(6) Design of the Red Mud facility to be robust with holding capacity enough for the safe management of the run off resulting under heavy rains.

(7) Independent drainage system for collection and discharge of rain water.

(8) Monitoring of the facility through satellite data.

7. BEST PRACTICES FOR DEVELOPMENT AND MANAGEMENT OF RED MUD DISPOSAL AREA

7.1 Long Term Planning and Design

For development and management of Red Mud Disposal Area (RMDA), the International Aluminium Institute (IAI) has recommended various aspects for planning and design of Bauxite Residue Disposal Area (BRDA) which covers (i) Environmental Impact Assessment (EIA) and preparation of the environment Management Plan (EMP) and (ii) Risk Assessment (RA) and preparation of Disaster Management Plan (DMP).

The key aspects recommended by IAI for consideration in the development of the BRDA include:

- Comprehensive characterisation of the chemical and physical properties of the residue material, geological, environmental and social setting at and around the proposed site.
- Involvement of the regulatory authorities and local communities/stakeholders.
- Identification of all potential environmental, social, economic, health and safety risks and preparation of plans for environmental management, monitoring, closure and rehabilitation.
- Establishment of a risk assessment process at an early stage of the planning of BRDA.
- Establishment of a geographically, socially and environmentally sustainable design for the BRDA.
- Identification of the hazards – what can happen, where and when, and how and why?
- Risk Analysis – identification of existing controls, determination of the likelihoods and consequences, and the level of risk.
- Evaluation of the risks – comparison of the risks with the design criteria and incorporation of the risk in the design criteria and Identification and assessment of the options for mitigation for management of the risks. Specially, in respect of the likelihood of earthquakes, tsunamis, hurricanes, and severe storms.
- Collection and compilation of the baseline environmental data prior to development of a BRDA should include including, groundwater levels and quality, water content and geochemistry of foundation soils and rocks, air quality, fauna and flora, natural and background radiation levels where radioactivity is associated with the source bauxite material, underlying geology and hydrogeology, history of extreme meteorological events. Physical and chemical characteristics of the bauxite residue etc.
- Identification of negative environmental impacts on land, water, air and biota and plans for their mitigation.

7.1.1 Storage Facility Design Criteria

Key design criteria of a bauxite residue storage facility include:

- Minimum, maximum and average residue rates at which the delivery system will operate.

- Geochemical characteristics which may influence the selection of the most appropriate design for operation and closure.
- Solids concentrations and average solids concentration
- Annual and life-of-operation residue tonnages
- The rated maximum capacity of the return water system
- History of extreme meteorological events
- Proximity to habitation and water courses
- Propensity of seismic activities and tsunamis
- Public health and safety, community and environmental compliance targets, defined in consultation with stakeholders, including seepage, ground water quality, decommissioning, rehabilitation/closure requirements, air quality and radioactivity and operating and maintenance requirements.

7.1.2 Construction

The BRDA to be constructed by skilled manpower and use of quality control of construction materials. The principal considerations for design of a bauxite residue containment structure mentioned are:

- Foundation conditions
- Geotechnical parameters of the construction materials
- Geotechnical slope stability
- Seepage and the need for internal drainage or clay cores and cut-offs into the foundation beneath the containment wall.
- Staged construction, either by progressive wall raising, addition of containment cells or construction of new facilities over time
- Selection of construction techniques and equipment requirement
- Quality assurance of construction process.

7.1.3 Seepage control

The aspects recommended for consideration in the design for control of seepage are:

- Hydraulic characteristics of the foundation beneath the residue storage facility, including the presence and value of groundwater, and the need for a liner.
- Hydraulic characteristics of the containment wall, including the need for a clay core and cut-off into the foundation beneath the containment wall.
- Impact of seepage from the residue on surface and ground water.
- Prevention of low permeability lenses or layers forming on the residue beach that could cause future seepage or stability concerns
- Under-drainage to remove gravity drainage from the deposited residue.
- Decant systems designed and operated to limit the storage of supernatant water and incident rainfall off the surface of the residue, and hence limit seepage.

7.1.4 Bauxite Residue Transportation

The IAI recommendations are only *slurry pipeline transportation involving i.e.* pumping of the residue as slurry along a pipeline to the storage facility. This implies that the filtration system is to be provided as close as possible to the disposal area. The slurry pipeline corridor to be designed to protect the environment against spills due to possible pipeline leaks/failures and breaks, and the clearing of pipeline blockages. Methods suggested for controlling the discharge of residue if such incidents occur include:

- Construction of containment drains of sumps along the pipeline corridor
- Sleeving of the pipeline with a larger diameter pipe for situations where the residue pipeline is traversing sensitive environments (for example, a river crossing) or crossing transport routes
- Use of differential pressure sensor or flow measurement instrumentation and alarm system to alert operators in case of pipeline failure.

7.1.5 Operation Manual

The IAI best practice also include having an operating manual for each storage facility and alignment with the design objectives of the facility to guide facility operators with the daily operation, as well as with forward planning of the facility’s operation and maintenance. The operating manual should describe and the operators should receive training in:

- The facility’s daily operation
- Residue deposition — layer drying to maximise strength and minimise seepage
- Water - management of the decant pond and efficient water use to maximise stability
- Dust control
- Procedures requiring specific precautionary measures, such as the correct order of valve opening/ closing to avoid blockage of residue pipelines
- Procedures for changing and flushing residue pipelines
- Key indicators used to monitor the facility’s successful operation
- Operator’s role and responsibilities in support of residue management plan
- Scheduled and preventative maintenance to keep critical equipment operational
- Recording and storing of monitoring and performance data
- Reporting any exceptional, untoward or unexpected observation to a supervisor, and to follow through with emergency and risk management actions.
- Monitoring of bauxite residue facilities should include:
- Installation of groundwater monitoring equipment beneath and surrounding the facility
- Surface and groundwater quality sampling, upstream and downstream of the facility
- Daily inspection of all bauxite residue storage facilities and associated pumping and pipeline systems should be undertaken and observations recorded. Unusual observations or maintenance requirements must be documented and appropriate

action taken, including reporting to regulators and the community. Inspections should include:

- Position of the decant pond and observations relating to freeboard requirements (water levels with respect to dam crest levels)
- Visual and operating checks of lead indicators, such as damp, seepage and erosion
- Status of leak detection systems and secondary containment systems
- Status of automatic flow measurement and fault alarms
- Dam/levee/dyke integrity
- Condition of pump and pipeline systems
- Assessment of impacts to birds and other wildlife or livestock

7.1.6 Disaster Management or Emergency Action Plan (DMP)

All bauxite residue storage facilities to have DMPs. to ensure that in the unlikely event of a failure, appropriate actions can be taken to minimise the safety risk to people on and off the site, and to minimise any impacts to the environment by responding to the incident in an organised and systematic manner. The DMP should:

- Identify conditions that could result in an emergency, such as severe storms, tsunamis, sabotage
- Describe procedures to isolate people from hazards, including the warning and evacuation of downstream communities
- Identify response plans to mitigate impacts, such as clean-up plans and resources required to implement the emergency action and response plans
- Identify emergency response training requirements for key people and document the location of emergency warning alarms and maintenance requirements to ensure serviceability at all times.

7.1.7 Performance Monitoring

Performance monitoring is required for the timely capturing of any deviation from residue management plans and providing of the adequate opportunity to review and, as necessary, develop contingency plans. The monitoring includes a transparent, accessible, representative and thorough management of the data.

7.1.8 Performance Audit

The performance auditing (both internal and independent third party) should include the methodologies employed for performance tracking data acquisition to ensure:

- Sufficient data resolution and compliant with that required by applicable guidelines;
- Relevance to risk mitigation or assessment;
- Overall performance against design.
- Validation of the planning and management principles including the subsequent to changes in operations or residue quality and/or quantity. This should include, (i)

performance against design — crest and beach levels, residue tonnage stored and volume occupied, (ii) assessment of stability under normal and seismic loading and design meteorological events, in situ residue parameters (density, strength and permeability) and position of phreatic surface, (iii) performance of seepage control measures such as under-drains (for seepage control), or internal filters (which control internal erosion or piping), (iv) liner condition, where used, (v)history of extreme meteorological events, (vi)status and condition of monitoring systems, their performance in detecting changes in lead indicators (environmental and/or structural), and the analysis and evaluation of monitoring data against predicted trends, (vii) groundwater monitoring results — comparison of the groundwater levels and quality against the 'baseline' data and against design and closure criteria, considering, the near-surface lateral seepage which may stress vegetation or destabilise a containment wall and vertical seepage which may cause localised mounding beneath the storage, (viii) operational performance — residue deposition practices (thin layer) and surface water control (minimum stored water and maintenance of required freeboard), (ix) assessment of operational incidents, and recommendations for improvements or modifications to rectify shortcomings.

Reference: https://bauxite.world-aluminium.org/fileadmin/user_upload/Bauxite_Residue_Management_-_Best_Practice__English__Compressed.pdf

7.2 Major Aspects Needing Attention

(i) The site selection of the site for the expansion or development of BRDA requires conducting of the Environmental and Risk Assessment studies for the confirmation of the suitability of the site for the proposed development. The Environmental and Disaster Management Plans (EMP and DMP) are to be prepared and implemented and the industry to be prepared for meeting the situation of any facility failure event.

(ii) The storage of the bauxite residue is to adopt the upstream dry stacking method.

(iii) The filtration system should be close to the Red Mud disposal area.

(iv) The BRDA facility should have an operational manual.

(v) An internal as well as third party performance audit of the BRDA is essential.

8. RED MUD UTILISATION OPTIONS

8.1 Review Scope

In 1887, with the development of Bayer's Process for alumina refineries, the concern for management of Red Mud aroused as it is generated in very large quantity. Decades after that, the approaches have changed from unrestricted disposal methods to storage in engineered ways. Several research has been carried out to analyse the scope of Red Mud for utilization. The utilization scoped investigated and the obstacles that exist for its utilization on a large scale have been briefed here.

It may be clarified that utilization of Red Mud refers to its usage in different applications and not the storage in an area to be rehabilitated for other uses like agriculture or natural habitat, etc.

8.2 Historical Perspective

The US Bureau of Mines (USBM) initiated a program of research in 1996, "To determine feasible uses of Red Mud". The focus of the work was "to develop methods for directly utilizing or for recovering mineral values from Red Mud". The primary motivation for the research was to find a solution to an environmental issue, especially in view of the environmental implications of its storage in ponds. The creation of value from the residue itself therefore appeared as an enabler to the solution of the environmental issue rather than as an end in itself. The USBM report identified a variety of ways in which residue could be used, either as a source of metals or for use in building materials of agriculture. However, Red Mud is utilized in significant quantities.

The Red Mud varies in its composition and properties, both because of differences in bauxite feed and the nature of the Bayer refinery circuit. Also, in case of the re-mining of Red Mud from the storage area, chemical reactions over time within the residue body would alter the composition/properties. Therefore, utilization approach would also vary. The utilisation of fresh residue may be important as it is likely to have more environmental implications.

8.3 Regulatory Aspects

Untreated bauxite residue gets classified as a hazardous material or non-hazardous and the requirements of its handling and management also vary from country to country. The hazardous classification however seems to be based primarily on to its alkalinity rather than heavy metal or naturally occurring radionuclide content (NORM). Ensuring sufficient soda removal and/or neutralization prior to downstream processing would enable residue to be transported and handled as a non-hazardous material. Exceptions are likely to be location specific cases relating to heavy metal or NORM levels; which illustrates the importance of further research into elemental associations, liberation and chemistry with the various residues. Such scientific knowledge would considerably clarify the liability related issues and aid risk assessments.

Over the past several decades a lot of efforts have been made to find environmentally-friendly and cost-effective techniques to utilize the RM. However, the recycle and reuse of very massive quantities of generated RM is still a challenge for the alumina industry all over the world. Moreover, the transportation costs from the alumina refinery to the processing plant is another problem. The future management of this residue and moving it towards zero waste are two tremendous environmental concerns. According to the most important classification shown below, a wide range of research fields have been conducted to develop some methods for effective utilization of RM.

8.4 Options for Utilisation

8.4.1 Metal Recovery

Recovery of metals from RM has attracted many research interests due to increasing demand and value for aluminium, iron, titanium and rare earth elements such as vanadium, gallium, scandium, zirconium and lanthanides. Iron oxide is the major oxide in the RM followed by alumina, silica, titanium dioxide and rare earth elements. Treatment of the RM has different metallurgical ways consisting of pyro-metallurgy and hydrometallurgy. Pyro-metallurgical and hydrometallurgical treatments are the two most commonly used methods to recover valuable metals from RM. Despite the researches accomplished in recovery of metals from RM, pyro-metallurgical processes have many obstacles such as high energy consumption and generation of worthless residues. In contrast, hydrometallurgical processes are more promising for the future. However, metals can be recovered from RM either by direct metallurgical methods or by combining hydrometallurgical method with a pyro-metallurgy. Among the hydrometallurgical methods of extraction, acid leaching of metals from RM is an effective way due to its potential to allow selective recovery through extraction. Development of convenient metallurgical processes for metal recovery from RM plays a significant role to achieving zero waste and a thorough recovery of valuable minerals inside the RM.

A brief overview on basic techniques applied for valuable metals recovery including aluminium, iron, titanium and rare earth elements (REEs) from RM has been described in the subsequent paragraphs.

8.4.2 Iron Recovery

Iron oxide in RM is typically the major constituent. The RM is considered as a low-grade iron ore containing 30%–50% iron and many attempts have been carried out on iron recovery including direct magnetic separation, roasting and reduction smelting processes, reduction roasting by adding sodium salt), reductive roasting followed by magnetic separation, reduction in hydrogen atmosphere followed by magnetic separation, magnetic separation after co-roasting with pyrite, thermal plasma technology, microwave reductive roasting, mineral acid leaching, and selective leaching of iron with oxalic acid.

8.4.3 Aluminium Recovery

The remaining aluminium in the RM composition ranges from 14% to 17%. Among the metallurgical processes of aluminium recovery, the most notable ones are sintering process, reduction sintering process, hydrothermal process, combined pyro- and hydro-metallurgical process, reduction sintering and magnetic separation, acid leaching, and bioleaching.

8.4.4 Titanium and Rare Earth Elements (REEs) Recovery

Although Ti is expensive and has a complex processing, the advantages of using titanium outweigh its cost. Titanium dioxide or Titania (TiO2) in RM can exist in the form of anatase and rutile polymorphs or with other minerals. Pyrometallurgy- and hydrometallurgy-based methods are mainly employed for titanium retrieval from RM. Pyro-metallurgical processes typically include extracting pig iron, a soda and alumina-rich stream and a slag containing titanium, silica, lime, residual alumina and magnesium. Besides the pyro-metallurgical processes, a lot of research work has been carried out on the recovery of titanium dioxide from RM using sulfuric, phosphoric, nitric and hydrochloric acids. It has been found that hydrochloric acid leaching of the RM followed by sodium carbonate roasting of the leached residue significantly increases TiO2 recovery from 36% to 76%. To achieve such an increased recovery, the leaching temperature, roasting temperature and time should be 90°C, 1150°C and 115 min, respectively. Solvent extraction is another possible technique for the recovery of titanium from RM. In this process, the use of hydrochloric acid containing bis-(2,4,4-trimethylpentyl) monothiophosphinic acid (Cyanex 302) and bis-(2,4,4-trimethylpentyl) dithiopho- sphinic acid (Cyanex 301) led to favorable results. One important point is that the recovery of titanium does not require an exact control of pH, and titanium is easily separated from the co-recovered iron by selective stripping.

The recovery of other REEs such as lanthanum (La), vanadium (V), zirconium (Zr), gallium (Ga), cerium (Ce), yttrium (Y) and thorium (Th) has been investigated in several researches. A high vanadium oxide recovery of more than 99% from RM was achieved through adsorption onto activated carbon. The process included the solubilisation of vanadium, adsorption onto activated charcoal, desorption, precipitation and finally calcination. Due to increasing trends of the gallium demand in electronics industry, recovery of gallium from Bayer liquor was reviewed by. By using Kelex 100 solvent extraction system, about 80% of the gallium in Bayer liquor was extracted. Given the current trends for REEs demand in high-technology applications and the rapid increase in their price, it is expected that research in REEs recovery from RM will continue to grow.

8.4.4.1 Cement Clinker

The summary observations contained in the study report “Opportunities for using bauxite residue in **Portland cement clinker** production (March 2020)” of the International Aluminiu m Institute (IAI) are as follows:

- From the evidence from the cement plants that are already using bauxite residue on an industrial scale, it is clear that bauxite residue can satisfactorily be used in cement clinker manufacture with only slight changes to their operating process. With the appropriate bauxite residue, typically a usage rate of 3 to 5 % can be accommodated.

However, there is no one size fits approach for utilization of red mud in cement as it is largely driven by the quality of limestone to be replaced with bauxite. From the industrial experience to date, key aspects seem to be: a relatively low moisture content - desirable moisture should be <15%. It is, however, manageable at 15-20% to overcome handling challenges and this can readily be achieved by bauxite residue producers, some alumina refineries have used a plate and frame filter press to produce a satisfactory product whilst others have reached a satisfactory level by air drying the bauxite residue.

- A moderately low sodium content, a value of <2.5% Na2O has been indicated as satisfactory but it will depend on the composition of the other raw materials;
- The appropriate aluminium oxide to iron oxide ratio (an iron oxide to alumina ratio of 0.8:1.2 in the raw mix was found to give the best results in one study although some plants will use the bauxite residue to supplement the iron level whilst others use it for the alumina content); and
- The reasonable proximity of a cement plant (up to 1200 km has been found to be acceptable in one case), however, logistics of red mud is not viable even at a current freight rate of Class 100 due to longer lead distance.

There is believed to be scope for many more clinker producers to use bauxite residue leading to improvements in the environmental footprints of both the aluminium and cement industries. However, there are still issues which involved which vary from industry to industry.

(*https://www.world-aluminium.org/media/filer_public/2020/03/16/opportunities_for_use_of_bauxite_residue_in_portland_cement_clinker_2020.pdf)

The IAI's document on "Opportunities for use of bauxite residue in **special cements** (March 2020)" summarise as (i) the prospects of large-scale utilisation of bauxite residue in cement are very promising. Firstly, because the iron and aluminium components of the bauxite residue are valuable additions in the production of both Portland Cement and 'special' cement clinkers; and secondly it has been shown at a laboratory scale by several research groups that bauxite residue may successfully replace clinker in blended cements at dosages between 10 and 20 wt%. If used as produced, this would have a significant impact on the cement industry CO2 emissions as the clinker production is responsible for 85 % of the total emissions in an integrated cement plant.
The existing code of cement does not allow materials like red mud as Supplementary Cementitious Materials (SCM) in cement. Moreover, detailed durability studies need to be carried out through recognised NABL accredited labs with Indian raw material.

(https://www.world-aluminium.org/media/filer_public/2020/03/16/opportunities_for_use_of_bauxite_residue_in_special_cements_2020.pdf

Another document of IAI on "Opportunities for use of bauxite residue **in Supplementary Cementitious Materials** (March 2020)" concludes that a considerable work has been undertaken on a laboratory/pilot scale exploring opportunities for bauxite residue as a filler in blended cements, sometimes for their pozzolanic activity but also to improve the mechanical properties in blended cement by other mechanisms such as optimising packing density or rheological characteristics. It has been observed at laboratory scale by several groups of researchers that bauxite residue as produced or after calcination, pure or mixed with other additives, may successfully replace clinker in blended cements at dosages between 10 and 20 wt%. If used as produced, this would have a significant impact on the cement industry CO2 emissions as the clinker production is responsible for 85 % of the total emissions in an integrated cement plant.

The usage of bauxite residue in clinker or blended cement productions will most likely in locations where there is a shortage of alternative conventional raw materials such as natural clays, bauxite and iron ore for the former and fly ash, blast furnace slag and ground limestone for the latter. In these situations, the use of bauxite residue would help the cement industry reach two of their most important strategic targets: resource efficiency, by replacing non-renewable iron and alumina sources, and CO2 emissions by minimising clinker production, the main CO2 origin in the cement manufacturing process. (https://www.world-aluminium.org/media/filer_public/2020/03/16/opportunities_for_use_of_bauxite_residue_in_supplementary_cementitious_materials_2020.pdf)

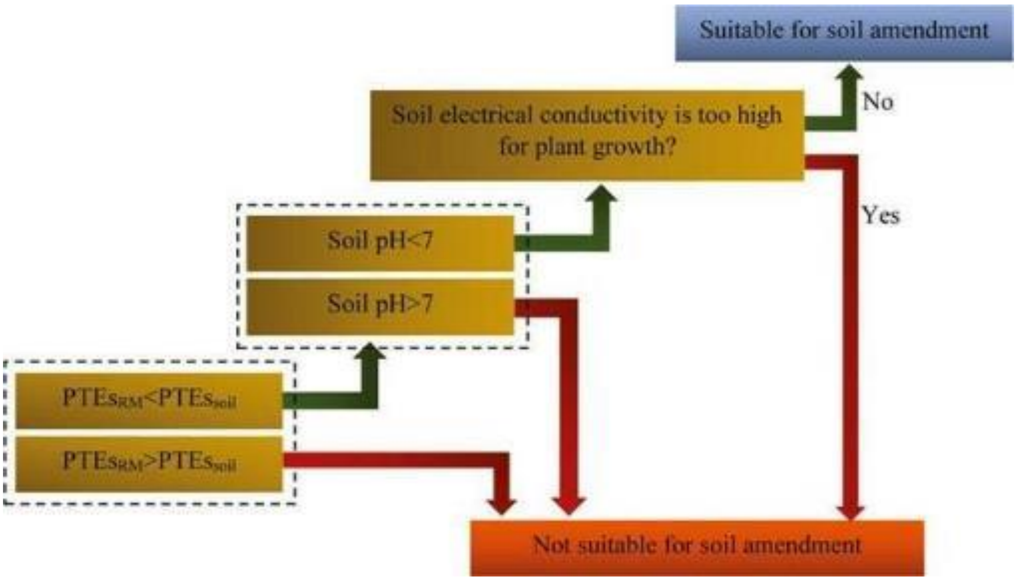
8.4.5 Adsorption

Since removal of organic and inorganic pollutants from aqueous media is necessary for health and environmental protection, conventional methods such as reduction, precipitation, adsorption, oxidation, membrane filtration and ion exchange are commonly used. Industrial solid wastes have been applied as effective adsorbents due to the easy availability and economic feasibility. Among them, RM presents an adsorption capacity for removing heavy metals from wastewater. Moreover, the RM has been found to remove fluoride, arsenate, phosphate, nitrate, hexavalent chromium, copper, cadmium, lead and dyes from aqueous solution. Also, the RM adsorption efficiency has been compared with other low-cost adsorbents in the literature. Several activation methods have been suggested to increase the adsorption properties of RM such as acid treatment, heat treatments and mixing the RM with other materials). The resulting activated RM acts as an inexpensive adsorbent and it was found to efficiently remove pollutants from aqueous solutions.

8.4.6 Soil Amendment

In spite of the fact that RM is contaminated with heavy metals, its application in environmental remediation has extensively been investigated. The RM could be an efficient soil amendment due to its fixation of heavy metals. The heavy metals are invariable and they are not as degradable as organic pollutants in the soil. The RM can easily adsorb different metal ions and it has a significant effect in removing heavy metals from contaminated soil.

The published information has also suggested use of a preliminary decision tree scheme for evaluation of the suitability of RM as soil amendment agent. As per the scheme shown below, the suitability of the RM for soil amendment depends on soil pH, soil electrical conductivity, and total potentially toxic elements (PTEs) of RM.



The investigations include the efficiency of RM to stabilize heavy metals in two types of soils, soils polluted by industrial activities and sewage sludge. In both soils, using Red Mud resulted in low concentrations of metals in metal fluxes and the soil pore water. Also, the neutralized RM (pH 8) has the capability to decrease phosphate leaching into ground and surface water due to the high concentration of iron and aluminium oxides.

In another study, the RM mixed with the sandy soil ranged between 0 and 50%. The results demonstrated that the RM applied at 5% had positive effects on the degraded acidic sandy soil, remarkably by increasing soil pH, improving water holding capacity and soil texture.

Since the mobility of metals is closely related to pH, the RM amendment of contaminated soil can enhance metal release from the amended soil. Moreover, the RM-amended soil can result in benefits for ecosystems in decreasing the mobility of potentially toxic elements to transfer to the environment. The use of RM for soil amendment would be an effective way to decrease the current storage.

8.4.7 Catalysis

The utilization of industrial solid wastes containing catalytically-active metals such as Ni, Fe, V etc., as an alternative to commercial catalysts can assist decrease the cost related to the use of catalyst. The RM which is majorly a combination of inorganic oxides of Fe, Al, Ti and a few amounts of Si, Na and Ca is a potential alternative catalyst at the commercial scale.

The simultaneous presence of various metal oxides in the RM composition makes it less susceptible to catalyst poisons like sulphur, and hence it is able to retain its catalytic activity over a relatively long period of time.

8.4.8 Oxidation Reactions

It has been extensively accepted that catalytic oxidation is a very interesting method for removal of volatile organic compounds (VOCs), which induce intense environmental detriments. In this field of research, the noble and transition metals have been widely employed to eliminate VOCs, but with various restrictions. The co-presence of metal oxides in RM sparks the idea of using the RM as an alternative catalyst for replacing the commercial noble metal and transition metal oxides in catalytic-related applications.

Proper treatments can be applied to prepare RM-based catalysts. For instance, loading of Pt on the air-thermally treated RM was very efficient for the removal of VOCs.

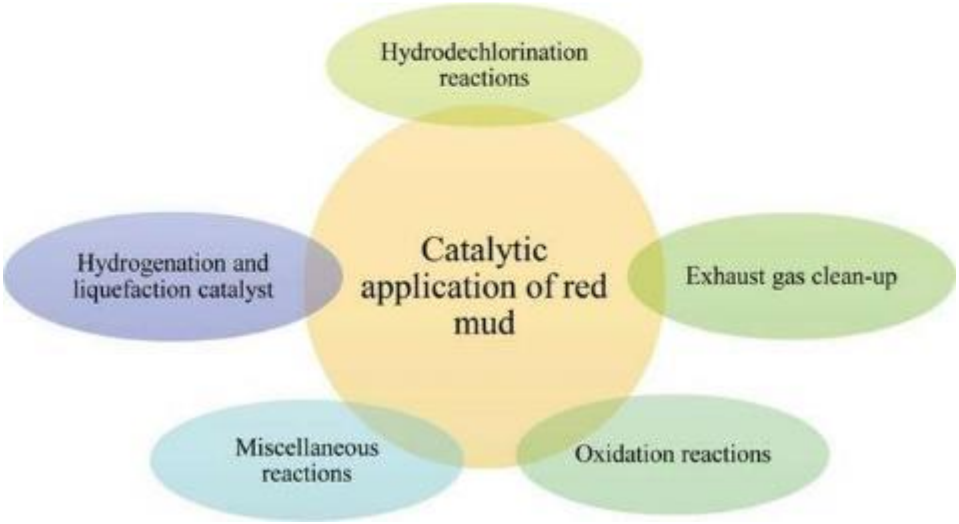


Figure 27 : Catalytic application of Red Mud

a) Hydrogenation Reactions

According to this method, the RM was dissolved in HCl to obtain a metal chloride leachate. The re-precipitation was then performed by the addition of ammonia. It was found that untreated RM exhibited a naphthalene conversion efficiency of 3.55% while the treated RM possessed a conversion efficiency of 58%. There are number of other publications which can been referred for specific applications.

b) Dechlorination and Hydro-Dechlorination Reactions

Catalytic dechlorination and hydrodechlorination reactions are efficacious and ecofriendly methods for the decomposition of chlorinated organic compounds. Several studies have been reported the catalytic application of RM in hydrodechlorination and dechlorination reactions. These include investigation of the utilization of RM as a catalyst for hydrodechlorination of tetra- chloroethylene. They evaluated the catalytic activity of sulfided RM and RM based-sulfided catalysts and found that the sulfided RM presented a better activity. But the catalyst suffered from a low stability at reaction conditions, because of poisoning by HCl.

c) Exhaust Gas Purification

The RM has already been studied for the catalytic removal or destruction of certain air pollutants. Among these studies are the following: recovery of sulfur from sulfurous waste gases, catalytic combustion of methane, selective catalytic reduction of NOx, elimination of VOCs, removal of HCl from exhaust gases, dioxins and CO, hot gas clean-up of coke oven gases and gasification products. The RMs from different sources have been employed as catalysts for reduction of SO2 in the presence of CO. It was found that the RM wastes having high Al and Fe content exhibited good catalytic activity.

The RM has been investigated to exhibit an excellent activity in the selective catalytic reduction of NOx. They proposed grinding/acid–alkali neutralization technique to utilize the RM waste as iron-based catalyst. The resulting catalyst presented a NO conversion of more than 90% above 400°C in the presence of SO2 and H2O. The result is even better than that of a commercial V-W-Ti catalyst. In another study a low-cost RM-based catalyst was prepared and tested in the ammonia-selective catalytic reduction of NOx. It concluded that the RM was a potential material for denitration catalyst. Their results demonstrated that the doping of Ce significantly increased the NOx conversion as much as 88%.

d) Other Applications

In addition to the uses mentioned above, the RM has also been studied in other applications such as in the process of steel making and as slag additives. The RM is considered as one of possible supplements utilized as a source of Al, Si, and Ca to improve the setting, separation, and quality characteristics of the slag.

Generation of ceramic products such as double-layer glass-ceramic tile, glass ceramic foam materials, roof tile/brick, and lightweight ceramic floor are from other areas of RM application. The microstructural and mechanical characteristics disclosed that the production of double-layer glass-ceramic tiles from the RM may be an attractive approach for converting the RM into building materials. The low bulk density glass ceramic foams can be produced by blending RM, fly ash, and CaCO3 as foaming agent at low sintering temperature. By replacing natural clay with 30 wt% of low sodium hydroxide-containing RM and applying calcination temperatures of above 950°C, ceramic tiles with acceptable properties can be allowed. The ceramic bricks with excellent water permeability and much decreased pH and conductivity could be fabricated by mixing appropriate proportions of RM, water, and silicon dioxide

The high iron content in RM made it an appropriate component in pigments and paints. A variety of brown-red shades produced by the RM. Sintering the RM at 1300°C makes it suitable alternative for the hematite pigment. Combining the RM with electroplating sludge in different proportions, following by calcination at 1200°C could result in black and brown pigments with appropriate colouring strength and thermal stability.

The use of RM in the preparation of composite RM/polyaluminum chloride coagulant is expected to be cost-effective for the efficient removal of phosphate from aqua medium. The RM can also be used as Al source for the fabrication of magnetic zeolite. In a recent study, wool ball-shaped zeolite was synthesized using the RM and colloidal silica. The prepared zeolite can be considered for wastewater treatment. The RM can even be used for neutron shielding application. For this purpose, the RM was first treated with boric acid and then mixed with polyester resin.

Apart from above, Red Mud may also be utilized for backfilling of spent mines. In this regard, a pilot study is being carried out by IIT Bombay for backfilling of Baphlimali Bauxite Mine with Red Mud at M/s Utkal Alumina International Ltd., Rayagada, Odisha.

8.5 Challenges and Future Perspective

Bauxite residue is not randomly distributed about the globe in an uncontrolled manner, but predominantly exists in discrete locations at which it is generally well contained, closely controlled and subject to safe environmental conditions. The best way to solve RM disposal problems is to develop technologies that can process a huge amount of RM.

The current barriers that need to be overcome include amount, feasibility, quality and risk associated with disposal of Red Mud.

To successfully transition RM from a waste to be disposed at a cost, to a new product to create overall value, will require more than the development of technological solutions. The barriers that will need to be overcome are summarised as follows:

Volume	• Reuse options must utilize high volume
Performance	• Performance of Red Mud must be competitive with substituted material • Effective removal/treatment of soda for some applications
Cost	• Evaluating the economics of current Red Mud management • Economics of additional downstream processing • Co-use of other by-product waste streams
Risk	• Assessment of health, safety and environmental risk associated with transport, processing and application • Business risk associated with product quality and various liabilities • Removal of soda, alkalinity and removal or immobilization of heavy metals and NORM • Lifetime/durability of the secondary product • Liability issues covering heavy metals and NORM components

In order to increase utilization of red Mud in cement clinker production, study be carried out to determine the fate of toxic metals namely, Arsenic, Cadmium, Chromium (Total), Chromium (VI), Lead, Nickel and Cobalt.

Further, there is scope to assess a sustainable method for partial neutralization of Red Mud to the extent that the quality of the leachate/run off generated from the use of this material as a filler complies with the inland surface water standards prescribed in Schedule -VI of the EP Rules 1986.

9. ENVIRONMENTAL EVALUATION OF RED MUD FOR BENEFICIAL USES

The Red Mud generated from the processing of bauxite is not only highly alkaline but also contains toxic metals like arsenic, cadmium and chromium (VI). It is therefore essential to make an extensive assessment of (i) the constituents of potential concern (COPC) contained in it and (ii) the environmental, economic and social impacts of such a material for any beneficial purpose or disposal. The present use of the Toxicity Characteristic Leaching Procedure (TCLP) is limited to the its classification for the purpose of regulation and this test does not provide the environmental and other assessments that are required to adequately support the beneficial use determination or disposal process.

The waste material Red Mud which is presently being disposed almost entirely into approved storage facilities, does have the potential of beneficially uses. There are numerous environmental, economic and performance benefits of utilizing Red Mud for appropriate beneficial uses. The potential benefits associated with the beneficial use of Red Mud include preservation of natural resources, reduced air and water pollution from extraction activities, reduced greenhouse gas emissions, reduced production costs, and avoided use of landfill space. This helps in the sustainable management of this waste through adoption of approach that aims to reduce impacts to human health and the environment associated with this material over its entire life cycle (e.g., extraction, manufacture, distribution, use and disposal).

The US EPA has developed a methodology for evaluating the beneficial uses of Industrial non-hazardous wastes (including Red Mud) called therein is as “secondary materials”. These methodologies include the following:

1. **US EPA Methodology (2016):** The methodology is divided into three phases: planning and scoping, impact analysis, and final characterization. Each beneficial use evaluation conducted using this methodology must progress through these three phases, with the flexibility in how each is to be applied.
2. **Leaching Environmental Assessment Framework (LEAF):** The document provides guidance on the use and application of the Leaching Environmental Assessment Framework (LEAF) published by the United States Environmental Protection Agency (U.S. EPA or the Agency). The purpose of this guide is to provide an understanding of LEAF to facilitate its broader use in environmental assessment. LEAF is a leaching evaluation framework, which consists of four leaching tests (i.e., U.S. EPA Methods 1313, 1314, 1315 and 1316), data management tools, and approaches for estimating constituent release from solid materials. The LEAF tests consider the effect on leaching of key environmental conditions and waste properties known to significantly affect constituent release.

The details on these methodologies are provided at ***Annexure-II***.

10. REHABILITATION OF RED MUD DISPOSAL AREA (RMDA)

Red Mud is highly alkaline in nature of Red Mud poses environmental and health risks. The extremely high pH and salinity accompanied by high water holding capacity and low microbial activity of the Red Mud poses serious challenges for rehabilitation making it difficult to restore the ecological balance of the disposal site.

10.1 Rehabilitation Approach Options

The main drivers for the closure and rehabilitation of a RMDA reported are:

- Eliminate contaminant runoff
- Control fugitive dust.
- Improve visual impact.
- Reintegrate with adjacent vegetated area.

The approach to RMDA rehabilitation mainly follows one of two main strategies namely, (i) providing a cap or cover of soil or soil-like material to provide a plant growth medium and (ii) natural rehabilitation which refers to improving of the physical and/or chemical properties of the residue using amendments (e.g. gypsum, bio solids, or compost) followed by direct vegetation of the Red Mud surface.

Recent research on the rehabilitation of RMDAs has shown that the use of natural rehabilitation is a viable alternative to soil capping and enables the transformation of the remediated part of the Red Mud into a soil capable of supporting a self-sustaining ecosystem.

10.2 Natural Rehabilitation

a) Overall Mechanism

The natural Rehabilitation of RMDA has been referred to as selection amendments to aid lowering of pH values and reducing electrical conductivity (EC). It is also desirable to increase cation exchange capacity (and decrease the exchangeable sodium percentage) and stimulate the accumulation of plant and microbial nutrients, such as organic C, NH_4^+, NO_3^-, PO_4^{3-}, and K^+ in the Red Mud. The most commonly methods studied on site with regard to their relevance to the Indian conditions are given in the subsequent paragraphs.

b) Gypsum Amendment

This method involves surface amendment with calcium sulphate (gypsum $CaSO_4 \cdot 2H_2O$, anhydrite $CaSO_4$) for the rehabilitation of the RMDA. Adding gypsum will decrease (as reported) exchangeable sodium concentration (Ca^{2+} ions exchange against Na^+), reducing sodicity of the material. Na^+ along with added SO_4^{2-} will leach down the profile with the percolating drainage water. Additionally, calcium ions will precipitate with carbonate (CO_3^{2-}) in soil water to calcite ($CaCO_3$) and, in this way, reduce alkalinity and pH. This in turn will reduce Al solubility. Furthermore, gypsum can promote flocculation of clay particles and the formation of soil aggregates, as well as increase hydraulic conductivity. This is a result of calcium ions displacing the sodium ions on clay particles, which results in a closer packing and better aggregation of the clay particles.

c) *Organic Amendment*

Addition of organic matter to Red Mud is reported to have several positive effects on the plant growth ability. These include, addition of organic carbon as a soil enhancer and supply of plant nutrients (e.g. N, P, S) substances, chelation and formation of stable complexes with metal cations (e.g. Cu, Zn, Mn, Al), water retention, and formation and stabilisation of soil structure. Additionally, organic matter is an energy source for soil organisms, including bacteria, fungi, earthworms and other soil fauna.

Introduction and incorporation of organic wastes and amendments into the surface layers of Red Mud is reported to the most practicable way of increasing microbial activity. This, in turn, will promote the formation of a functioning below-ground ecosystem containing microflora and fauna (e.g. bacteria, fungi, protozoa and nematodes), mesofauna (e.g. collembola, cicari) and macrofauna (e.g. earthworms and termites). These organisms interact in carrying out many soil functions, including the flow of energy and nutrients through the soil system.

Fermentation of organic matter will contribute to an acidifying effect by generating organic acids and CO2. This is reported to be also of help in reducing the alkalinity of Red Mud. Addition of organic wastes will also increase the water holding capacity and increase the soil structure by creating more-stable aggregates, which, in turn, stabilise channels and pores, allowing drainage and aeration.

10.3 Overall Current Scenario

The current research status does not suggest any ideal methodology for remediation of the RMDAs. However, there is still lack of long-term success in rehabilitation of RMDAs and the key aspects of which require further understanding are:

(i) Soil genetic characteristics in natural weathering process of Red Mud in the area.

(ii) Diagnostic soil characteristic in the concerning the RMDA.

(iii) Soil-forming factors during the pedogenic process of Red Mud

(iv) Indicators and facilitators of the rehabilitation process in the area.

(v) Colonization of tolerant plants and microbial populations in the area.

(vi) Screening of tolerant plants and microbes such as halophytes, alkaline-tolerant plants, aluminium-tolerant plants, and alkaliphilic microorganisms.

(vii) Mechanisms of soil aggregate formation and regulation during pedogensis of Red Mud.

(viii) Humification of soil during pedogensis of Red Mud.

(ix) De- alkalization and desalinization of the restored Red Mud.

(x) Environmental risk analysis its management in the rehabilitation process.

The long term sustainability of the natural rehabilitation efforts is expected to further depend on the, (i) the availability and plant content of key nutrients, (ii) the development of target soil test values for macro- and micronutrients calibrated in revegetating red mud for the plant being used for revegetation, (iii) the availability and plant content of potentially toxic heavy metals and metalloids, (iv) determination of threshold levels of these elements for plants and microbes living in bauxite residue. (v) the risk of transfer of such metals and metalloids to grazing animals and wildlife, (iv) soil faunal colonisation activity and their effects on ecosystem function, (vi) the effectiveness of inoculation of soil fauna on ecosystem function, (vii) the ability of introduced plant communities to withstand environmental stresses, and (viii) the capacity of introduced plant communities for self-propagation.

10.4 Key Documents/Publications Studied

(i) Remediation and Rehabilitation (Sort out the sodium!), Ronan Courtney, 3rd International Bauxite Residue Valorisation and Best Practices Conference, Virtual Conference, September 29- October 1, 2020 (ronan.courtney@ul.ie).

(ii) Ecotoxicological risk assessment of revegetated bauxite residue: Implications for future rehabilitation programmes (2020) https://www.sciencedirect.com/science/article/abs/pii/S0048969719343359

(iii) Challenges for the closure and natural rehabilitation of bauxite residue disposal sites (2019)
https://papers.acg.uwa.edu.au/p/1915_08_Torgersrud/

(iv) Soil quality and vegetation performance indicators for sustainable rehabilitation of bauxite residue disposal areas: a review (2019)
https://www.publish.csiro.au/sr/pdf/SR18348

(v) A field assessment of bauxite residue rehabilitation strategies (2019)
https://www.sciencedirect.com/science/article/abs/pii/S0048969719304255

(vi) Soil Salinity Testing, Data Interpretation and Recommendations
https://secure.caes.uga.edu/extension/publications/files/pdf/C%201019_3.PDF

(vii) Sustained Bauxite Residue Rehabilitation with Gypsum and Organic Matter 16 years after Initial Treatment (2018)
https://pubs.acs.org/doi/pdf/10.1021/acs.est.7b03568

(viii) Bauxite Residue Disposal Area Rehabilitation, Kevin McMahon, Proceedings of 35th International ICSOBA Conference, Hamburg, Germany, 2 – 5 October, 2017 (kevin.mcmahon@augh.com)

(ix) Long Term Residue Management Strategy, Pinjarra, Alcoa (2016) https://www.alcoa.com/australia/en/pdf/ltrms-pinjarra-refinery.pdf

(x) "Project Report on “Development of biophysical treatment technique for rehabilitation of red mud pond at HINDALCO, Belgaum, Karnataka, TERI, 2008”

(xi) A review of the characterization and revegetation of bauxite residues (Red Mud) (2015)
https://www.researchgate.net/publication/275411066_A_review_of_the_characterization_and_revegetation_of_bauxite_residues_Red_mud

11. RECOMMENDATIONS FOR ENVIRONMENTALLY SOUND HANDLING AND MANAGEMENT

11.1 Terms and Definitions as per these Guidelines

(i) Red Mud (RM): The reject generated in the Bayer Process of alumina production, which is classified as a high-volume effect waste (HVLE) under the HOWM Rules 2016 and required to be managed as per the CPCB guidelines given in this document.

(ii) Dry Stacking Facility (DSF): The facility designed for dry stacking of the Red Mud filter cake with moisture content less than 28% and alkali concentration (as Na_2O) less than 3.0%. The alkali concentration of 3% may further be reduced by adopting Best Available Technologies (BAT). The Red Mud filter cake disposed in DSF does not include other waste generated from any of the associated processes/disposal facilities.

(iii) Settling Pond (SP): The pond for settling-in the rain water runoff from the DSF provided.

(iv) Supernatant Liquid Collection and Recycling Pond (SNLP): The pond provided (as per these guidelines) for the storage of the overflow from the SP and the associated facility for its pumping and recycling in the alumina production process.

(v) Red Mud Disposal Area (RMDA): The area comprising of the DSF, SP, SNLP and all the other associated infrastructure for which Environmental Clearance (EC) has been obtained under the EIA Notification of 2006 for disposal of the Red Mud.

(vi) Red Mud Pond (RMP): This is a lined/unlined lagoon constituted earlier for holding Red Mud Slurry with arrangement of recirculation of supernatant liquid. The earlier practice of handling of Red Mud included its disposal in slurry form into Red Mud ponds.

11.2 Applicability of these Guidelines:

These guidelines are applicable to:

(i) To the existing Red Mud generating units; construction of new DSF; Operation or closure or proposed for closure of DSF(s); closed RMP; lateral expansion of the existing DSF(s); and any expansion in the alumina production leading to increase in Red Mud generation.

(ii) For handling, transportation, disposal and utilisation of Red Mud including management of RMDA.

11.3 Red Mud Generation

(i) Minimization of the Red Mud generation through use of better-quality ore where possible.

(ii) Minimization of the Red Mud generation through process parameter control or optimization.

(iii) Increased washing of the Red Mud to get lowest possible alkali concentration in Red Mud. Further, BATs may be adopted for reducing the alkali concentrations below 3.0%.

(iv) Monitoring of the Red Mud quality once in a day for pH and moisture, whereas, electrical conductivity, alkali concentration (as Na_2O) and toxic heavy metals- Arsenic, Cadmium, Chromium (Total), Chromium (VI), Lead, Nickel and Cobalt may be analysed quarterly. The results should be compiled and reports to be sent annually to the SPCB and CPCB.

11.4 Red Mud Filtration

(i) Discontinue the use of RMP and complete shifting from an RMP system to DSF with high pressure filtration technology capable of providing filter cake with moisture content less than 28% within a period of one year.

(ii) Adoption of press high pressure filtration technology generating a filter cake with a moisture content less than 28% for any expansion of the alumina production capacity and establishment of new alumina plants.

(iii) The transfer of Red Mud slurry from the refinery to the filtration building be carried out through pipelines.

(iv) The filtration system to be located as close as possible on the upstream side of RMDA for any further expansion of the alumina production capacity or change in the location of the RMDA or establishment of any new refinery.

(v) The handling of the Red Mud in and around the filtration unit to be under covered shed.

(vi) The pipelines from filtration unit to the RMDA be laid at a safe distance from surface water body/river, public road, state/national highway, railway tracks etc. so as to prevent spillage/contamination.

Note: All the existing Red mud generating units are required to install filter press and shift to dry stacking of Red Mud (with moisture content not more than 28%) within 01 year from publication of these guidelines.

11.5 Site selection and location criteria for the Red Mud Disposal

For expansion of the RMDA at the existing location or change in the location of RMDA or establishment of new industry, following criteria be considered:

As far as possible, new Red Mud disposal site or expansion of the same should be located within or near the existing industry premises. In case, if it is required to construct ex-situ RMDA, the same may be located at a site based on the approval by MoEF&CC/SPCBs/ PCCs on case to case basis and may be looked upon while granting EC and Consent. The siting criteria may take into account the nature and impact of RMDA on the surroundings (i.e. habitats, natural and manmade water bodies, roads, railway tracks, etc.)

11.6 Red Mud Handling and Disposal

A. Dry Stack Facility

(i) The filter cake from the filtration system be transferred through covered belt conveyer to the DSF.

(ii) The conceptual design given in Part ‘B’ of this section with upstream stacking method for the disposal of filter cake in the DSF be adopted which shall include DSF, SP, SNLP and all associated facilities.

(iii) The DSF to be sloped to ensure unhindered gravity flow of all the run off from the stacked Red Mud into the SP.

(iv) The cumulative capacity of the SP and SNLP to be adequate to hold all the run off in case of heavy rains leaving a bare head of at least one meter in both.

B. Design Considerations for new DSF

Conceptual Design and Description of the Red Mud Disposal Area (RMDA)

Design* of the RMDA
(*The orientation of the facilities can be adjusted as per the geography of the area)

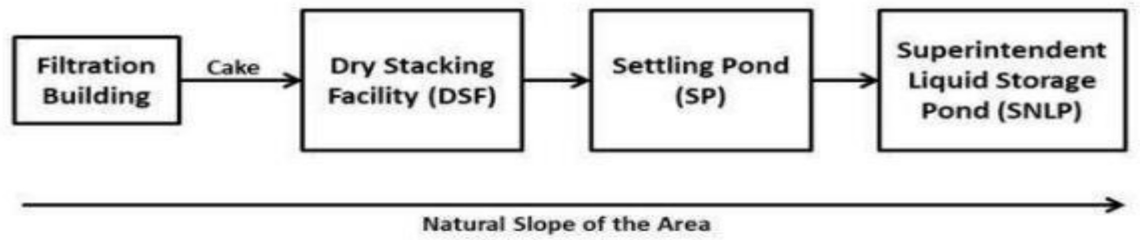


Figure 28: Cross section of the DSF

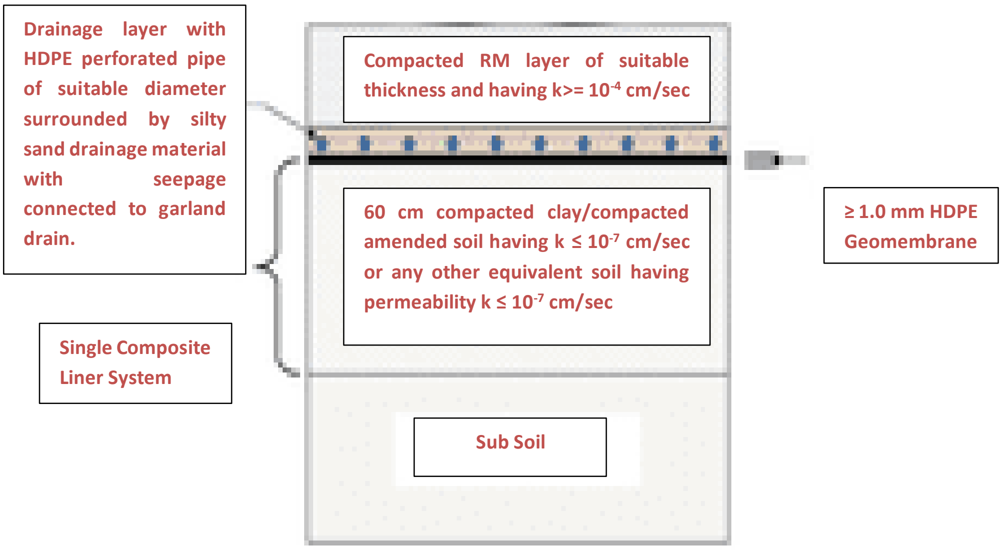


Figure 29: Suggested liner system for DSF

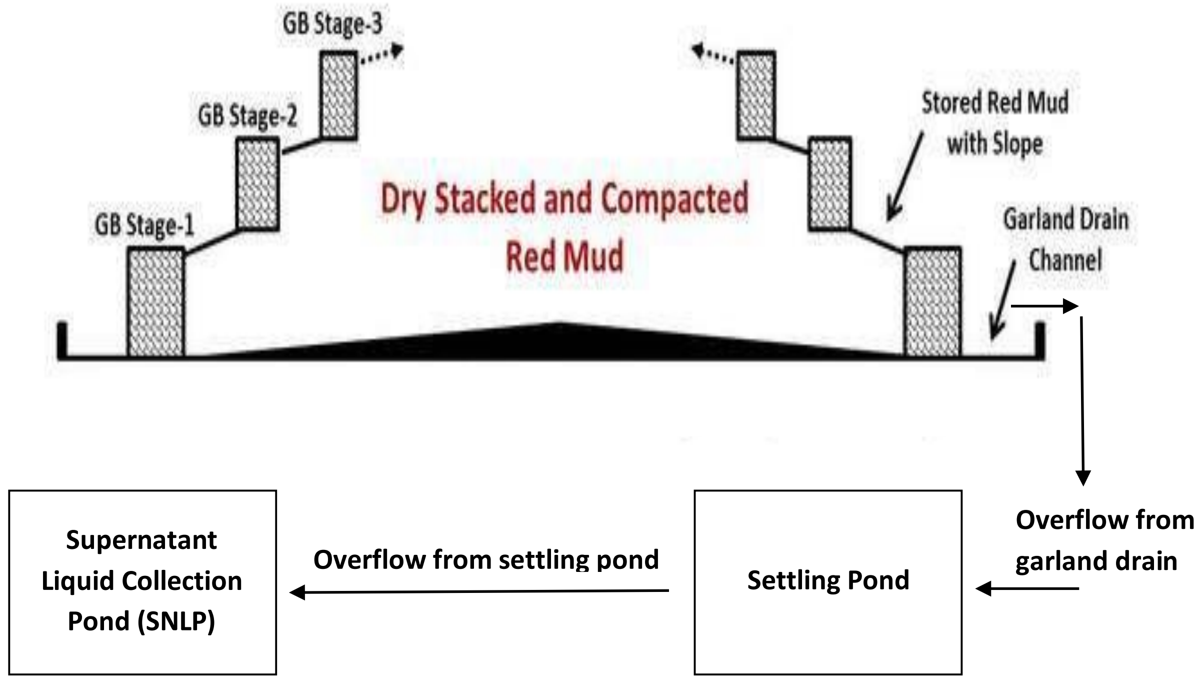


Figure 30: Stages of RMDA

Note: A typical layout of the RMDA provided in the guidelines has to be followed. The design specification may vary depending upon the geographical, hydrological and geotechnical conditions, however, the same is required to be designed by a competent engineering consultancy firm/agency and the same shall be vetted by a reputed technical institution in the country.

Further, in case the height of DSF is to be raised beyond 30m, a report on the technical/engineering aspects/safety, duly vetted by a reputed government institution is required to be submitted to SPCB and copy of the same to be forwarded to CPCB for comments. The unit may take necessary approvals from MoEF&CC/SPCBs/PCCs as required.

Description of the RMDA Design

i. Location of the Facilities

a) Location of the facilities (DSF, SP and SNLP) to be based on maximum utilization of the natural slope in the area for gravity flow of the run -off from the DSF to the SP and its overflow to the SNLP.

b) Filtration building to be located on the upstream side and as close to the RMDA.

c) Belt conveyor to be aligned in a way that enables direct transport of the cake from the filtration building to location of its unloading close to the DSF inside the RMDA.

d) The open to sky areas including the haul roads involved in the transport of Red Mud from this conveyor belt off-loading location to the DSF should be sloped to enable gravity flow of the run off to the SP.

e) The approach to the RMDA should be from the upstream side with drainage provided for diversion of all rain water run water from the upstream to the nearby by natural drains.

f) The proposed area should be sufficient for development of RMDA for disposal of the Red Mud generated for at least 25 years with stacked material preferably not exceeding the height of 30 meters from its base.

> **Note:** Units shall completely shift towards conveyer/ pipelines for transporting Red Mud from filter unit to DSF within 01 year from publishing of these guidelines.

ii. Development of Dry Stacking Facility (DSF)

a) The containment to be of a gabion wall or earthen dykes and garland drains channel. The bottom of the containment to be HDPE lined (≥ 1.0 mm) and sloped in a way that enables gravity flow of the leachate towards the gabion wall and finally to the garland drain channel. This will be for the first stage of stacking.

b) The stacking in the first stage to be done in a manner that ensures leaving of no low-lying area and least flat area on the stack. The run off and leachate from the DSF should gravity flow to towards the containment wall and finally into the garland drain.

c) The second stage containment will be little smaller compared to first stage containment and will be on the stacked material itself. This will be created by constructing a containment wall of smaller size (02 meters or so) in way that leaves certain width of the stacked material between the fist and the second containment wall with slope that leachate/ run off permeation to the through these walks to reach the garlands drain channel.

d) The third stage to be constructed in the same way on the material stacked in the second stage. The area covered will be lesser than the second stage and again a certain of stacked material will be left between the third and the second containment wall.

e) The number of stages, the heights/width of the gabion walls/earthen dyke for the different stages, the width of the stacked material to be left between the two successive gabion walls etc. to be calculated based on Red Mud holding capacity for reaching a height of 30 meters from the ground to the crest of the stacked material in the upper most stage. The stacked material in the uppermost stage also be compacted and sloped in the manner that enables gravity flow of all the run off through the preamble gabions walls down to the garland drain channel.

f) In case of the geographical limitations where providing the containment wall on all the sides is not possible, the sides without the wall should be prepared with appropriate construction and HDPE lining to protect the DSF into or from it. The slope of the DSF in this case also should be towards the containment wall to ensure collection of the leachate /run off in to the drain channel.

g) The approach roads within the RMDA should be developed in way that enable gravity flow of all the run off into the SP and easy movement of the mobile dust suppression vehicle as recommended in the guidelines.

iii. Settling Pond (SP) and Superintendent Liquid Storage Pond (SNLP)

a) The construction of SP as well as SNLP should be preferably without any digging of the ground.

b) The location of the SP should enable continuous collection of the run off from the DSF into it with no liquid left in continuous contact with the stacked material.

c) The SP may be constructed with two parallel parts in way that permits cleaning of one while the other is in use. The design in such cases should also permit use of both at any time and overflow from these to the SNLP.

d) The embankment of the SP to be constructed with an alkali resistant material. The entire base and sides of the SP should be lined by any impervious liner.

e) The SNLP should be located to receive continuous/controlled collection of the overflow from the SP. The rest recommendations made at (2) and (3) above also applies to the SNLP.

f) The SNLP to be provided with pumping station.

g) The upstream areas (if any) of the SP and SNLP to be provided with appropriate drainage to prevent any rain run off entry into these facilities.

h) Instead of separate SP & SNLP, a single settling-cum-holding pond may be constructed ensuring no overflow of runoff.

C. Other Measures for Handling, Operation and Management of DSF

(i) There should be vehicle tyre wash facility at the entrance of the approach to the Red Mud ponds. The washings to be collected into the runoff water collection pond

(ii) Providing fixed or stationary dust suppression system for the entire surface and approach/haul roads. The system should be designed for use of the collected run off for this purpose. Images of the truck mounted water sprinkler system which could be used for dust suppression on the haul roads, are given in ***Annexure – III.***

(iii) An Operational and Safety Manual should be prepared for RMDA. The aspects to be included (but not limited to) in the manual are listed in ***Annexure- IV.***

(iv) The Industry should conduct risk assessment study to the point of the complete collapse or washout of the stored material due to liquidation in bottom part resulting into spreading of the thixotropic mud and flooding and damages in the areas surrounding areas. There should be preparedness for the same as per the disaster management plan (DMP) within one year. The aspects to be included (but not limited to) in the study are listed in ***Annexure-V.***

The EIA/RA studies and preparation of the EMP/DMP for the development of RMDA should include its environmentally safe closure and rehabilitation.

(v) The industry should get satellite or areal imaginary testing of the RMDA done once in a year through an expert agency for any unusual displacement in the

RMDA and submit the report to SPCB and CPCB. This testing should also be done soon after any earthquake, heavy rain fall, storms etc. event for any adverse effect on the RMDA, take immediate counter measures in case of may impact and submit report to SPCB and CPCB.

(vi) The industry should conduct an internal safety audit of the RMDA for each of the financial year and submit the report to SPCB by the 30th of September of the flowing year.

(vii) The industry should conduct an external (third party) safety audit of the RMDA once in two consecutive financial years and submit the report to SPCB and CPCB by the 30th of September of the following year. The aspects to be included (but not limited to) in the audit are listed in ***Annexure-VI***.

(viii) The expansion of the RMDA at the existing location or change in the location of RMDA [or establishment of new industry] to be considered for the grant of EC.

(ix) Monitoring of river /surface/ ground water (minimum three locations each) and soil (minimum six locations each) on all the sides (except higher altitude side) up to at least 500 meters from the periphery of RMDA, for pH, and toxic heavy metals- Arsenic, Cadmium, Chromium (Total), Chromium (VI), Lead, Nickel and Cobalt, twice (in pre and post monsoon seasons) in a year and send the reports to SPCB and CPCB.

Note: All units shall periodically monitor the surface and ground water as per the monitoring protocol suggested under these guidelines, through a laboratory recognised under the Environment (Protection) Act, 1986 or any NABL Accredited Laboratory for assessment of the contamination (if any) and such assessment reports be submitted annually to respective SPCB/PCC and CPCB.

Further, all units should prepare risk assessment study report and Disaster Management Plan (DMP) within one year including aspects (not limited to) listed in ***Annexure-V.***

11.7 Closure and Rehabilitation of DSF/RMP

A. Closure of DSF/RMP

On completion of the operational life of the DSF or on exhaustion of its capacity, the DSF should be closed/ capped. The cover system shall be designed, constructed and installed so as to fulfil the following:

a) Prevent infiltration of precipitation into the closed DSF.

b) Promote drainage of surface water accumulated on the cover.

c) Minimize erosion of the cover

d) Withstand or accommodate the settlement of the cover to maintain its integrity.

e) Have a permeability less than or equal to the liner system.

f) Ensure drainage of water trapped within the DSF and subsiding of solids to maximum possible extent.

g) The slope of DSF should be maintained in a way to prevent ponding on top or anywhere on the capped DSF.

h) Function with minimum maintenance for the post-closure period for 30 years.

B. Rehabilitation of DSF/RMP

The main drivers for the closure and rehabilitation of a RMP reported are:

- Eliminate contaminant runoff
- Control fugitive dust.
- Improve visual impact.
- Reintegrate with adjacent vegetated area.

The approach to RMP rehabilitation mainly follows one of two main strategies namely, (i) providing a cap or cover of soil or soil-like material to provide a plant growth medium and (ii) natural rehabilitation which refers to improving of the physical and/or chemical properties of the residue using amendments (e.g. gypsum, bio solids, or compost) followed by direct vegetation of the Red Mud surface. The details on the rehabilitation approaches are given at section 10 of these guidelines. The rehabilitation approaches should include (but not limited to) the measures mentioned below:

a. Soil genetic characteristics in natural weathering process of Red Mud in the area.

b. Diagnostic soil characteristic in the concerning the RMDA.

c. Soil-forming factors during the pedogenic process of Red Mud.

d. Indicators and facilitators of the rehabilitation process in the area.

e. Colonization of tolerant plants and microbial populations in the area.

f. Screening of tolerant plants and microbes such as halophytes, alkaline-tolerant plants, aluminium-tolerant plants, and alkaliphilic microorganisms.

g. Mechanisms of soil aggregate formation and regulation during pedogensis of Red Mud.

h. Humification of soil during pedogensis of Red Mud.

i. De- alkalization and desalinization of the restored Red Mud.

j. Environmental risk analysis its management in the rehabilitation process.

k. Availability and plant content of key nutrients.

l. Development of target soil test values for macro- and micronutrients calibrated in revegetating Red Mud for the plant being used for revegetation.

m. Availability and plant content of potentially toxic heavy metals and metalloids

n. Determination of threshold levels of these elements for plants and microbes living in Red Mud

o. The risk of transfer of such metals and metalloids to grazing animals and wildlife.

p. Soil faunal colonisation activity and their effects on ecosystem function.

q. The effectiveness of inoculation of soil fauna on ecosystem function

r. Ability of introduced plant communities to withstand environmental stresses, and

s. Capacity of introduced plant communities for self-propagation.

Note: In case, the Red Mud generating units does not prefer for permanent closure of the existing DSF, in such a case, the unit is required to submit a proposal for the 'existing Red Mud utilisation and/or rehabilitation plan' through concerned SPCB/PCC with their recommendations to the CPCB seeking further approval.

C. Escrow

The Red Mud generating units shall submit adequate financial assurance (FA) in the form of escrow account to the concerned SPCB, in a form and manner to be prescribed by it, to indemnify the State from liabilities arising out of construction, operation, closure or abandonment of the RMPs, at the stage of approval for construction or expansion of the facility. Validity period of such FA shall be 25 years after closure.

However, in case of existing facility the financial assurance as above be submitted within 01 year from publication of these guidelines.

D. Closed Sites

For management of RMPs/DSF closed prior to publishing of these guidelines, following shall be applicable:

a) An inventory of RMP/ DSF be prepared w.r.t. quantity of Red Mud or other waste stored, sent for utilisation alongwith details on its utilisation or rehabilitation, if any.

b) Identification of activities to be carried out to ensure no long-term environmental impacts and risk assessment due to the closed RMP/DSF. Based on impact and risk assessment study, action plan be prepared including financial implications and time schedule for implementation. The same to be submitted to concerned SPCB who will consider and convey their acceptance with conditions as appropriate.

c) The occupier of the closed site shall be responsible for preparing and implementing the action plan as above. The action plan be implemented within the agreed time frame.

d) The options for management of Red Mud from RMP/DSF shall include, though not limited to, utilisation of Red Mud as per section 11.8 of these guidelines.

e) For exploring the options for utilisation of Red Mud other than given at section 11.80, permission of SPCB/PCC may not be required for sending samples of Red Mud for study/research purposes of up to 1000 kgs. The unit shall maintain the records in respect of quantity, purpose and end user details and submit the same to SPCB/PCC. Precautions shall be taken during packing and transport to ensure no spillage and leakage.

f) In case of orphan sites or for such sites where the occupier is unable to prepare and implement the action plan as above on account of bankruptcy/insolvency/liquidation etc., the concerned SPCB/PCC (by appointing a competent consultant) shall prepare the action plan in consultation with CPCB. Funds for the same shall be drawn from the escrow account created for the purpose (as per Part 'C' of this section), if available. If not, the State Government shall arrange to get the plan implemented from its environmental budget.

11.8 Red Mud Utilization

11.8.1 Cement Production

(i) The maximum concentration of hexavalent Chromium in cement (produced using Red Mud) not to exceed 2mg/kg (2ppm).

(ii) Red Mud generating units to provide covered shed in the loading and dispatch area of Red Mud for use in cement industries or other applications as permitted in EC.

(iii) The railway wagons/trucks used for the transportation of the Red Mud to be covered to eliminate any rain water coming into its contact on the way.

(iv) All handling and use of the Red Mud in the recipient cement industries to be carried out under covered areas.

Note: There are no Indian standards for concentration of Cr6+ in Cement. Hence, the said limit of 2 mg/kg has been taken from the EU directive 2003/53/EC of the European Parliament dated June 18, 2003 that's states "In order to protect human health, it appears necessary to restrict the placing on the market and the use of cement. In particular, the placing on the market and the use of cement or cement preparations containing more than 2 ppm chromium VI should be restricted in the case of activities where there is a possibility of contact with the skin".

11.8.2 Preparation of Construction Materials

(i) Use of Red Mud in the preparation of any material (including bricks) for use in the construction of roads, buildings etc. (excluding development of the RMDA) to be done on the basis of findings of the Environmental Impact and Risk Assessment.

(ii) The hexavalent Chromium concentration in the construction materials not to exceed 2mg/kg (2ppm).

11.8.3 Soil Amelioration

Pre-Feasibility study to be conducted on a case to case basis (location to location) to examine the Environmental Impacts and Risk Assessment w.r.t. application of Red Mud in soil amelioration. The study to follow the decision tree chart given in ***Annexure-VII***. If found feasible, further decision to be taken on the basis of findings of the Environmental Impact and Risk Assessment and approval of Ministry of Agriculture.

11.8.4 Recovery of Elements

Pre-Feasibility study to be conducted on a case to case basis for the specific application of Red Mud. If found feasible further decision to be taken based on the findings of the Environmental Impact and Risk Assessment. The quality requirements of the recovered product to include the concentration limits for toxic metals.

11.8.5 Backfilling of Bauxite Mines

The option for disposal of Red Mud filter cake in backfilling of bauxite mines pits may be considered after conducting a pre-feasibility study. The filter cake used for back-filing should meet the criteria given at section 11.1 (ii). Further, a pre-feasibility study should be conducted on case to case basis (location to location) addressing site specific aspects of compaction, permeability, leachate management, surface run-off, safety, etc. along with other engineering aspects. The unit to obtain necessary approvals from Ministry/Department of Environment, Department of Mines, SPCBs/PCCs and as may be necessary.

Note: To begin with the Red Mud generating units shall utilize minimum 25% of its annual generation in the first year that should be gradually increased over the in subsequent years and also plan for utilisation of legacy red mud be submitted to concerned SPCB/PCC within a period of 06 months. SPCB/PCC shall examine the said action plan, outline time-bound targets, monitor the progress and submit the status report to CPCB by 30th June every year.

To achieve the utilisation targets, necessary technologies, including de-alkalisation, should be adopted to enable increased utilization in construction material, soil amelioration, recovery of elements, etc. The Pre-feasibility studies as mention at section 11.8.3-11.8.5 shall be carried out in time-bound manner, preferably in 01-02 years.

Further, for any utilization of Red Mud other than above, the proponent may submit the proposal along with relevant details to CPCB through the respective SPCB/PCC with their assessment and recommendations for permitting the same by SPCB/PCC.

11.9 Guidelines for transportation, handling and storage of Red Mud within the generating unit or any other beneficial use

(i) SPCB shall ensure that vehicles registered under the Motor Vehicle Act, 1988, are used for transportation of Red Mud.

(ii) While transportation, the vehicles shall be properly covered (with tarpaulin sheets).

(iii) In case of any spillage of Red Mud, it is the sole responsibility of the transporter for clearing such spillage immediately.

(iv) The generator of Red Mud shall ensure that the transporter carries requisite documents having details such as:

   a. Name and address of Red Mud generating unit;
   b. Quantity of Red Mud transported;
   c. Vehicle registration number;
   d. Name and address of destination unit;
   e. Date of departure of transportation vehicle from the source of generation;
   f. Expected date of arrival to the destination along with route chart; and
   g. Any other relevant documents as required for transportation.

(v) For beneficial use of Red Mud, the utilizers shall ensure the following:

- Red Mud shall be stored under a covered shed of adequate size and the floor should be of impervious nature surrounded by the proper drainage system for collection of floor washings.
- In the storage and handling area, adequate arrangements (like water spray) are provided to arrest fugitive dust emissions.
- Maintain records on the details (name, address & quantity) of Red Mud received and utilized during the financial year and be submitted annually (by 30th June of following year) to SPCB/PCC and CPCB.

11.10 Red Mud Generation and Management Status

The industry should submit the annual report (Format given in ***Annexure–VIII***) covering the status of the Red Mud generated, stored in each pond/facility, quantity utilized and the concerned use application, and disposal for the financial year by 30th June of the following year to SPCB/PCC and CPCB.

Radioactivity of Red Mud should be analysed once in a year by the concerned Red Mud generating units and analysis results be submitted to the concerned SPCB/PCC as well as CPCB and for taking further action, if necessary.

12. RESEARCH AND AWARENESS

Research shall be carried out expeditiously to explore additional options for utilization of Red Mud. Some suggestive options are as below:

(i) Study of the fate of toxic metals namely, Arsenic, Cadmium, Chromium (Total), Chromium (VI), Lead, Nickel and Cobalt in the use of Red Mud in cement clinker production to help increasing use of this waste.

(ii) Study for establishment of a sustainable method for partial neutralization of Red Mud to the extent that the quality of the leachate/run off obtained in each of the US EPA Leaching Environmental Assessment Framework (LEAF) Test (1311, 1312, 13,13, 1314 1315, and 1316) complies with the inland surface water standards prescribed in Schedule -VI of the EP Rules 1986, and

SPCB/PCC in association with concerned stakeholders shall explore options for utilization and organize awareness programmes for effective implementation of these guidelines.

13. USEFUL REFERENCE LINKS

(1) https://www.environment.gov.au/system/files/resources/bc0e52ba-8f78-4ce1-83b4-4910f4a1f0e9/files/hazardous-waste-impacts.pdf
(2) https://www.environment.gov.au/system/files/resources/3b8179ea-c9ce-4b51-939c-deca12abd6a7/files/aus-hazwaste-data-reporting-standard-2019.pdf
(3) http://www.suape.pe.gov.br/images/publicacoes/normas/ABNT_NBR_n_10004_2004.pdf
(4) http://www.xinhuanet.com/politics/2020-04/30/c_1125925247.htm
(5) http://www.miit.gov.cn/newweb/n1146295/n1146592/n3917132/n4061768/c6191009/content.html
(6) https://megjc.gov.jm/docs/policies/august_2018_national_hazardous_waste_policy.pdf
(7) https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018XC0409(01)&from=EN
(8) https://www.readingthepictures.org/2011/04/toxic-red-sludge/
(9) http://www.epa.ie/licences/lic_eDMS/090151b280435239.pdf
(10) https://www.world-aluminium.org/media/filer_public/2020/03/16/opportunities_for_use_of_bauxite_residue_in_portland_cement_clinker_2020.pdf
(11) https://www.world-aluminium.org/media/filer_public/2020/03/16/opportunities_for_use_of_bauxite_residue_in_special_cements_2020.pdf
(12) https://www.world-aluminium.org/media/filer_public/2020/03/16/opportunities_for_use_of_bauxite_residue_in_supplementary_cementitious_materials_2020.pdf
(13) https://www.sciencedirect.com/science/article/abs/pii/S0048969719343359
(14) https://papers.acg.uwa.edu.au/p/1915_08_Torgersrud/
(15) https://www.publish.csiro.au/sr/pdf/SR18348
(16) https://www.sciencedirect.com/science/article/abs/pii/S0048969719304255
(17) https://secure.caes.uga.edu/extension/publications/files/pdf/C%201019_3.PDF
(18) https://pubs.acs.org/doi/pdf/10.1021/acs.est.7b03568
(19) https://www.alcoa.com/australia/en/pdf/ltrms-pinjarra-refinery.pdf
(20) https://www.aerb.gov.in/images/PDF/safety.dirno01-2010.pdf
(21) https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:178:0024:0027:EN:PDF;
(22) https://www.world-aluminium.org/media/filer_public/2020/11/15/technology_roadmap_-_br_use_in_cement_2020.pdf
https://www.nepa.gov.jm/new/services_products/applications/eias/docs/Clarendon/Jamalco/run_off_storage/EIS%20Report%20Final%20Version.pdf
(23) http://www.epa.ie/licences/lic_eDMS/090151b2801a276a.pdf
(24) https://www.qld.gov.au/__data/assets/pdf_file/0019/108316/bauxite-hills-eis-assessment-report.pdf
(25) http://conference2018.redmud.org/programme-br2018/
(26) https://www.aria.developpement-durable.gouv.fr/wp-content/files_mf/A39047_ips39047_001.pdf
(27) https://etn.redmud.org/
(28) http://redmud.org/

(29) https://www.epa.gov/hw-sw846/how-guide-leaching-environmental-assessment-framework
(30) https://www.epa.gov/smm/methodology-evaluating-beneficial-uses-industrial-non-hazardous-secondary-materials-and
(31) https://nepis.epa.gov/Exe/ZyPDF.cgi/P100PDDL.PDF?Dockey=P100PDDL.PDF
(32) https://www.epa.gov/hw-sw846/leaching-environmental-assessment-framework-leaf-methods-and-guidance#dataman

Annexure –I

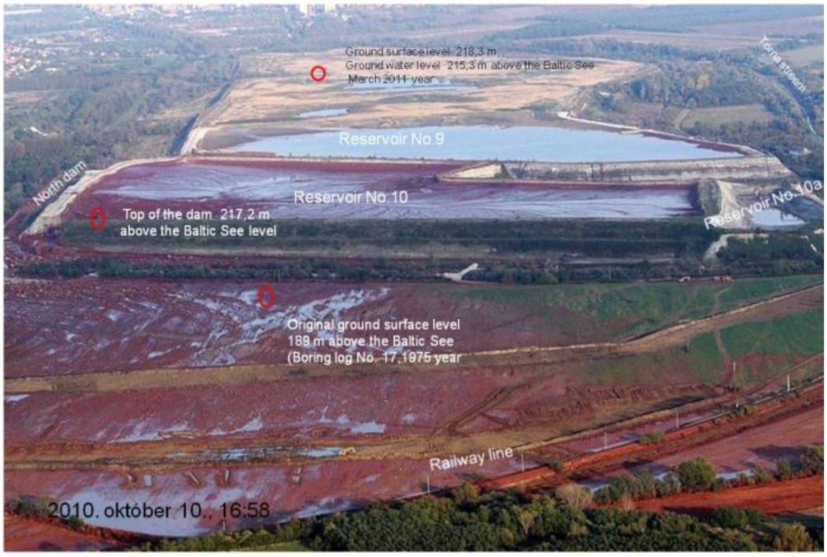
Investigations and identification of causes

AKJA, HUNGARY RED MUD DISASTER 2010

i. Background

The MAL, Refinery at Ajka has been transporting and disposing the Red Mud (generated as slurry) through pipeline (since its coming into operation in 1942) in the 10 reservoirs covering an area of 207 hectares. These 10 tailing ponds are in the Torna Creek's valley which is located between Ajka and Kolontár. Between 1943 and 1968 the Red Mud was being stored into Reservoirs No 1 to 4 located inside the factory premises. After 1967 six new reservoirs (No 5 to 10) were built outside on the west from the factory. 15.7 million m^3 of Red Mud was reportedly stored in these reservoirs before the accident in October 2010. The industry had also got permission in the year 2009, i.e. one year preceding the accident to raise the height of the dams of reservoir No 8 which had already been closed & cultivated and reservoir no 9, closed but kept under water, to reopen them as active reservoirs.

Overhead view of the reservoir system in an aerial photo of June 2010



Picture and altitude figures of the reservoir system after the embankment failure in October 2010 (http://redsludge.bm.hu)

The highly alkaline superintendent liquor from the reservoir in use is pumped back for reuse in the process. The Reservoir 10's volume is 4, 500, 000 m3 and its base is on 19 hectares. The height of the dam walls is between 21-25 metres, and the width is 10 metres at crest. There height of the supernatant liquor caustic liquor stored was 4.45 m on average and 8 mm in the middle of the pond as against the then permitted height of 1 m as average (1.5 m as maximum). The distance of the embankment from the closest village, Kolontár is just about 1 km. The bottom of the embankment was 10 m higher than the potentially affected lower part of Kolontár. The entire Red Mud storage reservoir system is located on an extensive gravel terrace covered by a mixed composition of mud-clay-sand deposit of the periodical water flow of the 4-5 m Torna stream bed

It may also be noted here that the Red Mud shows a special thixotropic behaviour, it does not easily lose its water content and assumes the behaviour of a thick, plastic liquid upon significant loading.

ii. Site Selection

Ten alternate sites were considered for the construction of the Reservoir No. 10, the site where it was finally built got selected most likely due to the lowest investment and operating cost, in view of its being next to the then already existing other reservoirs. The details of the comparison justifying the site selection could not be found in the published literature. The information available also do not cover any consideration of the impacts on the population & other life forms and the ecology downstream in the selection of this site and preparedness for the management such a disaster.

iii. Construction Materials and Methods

A schematic of the Red Mud disposal system of the Ajka Alumina Refinery is shown in Figure20.

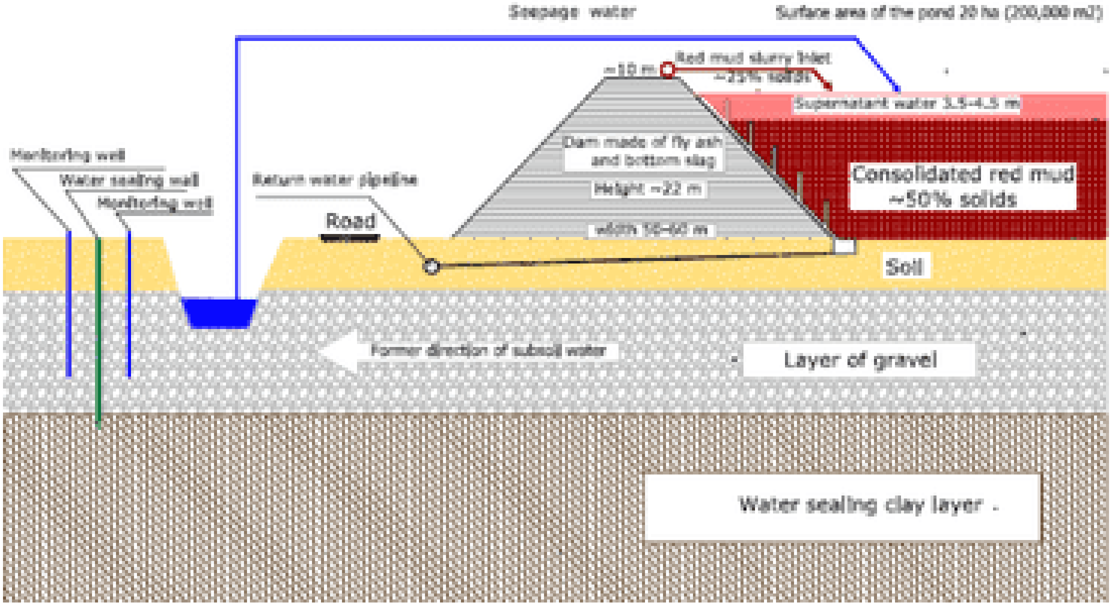


Figure 31: Red Mud disposal system of the MAL Refinery

The embankments of the Red Mud disposal Reservoirs No. 6 – 10 were constructed by utilizing the hydraulic character of the fly ash and bottom slag having considerable CaO content. The fly ash and bottom slag originated from the brown coal fired power plant located in the vicinity of the Ajka Alumina Refinery. The fly ash and bottom slag were slurried in water and transported to the embankment being built in layers of about 50 cm height. After settling the bottom slag and fly ash, the supernatant water was collected and pumped back to the power plant. The mixture solidified by itself and resulted in a material analogous to a concrete of fairly low quality. Although a thorough study on the characteristics of the bottom slag and fly ash of the neighbouring coal fired power plant has been reported to have been conducted in the course of the design of the embankment, no rigorous sampling and analyses program was in place for the construction of the embankment to ensure homogeneity of the embankment. This caused the extreme differences in its mechanical characteristics.

Preparation of the basement of the embankment is also been reported as unprofessional. Beside the topsoil, the next layer which had low shear stress, have been reported as not removed for preparation of the sound embankment base. This left the risk of water permeability of the soil and seepage.

The general view of the reservoir one day after the failure of the embankment helps the reader to get oriented. It should be noted that the Western wall of the breach of the embankment is vertical, therefore Figure 20 shows its cross-section. The figures. 21 and 22 demonstrate the inhomogenous nature of the material of the embankment. The caustic containing supernatant liquor seems to have penetrated into and through the long pocket of sand and clay.

Figure 21 hows a characteristic profile of the northern embankment of Reservoir No. 10 after the failure. The dam material is horizontally layered and is inhomogeneous in the sense that it is built up of layers of finer and coarser grain composition. The joint surfaces detected in core samples were located in the zones composed of coarser grains as the stability of zones with coarser grains is lower than that of layers built up of finer grains.

The embankment material was found to be as quasi-saturated with water. Due to the hydraulic chemical bond, the embankment was characterized by a relatively large strength. As a result of the construction technology applied, the embankment got layered and was of inhomogeneous structure, which manifested both in its strength and its water permeability characteristics.

Figure 32: Material of the northern embankment of Reservoir No. 10 after the embankment failure
(Photo: Dr. Tibor Horváth, November 2010)

Figure 33: Material of the northern embankment of Reservoir No. 10 with fly ash after the embankment failure

Significant differences (4-6 m) is on the north side of the dam and the east side of the barrier thickness (25-27 m). The temporary dam was built on the north side, perhaps with the intention of its capacity expansion through increase in the height of the embankment. The base width of the northern embankment is significantly different from the size of the other embankments, as it was considered a temporary structure, bearing in mind the possibility of a future extension. The slightly more than 20 m height of the solid part of the embankment is lower than the 26–27 m heights of the other embankments.

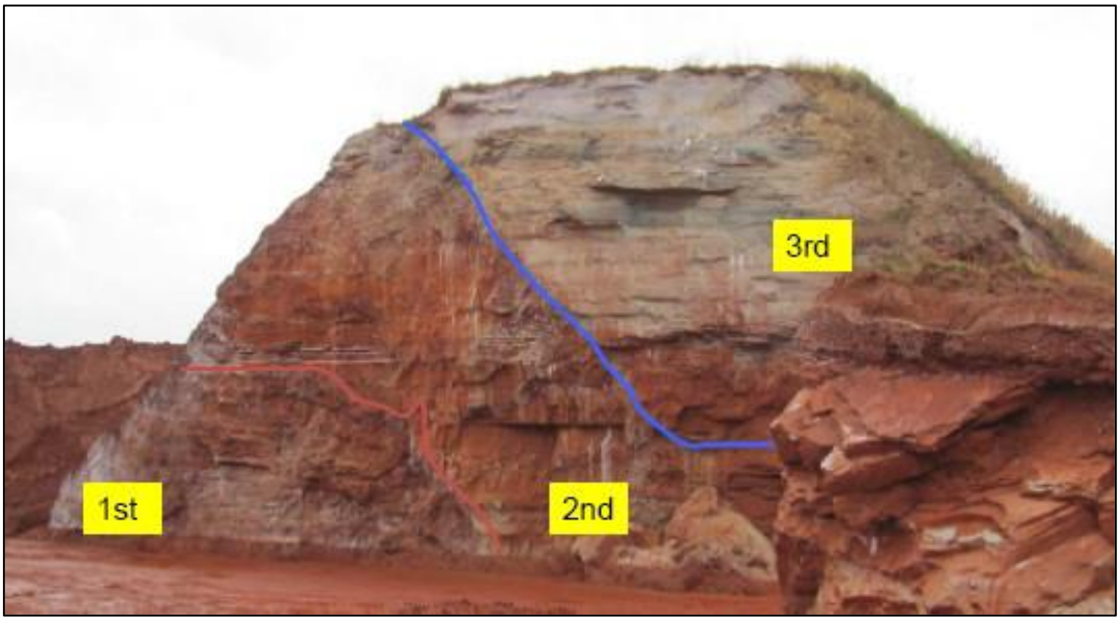


Figure 34: Stages of building of the embankment.

The findings of the investigations conducted by the various agencies reveals that the strength of the embankment is highly variable, i.e. there were great differences in strength between the Northern and Western walls of the embankment at the break. There were parts of the embankment which consisted of very low strength fly ash.

The soil failure of the fat clay soil was found at the surface of the original soil just below the basement of the embankment almost exclusively at the affected section. The fat clay reported as having become saturated with water, was further subjected to the chemical effect of the caustic content of the liquor accompanying the Red Mud over years and the clay lost most of its strength. The lower section of the dam which was built out of fly ash weakened due to the permanent load of water. The soil below the failed corner of the embankment therefore lost much of its strength, to the own weight of the quasi rigid dam and also to the load of the stored Red Mud slurry of low solids content.

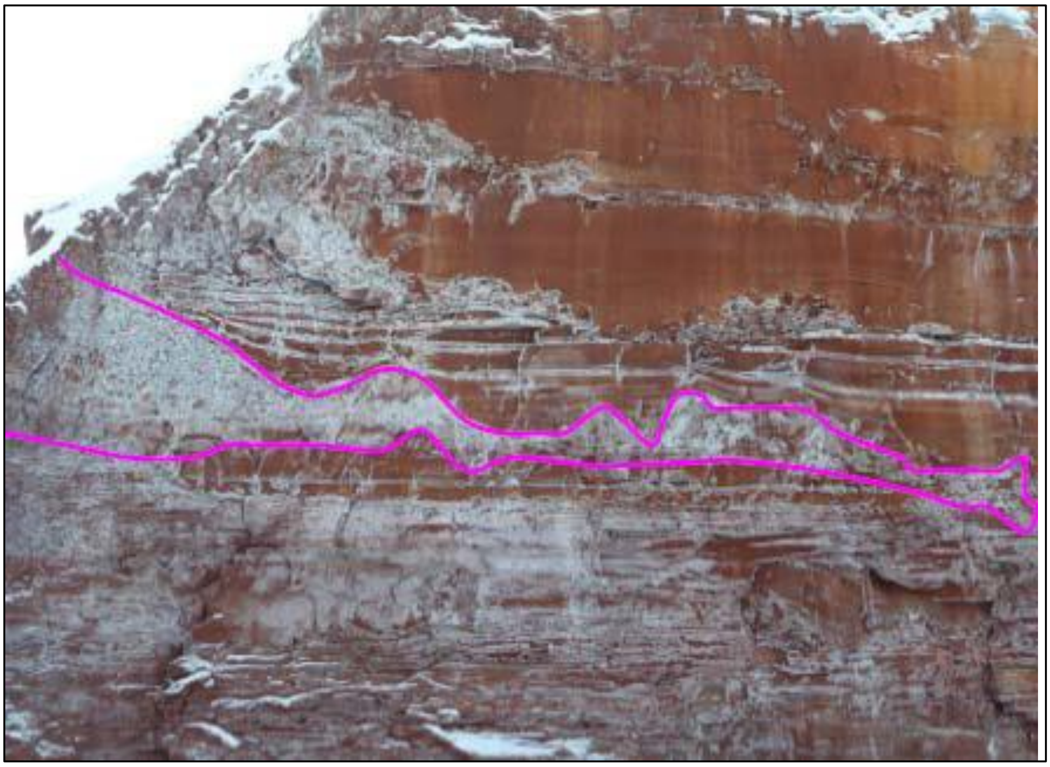


Figure 35: Caustic corrosion sack in the dam. The caustic containing supernatant liquor seem to have penetrated into and through the sand layer

The satellite images clearly show that the embankment was sinking in certain places at a rate of 1 cm per year, creating maximum shear stress precisely at the section where the dam finally broke. Also, this sinking itself might have occurred because of the slurry walling, or because of the dam base.

The analysis showed that the system of the Red Mud reservoir dam has been moving significantly for years. These dislocations are not only intensive, with their extent reaching and exceeding one centimetre yearly, but also, they are uneven along the dam. Some parts of the dam moved more, others moved less, and this led to the building up constant mechanical pressures in the system of the dam. Large differences of movement concentrated in a small area could equally have resulted in the fatal rupture and burst of the dam. The dam broke at the point of both the largest demonstrated movement and the largest differentiated movement.

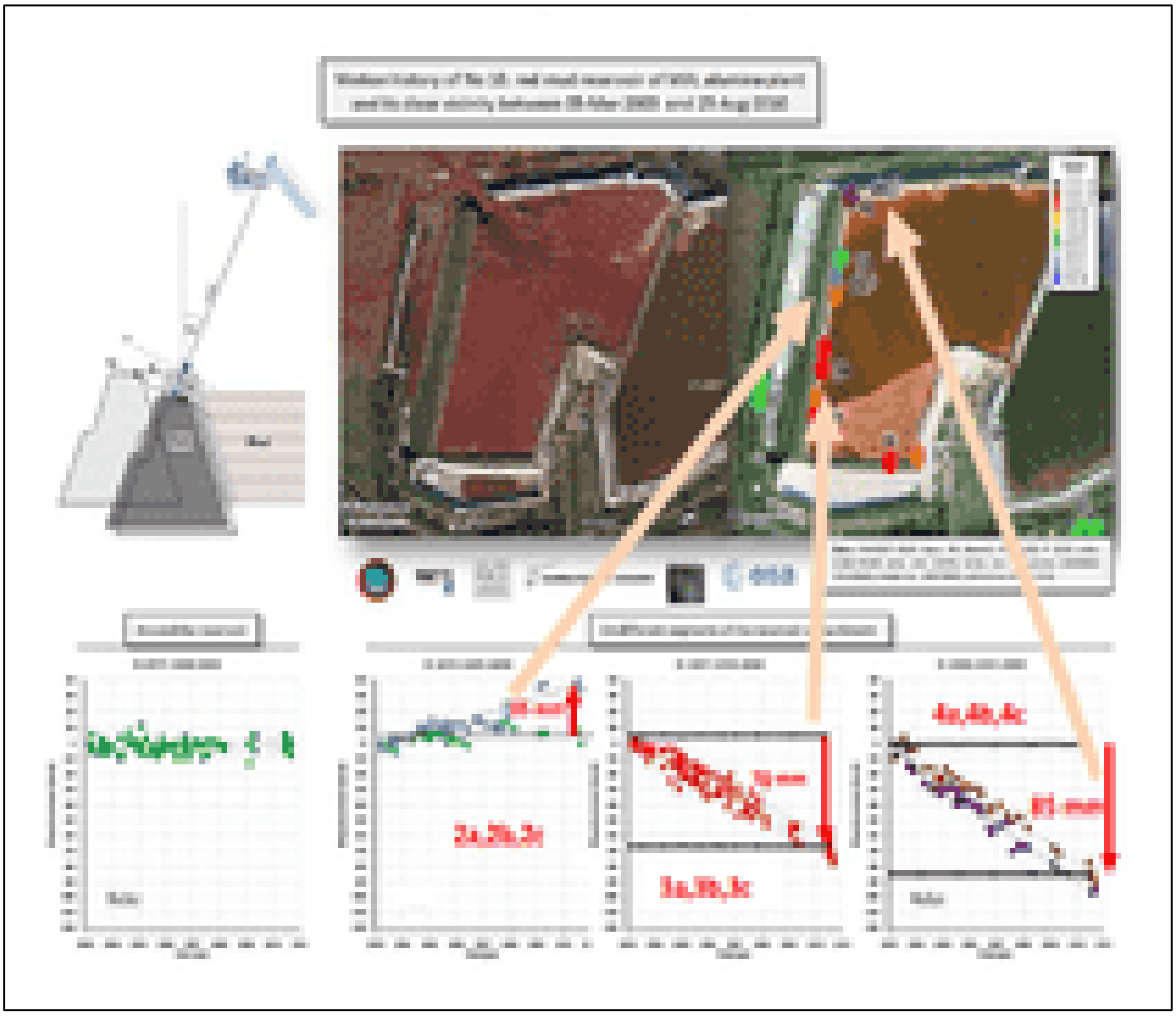


Figure 36: Summary of the satellite monitoring data

(Source: DigitalGlobe, Sample Imagery Gallery, Earth explorer: U.S. Geological Survey http://edcsns17.cr.usgs.gov/EarthExplorer/ (2011), Satellite Geodetic Observatory (KGO) of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI)]

iv. Sealing Wall

Water pollution was detected in the groundwater monitoring wells near the reservoir system in the 1970s–1980s. In compliance with the regulatory requirements, a watertight slurry wall was constructed to close down the southern and the western sides of the reservoir. Later, as the pollution spread over towards the north, the construction of a new type of grout curtain was started around the reservoir system in 1999. The length of the grout curtain was 1045 m on the northern side, 200 m on south side, and there were connected to the already existing slurry wall. Figure below shows the boundary structure around the reservoir system. The depth of the vertical closure was determined in relation to the depth of the watertight clay substratum, by minimum 1.0 m bellow it. The depth of the southern wall varies between 3.0 and 8.0 m, while 6.0-9.0-12.0 m appear on the south-eastern side.

The water sealing wall though prevented the surrounding subsoil water from being contaminated with caustic. Nevertheless, as a “side effect” the caustic concentration of the subsoil water continuously increased. The clayey minerals of the topsoil, especially its montmorillonite content reacted with the caustic. As the result, the topsoil under the NW corner of the embankment largely lost its strength, which was certainly harmful to the stability of the embankment. To be fair, it should be noted that the risk of such a reaction was not known in the technical literature or in operational experience at the time of design.

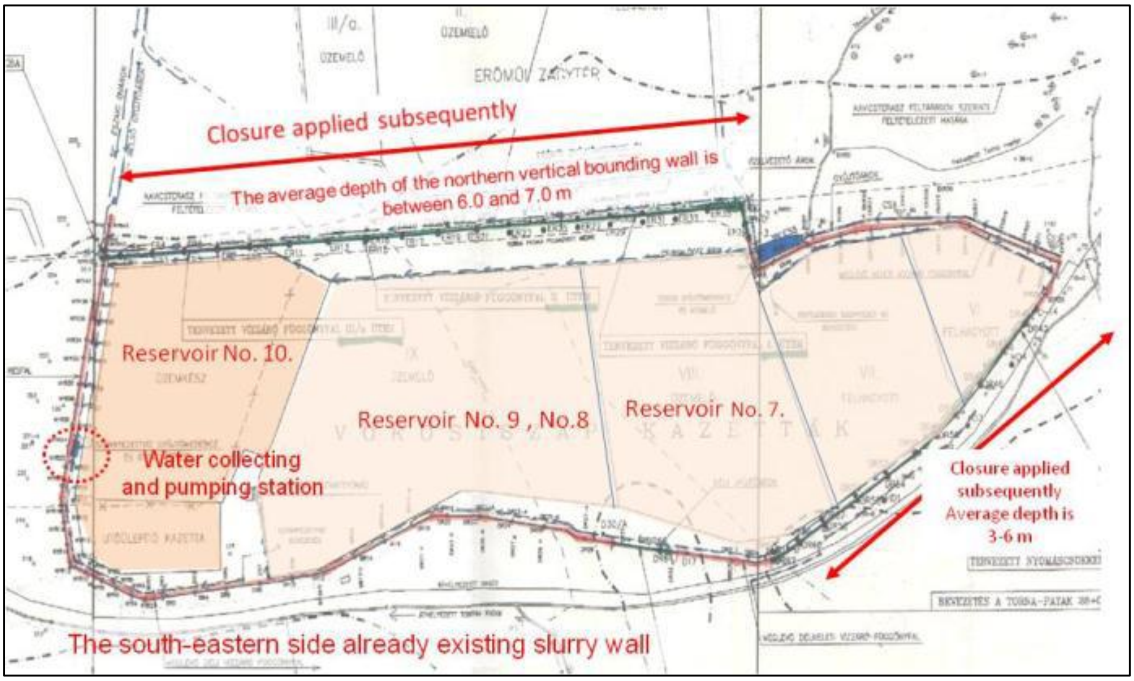


Figure 37: Site plan of the slurry wall and grout observed in the 1998 year (curtain boundary constructed at several stages)

v. Earthquake

In the course of the year before the failure of the embankment there were 17 earthquakes with a magnitude (ML) of 0.7 – 2.7 within a radius of 100 km. Out of them, there were 5 earthquakes with a magnitude of 1.7 – 2.7 in the months preceding the failure of the embankment

vi. Rainfall

The average of the 6 months' rainfall in 1997-2010 years was 397 mm. The amount of the precipitation in the preceding 6 months in 2010 before the failure of the embankment was extreme high, 838 mm.

vii. Wind

During the day of the failure of the embankment, the direction of the wind was SE which otherwise was rare and "attacked" the NW corner of the embankment. The effect of wind most probably was not the "cause" of the failure of the embankment, however, as a "butterfly effect" it may have played some role in the collapse of a rigid structure that stood above a weakened and soaked clay-rich topsoil.

It may be mentioned here that when the safety of an embankment is far from the required value, even these marginal external effects may constitute real risks.

Annexure –II

Evaluation Methodology Developed by US EPA

The evaluation methodology developed by US EPA can be used to determine whether the potential for adverse impacts to human health and the environment from a proposed beneficial use is comparable to or lower than from an analogous product, or at or below relevant health-based and regulatory benchmarks. The basis of taking decisions on the best use determinations of such materials are not to be limited to the protection of human health and the environment and should also incorporate the existing regulatory requirements, market demand, etc.

The applications of the methodology cover evaluation of a wide range of wastes materials for their encapsulated and un-encapsulated beneficial uses. The encapsulated beneficial uses are those where the secondary material is bound in a solid matrix that minimizes mobilization into the surrounding environment. Examples of encapsulated uses include, but are not limited to: aggregate in concrete; a replacement for, or raw material used in production of, cementitious components in concrete or bricks; filler in plastics, rubber, and similar products; and raw material in the manufacture of a product (e.g., wallboard). The un-encapsulated beneficial uses are those where the secondary material is used in a loose or unbound particulate or sludge form and involves the direct placement of the secondary material on the land. Examples of these applications include: structural fills; use in agriculture as a soil amendment; and aggregate.)

1. US EPA Methodology (2016)

a) Overall Phases and Steps

The methodology is divided into three phases: planning and scoping, impact analysis, and final characterization. Each beneficial use evaluation conducted using this methodology must progress through these three phases, with the flexibility in how each is to be applied. A summary flowchart of the three phases is presented on the following page in Figure 35.

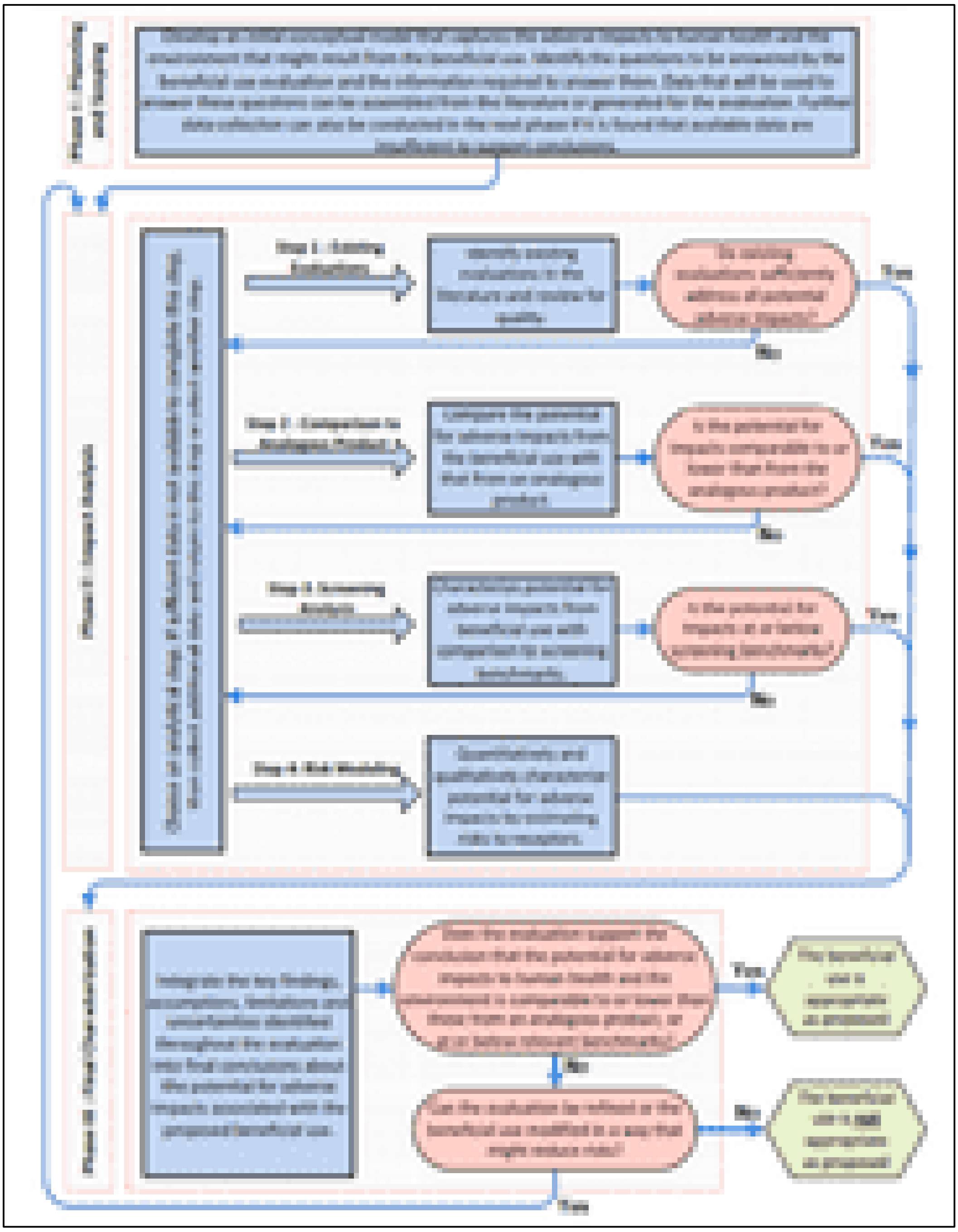


Figure 38: Summary Flow Chart of Beneficial use Methodology

b) Phase I – Planning and Scoping

The phase involves identification of the questions that are to be answered by the evaluation and the information required to answer them. Because of the substantial variability in the secondary materials generated, the range of potential uses for these materials, and the data available to characterize each, there is no single structure best suited for every evaluation. Therefore, careful planning is essential to ensure that the scope of the evaluation is well-defined, realistic, and ultimately forms a sound basis for the subsequent beneficial use determination.

The scope of the evaluation is primarily defined by how widespread the intended use is and the composition of beneficial use during the relevant stages of its life cycle. This information places bounds on the adverse impacts that may occur by defining the possible chemical constituents released, environmental media affected, and nearby receptors exposed. The scope decides the data needed to answer the questions posed by the evaluation.

c) Phase II – Impact Analysis

The objective of this phase is to find answers of the questions framed in planning and scoping through a combination of quantitative and qualitative analysis. This phase is presented as four distinct steps of namely. (i) Existing Evaluations, (ii) Comparison with Analogous Product,(iii) Screening Analysis, and (iv) Risk Modelling. This existing evaluation step consists of a literature review to identify any existing evaluations that are of sufficient quality to rely upon in the beneficial use evaluation. The purpose of this step is to avoid duplication of effort by building on previous works. The comparison with analogous product refers to the comparison between the beneficial use of the waste material with the use of the analogous products as virgin materials. The objective is to determine whether the potential for adverse impacts is comparable to or lower than from an analogous product. The screening analysis is for the characterization of the potential for adverse impacts from the beneficial use of the waste material use through a comparison with the relevant quality standards. A screening standard is a discrete value, typically a concentration in environmental media, set at a level below which exposures are not anticipated to pose concern. The objective is to identify individual constituents or entire exposure pathways that can be eliminated from further consideration with a high degree of confidence prior to more intensive modelling. This is accomplished with a combination of data and simplifying assumptions on beneficial use composition, environmental conditions, and/or receptor characteristics that result in a point estimate of exposures that ranges anywhere from a reasonable upper bound to a worst-case scenario. The risk modelling consists of a refined, quantitative and qualitative characterization of the potential for adverse impacts from the beneficial use. The objective is to reduce uncertainties enough to permit well-substantiated conclusions about the proposed use. This is accomplished by applying more realistic data and models that refine the estimates of release, fate, transport and exposure that are used to estimate the actual risks to receptors. There is flexibility in how these steps are applied in an evaluation. Individual steps can be omitted or used in the order that makes the best use of available data, so long as the analyses conducted are supported by sound science. If at any point during the analysis sufficient information is available to reach well-substantiated conclusions about the beneficial use, then the evaluation can proceed to the third and final phase.

d) Phase III – Final Characterization

This is the final phase for beneficial use evaluations which aims to integrate key findings, assumptions, limitations and uncertainties identified throughout the evaluation into final conclusions about the potential impacts to human health and the environment associated with the proposed beneficial use of the waste material. The emphasis of this phase is on providing context for the results of the beneficial use evaluation in a transparent, clear, consistent and reasonable manner to inform decision-makers and other relevant audiences, such as the general public.

If the evaluation shows that the beneficial use may pose concern, this does not necessarily mean that the use of the material is inappropriate under all circumstances. The concerns identified may be driven by a smaller subset of constituent levels, beneficial use design, environmental conditions, or other factors considered in the evaluation. This phase is used to highlight the conditions under which risks are below levels of concern or any additional steps that can be taken to ensure that the use is appropriate. Based on these results, decision-makers may choose to allow the beneficial use, either as proposed or with some additional conditions. Such conditions might include limitations on the amount of a waste material that can be incorporated into the beneficial use or on the constituent concentrations in the waste material used.

e) Detailed Description and Tools

The details of the further information and tools that can assist with specific evaluations are given in the US EPA's Beneficial Use Compendium: A Collection of Resources and Tools to Support Beneficial Use Evaluations, published in the year 2016. The use of US EPA's methodology and tools should incorporate the concerned local environmental and other regulations to ensure that their application is scientifically sound and accounts for any additional considerations required by such regulations.

2. Leaching Environmental Assessment Framework (LEAF) (US EPA 2019)

a) The LEAF Guide Document Brief

The document provides guidance on the use and application of the Leaching Environmental Assessment Framework (LEAF) published by the United States Environmental Protection Agency (U.S. EPA or the Agency). The purpose of this guide is to provide an understanding of LEAF to facilitate its broader use in environmental assessment. LEAF is a leaching evaluation framework, which consists of four leaching tests (i.e., U.S. EPA Methods 1313, 1314, 1315 and 1316), data management tools, and approaches for estimating constituent release from solid materials. The LEAF tests consider the effect on leaching of key environmental conditions and waste properties known to significantly affect constituent release. This document provides background on the LEAF tests as well as information on how to perform the tests and how to understand the test results. This document also provides guidance on the application of LEAF to assess leaching possibility of Constituents of Potential Concern (COPCs) from solid waste matrices for beneficial use, disposal, treatment, and remediation applications. In addition, this document addresses frequently asked questions about the four LEAF test methods, data management and reporting using freely-available software, and potential applications of the LEAF approach.

The approach to testing and evaluation presented in this guide is progressive in that each of the different methods provide information on the effect of different environmental parameters on leaching. Therefore, investment in each increment of additional testing and evaluation may reward the user with increasingly refined estimates of leaching. Traditionally, the potential for environmental impact through leaching of COPCs from a solid material disposed or otherwise in contact with the land into ground water or surface water can be estimated using one or more single-point leaching tests that represent a specific scenario or set of environmental conditions. Alternatively, LEAF testing may provide more reliable release estimates by assessing the impact on leaching of environmental factors and waste properties that are known to significantly affect constituent leaching and which vary in the environment and across waste forms. By testing over a range of values for release-controlling factors, the LEAF approach allows for flexibility in that a single data set can be used to evaluate multiple potential management scenarios for a material (e.g., disposal or beneficial use) under varied or site-specific environmental conditions.

The Agency recognizes that the leaching of organic constituents will follow the same principles (i.e., that key environmental conditions or waste properties that significantly affect leaching can be identified) but may require different testing methods to address controlling properties. Therefore, the next steps for the Agency are to adapt these methods or develop new methods applicable to evaluating the potential release of organic COPCs from waste or other materials.

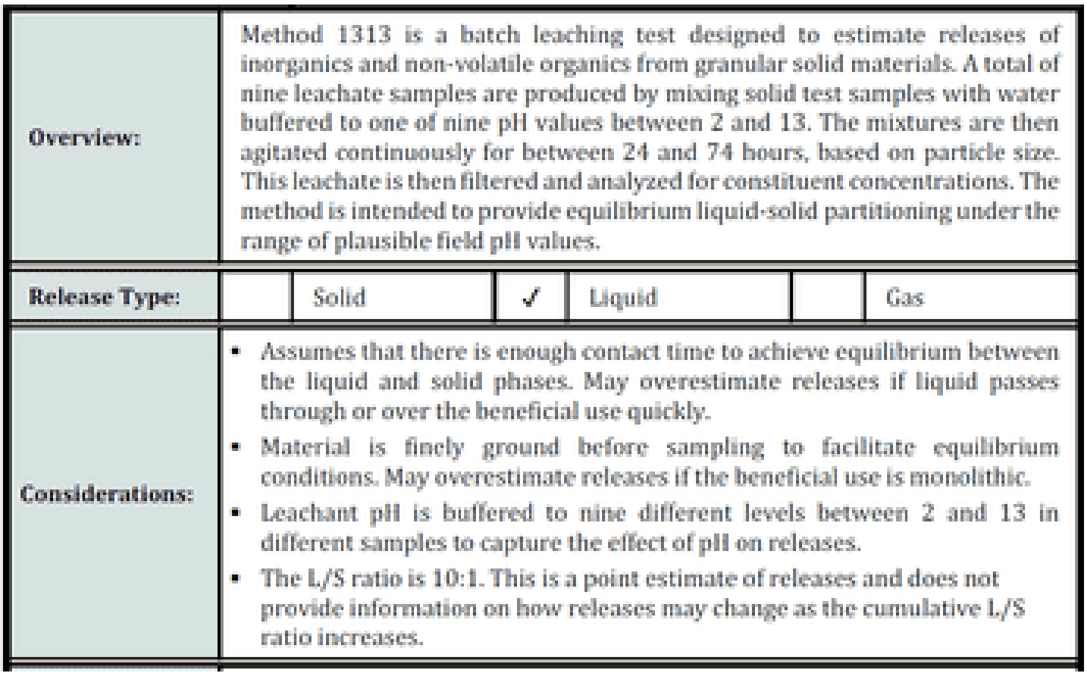
b) LEAF Leaching Tests

The LEAF leaching tests are a set of four distinct leaching test methods. These test methods directly address one of three most important factors affecting leaching of inorganics: the final leachate pH, the amount of water in contact with the material, and the physical form (i.e., granular vs. monolithic) of the material. The test methods also measure important parameters of the liquid such as pH, electrical conductivity (EC) and DOC under the final leaching conditions. Together, these methods provide information on the available content, peak leaching concentration, time-dependent release. These methods can be applied individually or in combination, based on information needed to characterize the leaching behaviour of the material of interest.

The LEAF tests are conducted under a specified set of conditions, which provides a standardized basis for comparison among different samples, materials, leaching tests and management scenarios. The data can be used to evaluate a range of environmental conditions that a given material may be exposed to in the field. The general description of each method and highlight the specifications for sample preparation and release simulation that determine how well these releases reflect the range of conditions a beneficial use may be exposed to in the real world are given below.

EPA Method 1313: Liquid-Solid Partitioning as a Function to evaluate pH for

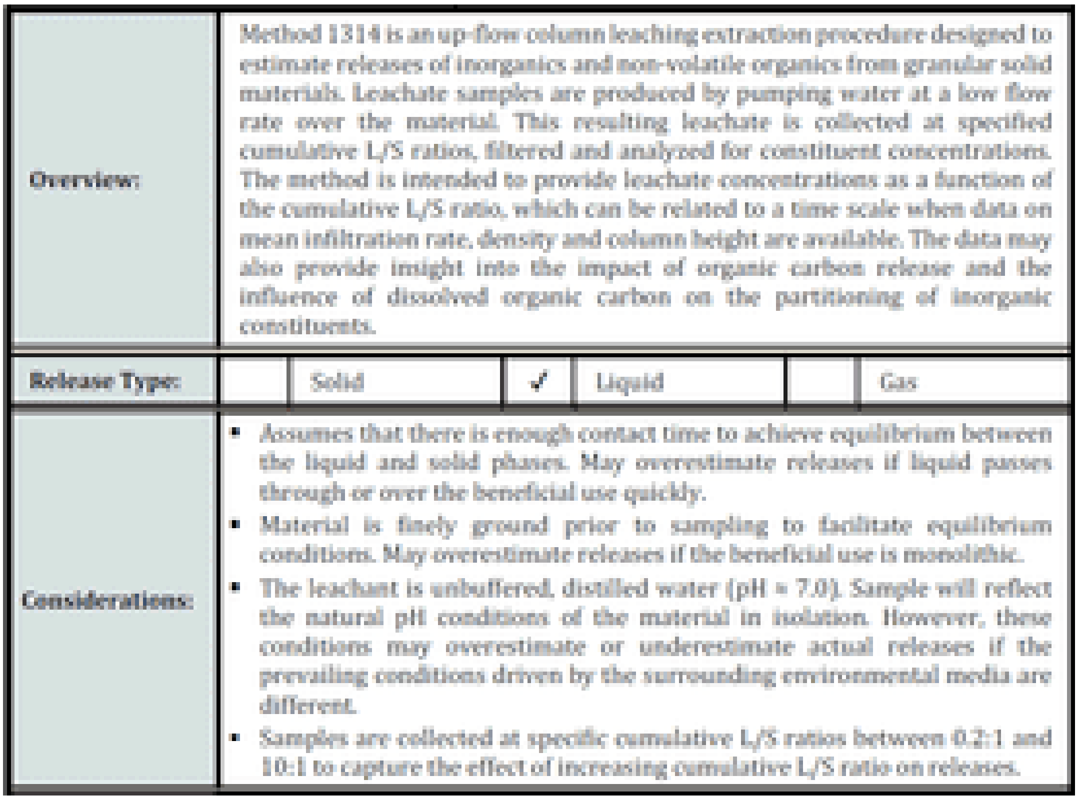
Constituents in Solid Materials Using a Parallel Batch Extraction Procedure



Overview:	Method 1313 is a batch leaching test designed to estimate releases of inorganics and non-volatile organics from granular solid materials. A total of nine leachate samples are produced by mixing solid test samples with water buffered to one of nine pH values between 2 and 13. The mixtures are then agitated continuously for between 24 and 74 hours, based on particle size. This leachate is then filtered and analyzed for constituent concentrations. The method is intended to provide equilibrium liquid-solid partitioning under the range of plausible field pH values.					
Release Type:		Solid	✓	Liquid		Gas
Considerations:	• Assumes that there is enough contact time to achieve equilibrium between the liquid and solid phases. May overestimate releases if liquid passes through or over the beneficial use quickly. • Material is finely ground before sampling to facilitate equilibrium conditions. May overestimate releases if the beneficial use is monolithic. • Leachant pH is buffered to nine different levels between 2 and 13 in different samples to capture the effect of pH on releases. • The L/S ratio is 10:1. This is a point estimate of releases and does not provide information on how releases may change as the cumulative L/S ratio increases.					

(Website: www.epa.gov/hw-sw846/validated-test-method-1313-liquid-solidpartitioning-function-extract-ph-using-parallel)

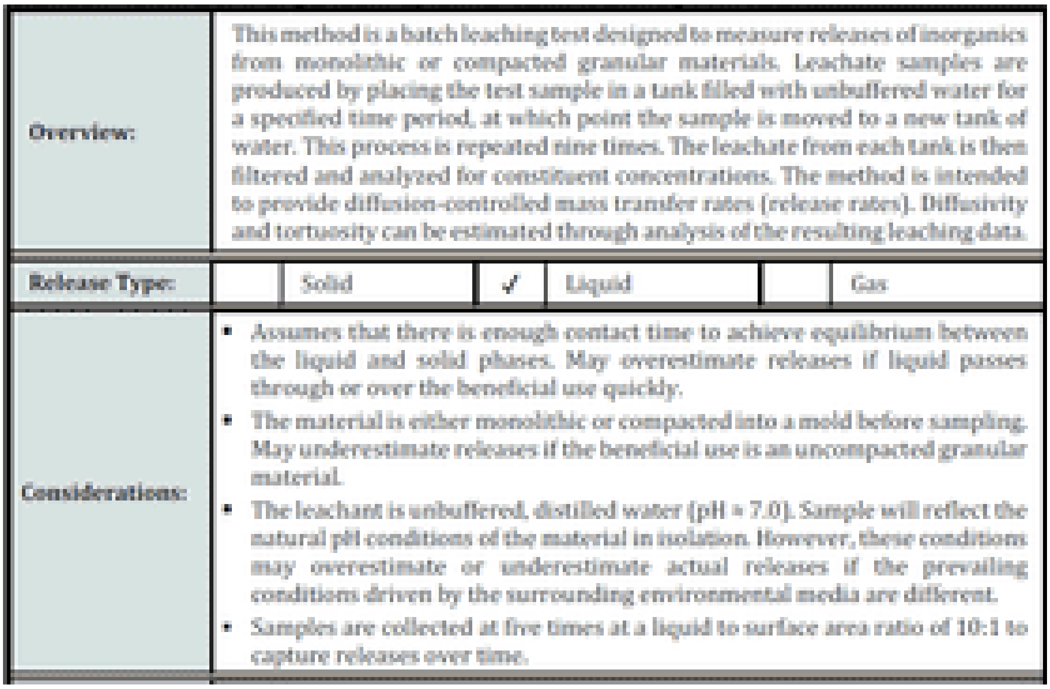
EPA Method 1314: Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio for Constituents in Solid Materials Using an Up-flow Percolation Column Procedure



Overview:	Method 1314 is an up-flow column leaching extraction procedure designed to estimate releases of inorganics and non-volatile organics from granular solid materials. Leachate samples are produced by pumping water at a low flow rate over the material. This resulting leachate is collected at specified cumulative L/S ratios, filtered and analyzed for constituent concentrations. The method is intended to provide leachate concentrations as a function of the cumulative L/S ratio, which can be related to a time scale when data on mean infiltration rate, density and column height are available. The data may also provide insight into the impact of organic carbon release and the influence of dissolved organic carbon on the partitioning of inorganic constituents.					
Release Type:		Solid	✓	Liquid		Gas
Considerations:	▪ Assumes that there is enough contact time to achieve equilibrium between the liquid and solid phases. May overestimate releases if liquid passes through or over the beneficial use quickly. ▪ Material is finely ground prior to sampling to facilitate equilibrium conditions. May overestimate releases if the beneficial use is monolithic. ▪ The leachant is unbuffered, distilled water (pH ≈ 7.0). Sample will reflect the natural pH conditions of the material in isolation. However, these conditions may overestimate or underestimate actual releases if the prevailing conditions driven by the surrounding environmental media are different. ▪ Samples are collected at specific cumulative L/S ratios between 0.2:1 and 10:1 to capture the effect of increasing cumulative L/S ratio on releases.					

(Website: www.epa.gov/hw-sw846/validated-test-method-1314-liquid-solidpartitioning-function-liquid-solid-ratio)

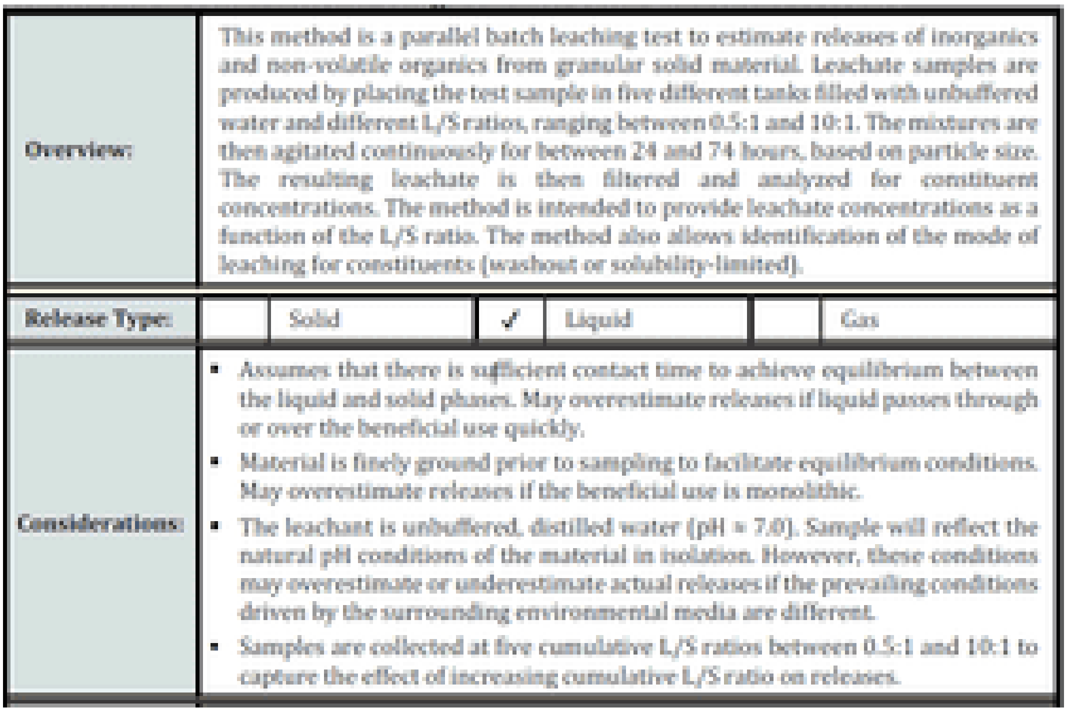
EPA Method 1315: Mass Transport Rates of Constituents in Monolithic or Compacted Granular Materials Using a Semi-dynamic Tank Leaching Procedure



Overview:	This method is a batch leaching test designed to measure releases of inorganics from monolithic or compacted granular materials. Leachate samples are produced by placing the test sample in a tank filled with unbuffered water for a specified time period, at which point the sample is moved to a new tank of water. This process is repeated nine times. The leachate from each tank is then filtered and analyzed for constituent concentrations. The method is intended to provide diffusion-controlled mass transfer rates (release rates). Diffusivity and tortuosity can be estimated through analysis of the resulting leaching data.					
Release Type:		Solid	✓	Liquid		Gas
Considerations:	▪ Assumes that there is enough contact time to achieve equilibrium between the liquid and solid phases. May overestimate releases if liquid passes through or over the beneficial use quickly. ▪ The material is either monolithic or compacted into a mold before sampling. May underestimate releases if the beneficial use is an uncompacted granular material. ▪ The leachant is unbuffered, distilled water (pH ≈ 7.0). Sample will reflect the natural pH conditions of the material in isolation. However, these conditions may overestimate or underestimate actual releases if the prevailing conditions driven by the surrounding environmental media are different. ▪ Samples are collected at five times at a liquid to surface area ratio of 10:1 to capture releases over time.					

(Website: www.epa.gov/hw-sw846/validated-test-method-1315-mass-transfer-ratesconstituents-monolithic-or-compacted)

EPA Method 1316: Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio for Constituents in Solid Materials Using a Parallel Batch Extraction Procedure

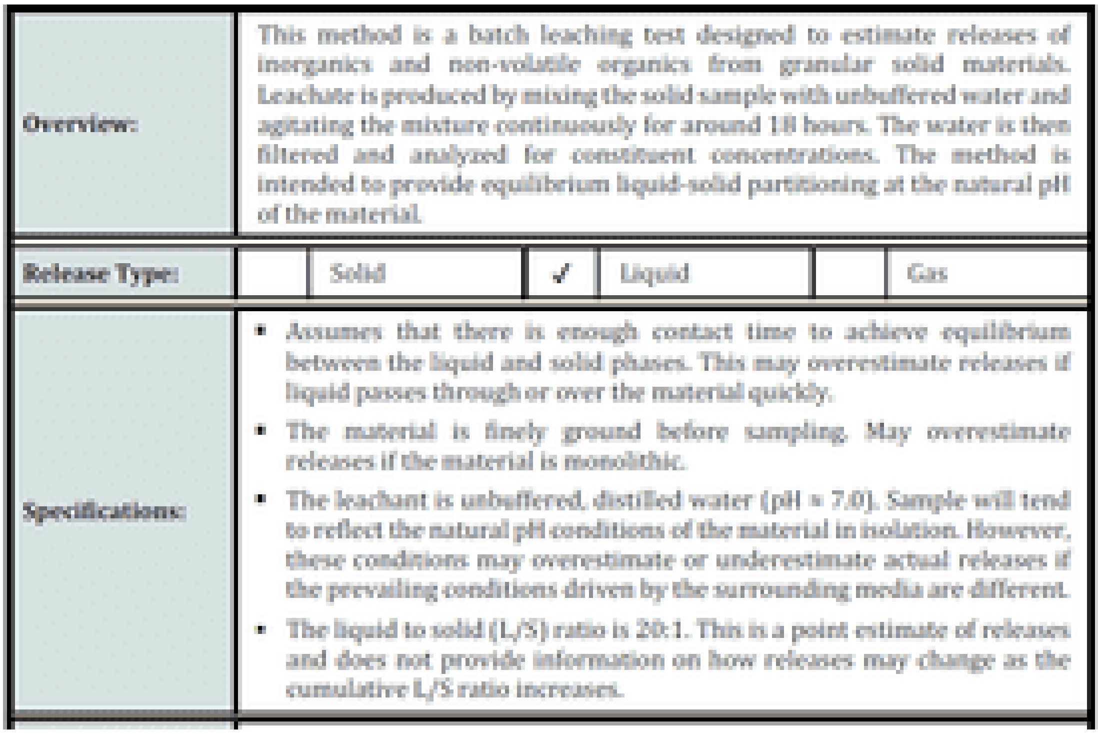


<table>
<tr><td>Overview:</td><td colspan="6">This method is a parallel batch leaching test to estimate releases of inorganics and non-volatile organics from granular solid material. Leachate samples are produced by placing the test sample in five different tanks filled with unbuffered water and different L/S ratios, ranging between 0.5:1 and 10:1. The mixtures are then agitated continuously for between 24 and 74 hours, based on particle size. The resulting leachate is then filtered and analyzed for constituent concentrations. The method is intended to provide leachate concentrations as a function of the L/S ratio. The method also allows identification of the mode of leaching for constituents (washout or solubility-limited).</td></tr>
<tr><td>Release Type:</td><td></td><td>Solid</td><td>✓</td><td>Liquid</td><td></td><td>Gas</td></tr>
<tr><td>Considerations:</td><td colspan="6">▪ Assumes that there is sufficient contact time to achieve equilibrium between the liquid and solid phases. May overestimate releases if liquid passes through or over the beneficial use quickly.
▪ Material is finely ground prior to sampling to facilitate equilibrium conditions. May overestimate releases if the beneficial use is monolithic.
▪ The leachant is unbuffered, distilled water (pH ≈ 7.0). Sample will reflect the natural pH conditions of the material in isolation. However, these conditions may overestimate or underestimate actual releases if the prevailing conditions driven by the surrounding environmental media are different.
▪ Samples are collected at five cumulative L/S ratios between 0.5:1 and 10:1 to capture the effect of increasing cumulative L/S ratio on releases.</td></tr>
</table>

(Website: www.epa.gov/hw-sw846/validated-test-method-1316-liquid-solidpartitioning-function-liquid-solid-ratio-solid)

c) *Other Leaching Tests*

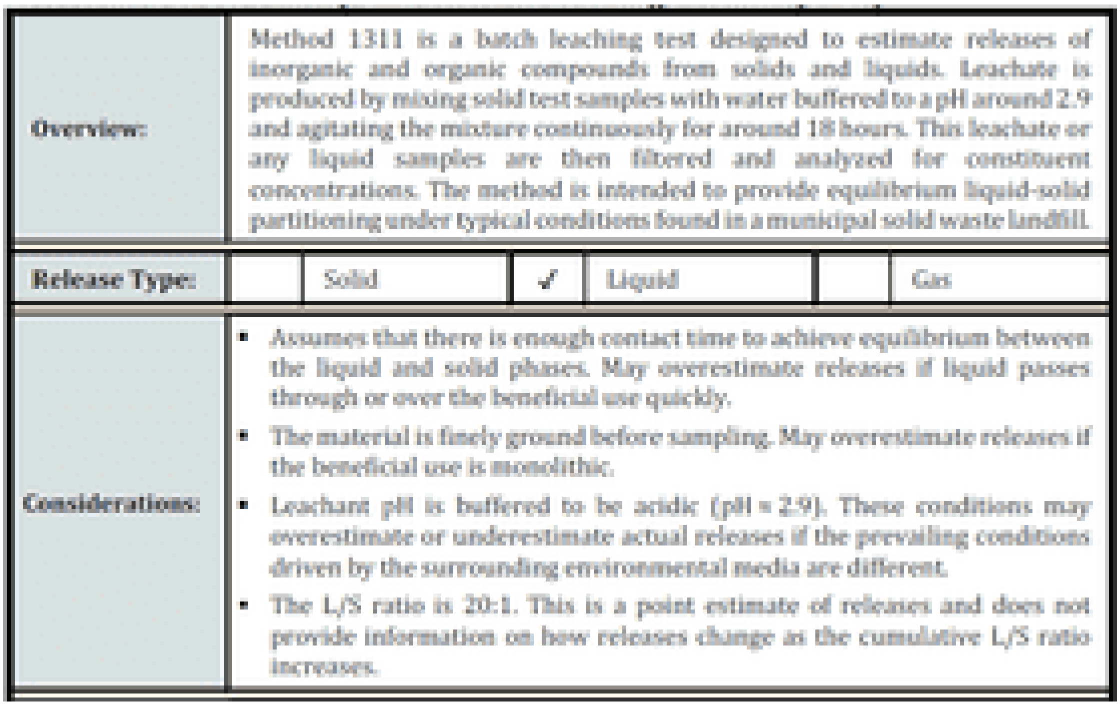
ASTM Method D3987-06: Shake Extraction of Solid Waste with Water



<table>
<tr><td>Overview:</td><td colspan="6">This method is a batch leaching test designed to estimate releases of inorganics and non-volatile organics from granular solid materials. Leachate is produced by mixing the solid sample with unbuffered water and agitating the mixture continuously for around 18 hours. The water is then filtered and analyzed for constituent concentrations. The method is intended to provide equilibrium liquid-solid partitioning at the natural pH of the material.</td></tr>
<tr><td>Release Type:</td><td></td><td>Solid</td><td>✓</td><td>Liquid</td><td></td><td>Gas</td></tr>
<tr><td>Specifications:</td><td colspan="6">▪ Assumes that there is enough contact time to achieve equilibrium between the liquid and solid phases. This may overestimate releases if liquid passes through or over the material quickly.
▪ The material is finely ground before sampling. May overestimate releases if the material is monolithic.
▪ The leachant is unbuffered, distilled water (pH ≈ 7.0). Sample will tend to reflect the natural pH conditions of the material in isolation. However, these conditions may overestimate or underestimate actual releases if the prevailing conditions driven by the surrounding media are different.
▪ The liquid to solid (L/S) ratio is 20:1. This is a point estimate of releases and does not provide information on how releases may change as the cumulative L/S ratio increases.</td></tr>
</table>

(Website: www.astm.org/Standards/D3987.htm)

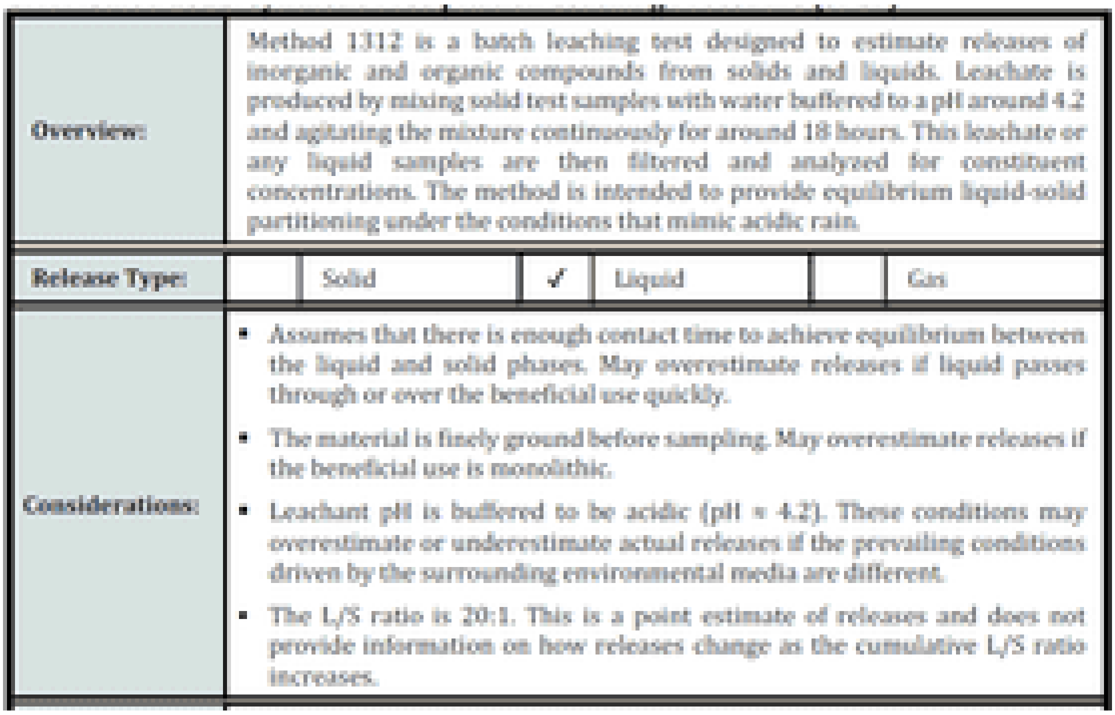
EPA Method 1311: Toxicity Characteristic Leaching Potential (TCLP)



Overview:	Method 1311 is a batch leaching test designed to estimate releases of inorganic and organic compounds from solids and liquids. Leachate is produced by mixing solid test samples with water buffered to a pH around 2.9 and agitating the mixture continuously for around 18 hours. This leachate or any liquid samples are then filtered and analyzed for constituent concentrations. The method is intended to provide equilibrium liquid-solid partitioning under typical conditions found in a municipal solid waste landfill.					
Release Type:		Solid	✓	Liquid		Gas
Considerations:	▪ Assumes that there is enough contact time to achieve equilibrium between the liquid and solid phases. May overestimate releases if liquid passes through or over the beneficial use quickly. ▪ The material is finely ground before sampling. May overestimate releases if the beneficial use is monolithic. ▪ Leachant pH is buffered to be acidic (pH ≈ 2.9). These conditions may overestimate or underestimate actual releases if the prevailing conditions driven by the surrounding environmental media are different. ▪ The L/S ratio is 20:1. This is a point estimate of releases and does not provide information on how releases change as the cumulative L/S ratio increases.					

(Website: www.epa.gov/hw-sw846/sw-846-test-method-1311-toxicity-characteristicleaching-Procedure)

EPA Method 1312: Synthetic Precipitation Leaching Procedure (SPLP)



Overview:	Method 1312 is a batch leaching test designed to estimate releases of inorganic and organic compounds from solids and liquids. Leachate is produced by mixing solid test samples with water buffered to a pH around 4.2 and agitating the mixture continuously for around 18 hours. This leachate or any liquid samples are then filtered and analyzed for constituent concentrations. The method is intended to provide equilibrium liquid-solid partitioning under the conditions that mimic acidic rain.					
Release Type:		Solid	✓	Liquid		Gas
Considerations:	▪ Assumes that there is enough contact time to achieve equilibrium between the liquid and solid phases. May overestimate releases if liquid passes through or over the beneficial use quickly. ▪ The material is finely ground before sampling. May overestimate releases if the beneficial use is monolithic. ▪ Leachant pH is buffered to be acidic (pH ≈ 4.2). These conditions may overestimate or underestimate actual releases if the prevailing conditions driven by the surrounding environmental media are different. ▪ The L/S ratio is 20:1. This is a point estimate of releases and does not provide information on how releases change as the cumulative L/S ratio increases.					

(Website: www.epa.gov/hw-sw846/sw-846-test-method-1312-syntheticprecipitation-leaching-procedure)

Annexure –III

Truck Mounted Water Sprinkler System

Annexure –IV

Aspects to be included (but not limited to) in the Operational Plan and Safety Manual

(1) Responsibilities, activities, performance indicators and records.

(2) Ensuring use of PPEs.

(3) Transport of Red Mud with optimum solids (moisture equal to or less than 25%) and its deposition in layers to maximise maturing by drying and consolidation.

(4) Storage of Red Mud to the extent and in the manner permitted. The dry stacking method to be based on "field stacking" which involves placement of the Red Mud in a thin layer over a short period of time at a series of locations to allow the Red Mud to mature rapidly. This allows higher stacking angle and easier movement on the surface by equipment.

(5) Storage capacity development within the DSF using the upstream stacking method with gabion/rock walls provided for each stage to contain the stack after every 2-3 meters of stacking.

(6) the underlying Red Mud supports the upper rockfill embankment.

(7) Monitoring of the stability of Stack and embankments.

(8) Maintaining integrity of the HDPE/ geomembrane liners.

(9) Ensuring run off water remaining in contact with the stacked material.

(10) Maintaining a bare head of atleast one meter in the SP and SNLP.

(11) Maintaining of the dust suppression system.

- Minimisation of mud flat area exposed to dusting risk.
- Keeping mud flats in service as long as possible to limit areas of potential dusting.
- Switching of points regularly to cover drying mud with wet mud.
- Switching mud points regularly to aid stacking angle lift.
- Opening of relevant valves on sprinklers at a time and rotate as required.

(12) Routine inspection of the RMDA drainage and recycle system, nearby surface water ground water sources, etc.

(13) Ensuring trye washing of all the vehicles leaving the RMDA

(14) All incidents, whether of an environmental or health and safety nature are reported and investigated to ensure that any necessary remedial action is taken and to prevent re-occurrence of the incident.

(15) Preparedness action as pert the DMP.

Annexure –V

Aspects to be included (but not limited to) for the Assessment of the RMDA Failure Risk

(1) Static Liquefaction of the Stacked Material

(2) Dynamic Liquefaction of the Stacked Material

(3) Seismic Effect

(4) Slope Failure

(5) Erosion Induced Slope Failure

(6) Slope Instability

(7) Foundation Failure

(8) Overtopping

(9) An estimation of the probability of the failure mechanisms that may occur

(10) An indication of the route and geometry of a flow of water and liquefied Red Mud as a frictional granular flow following a breach in the DSF or SP or SNLP.

(11) Details of procedures to mitigate the risk of the failure scenarios identified.

<u>Annexure –VI</u>

Aspects to be included (but not limited to) in the Performance Audit of the RMDA

(i) Site management & responsibilities.

(ii) Operational principles

(iii) Waste analysis

(iv) Waste handling & placement

(v) Dust control.

(vi) Surface water management and protection.

(vii) Groundwater management and protection.

(viii) Leachate management and disposal.

(ix) Life expectancy.

(x) Emergency preparedness.

(xi) Restoration.

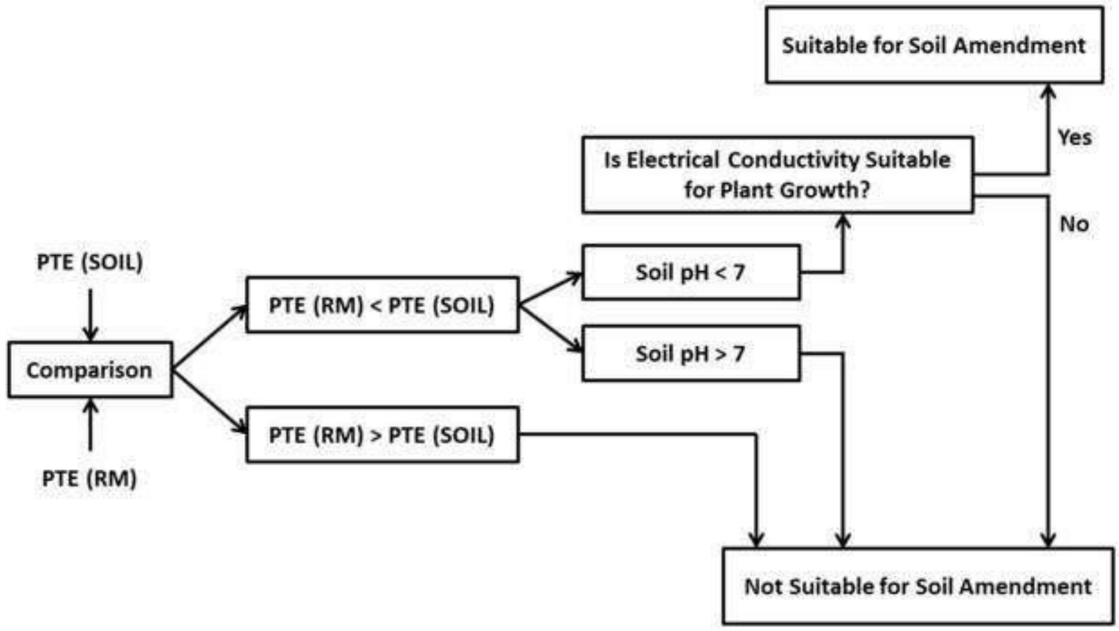
(xii) Aftercare management.

(xiii) Implementation of the Environmental Monitoring Programme (frequency, instrumentation, locations, design and maintenance of monitoring points, quality control, recording, protocols, assessment reporting, procedures for non-compliance) for;

- Surface water monitoring.
- Groundwater monitoring.
- Leachate monitoring.
- Mud stability, levels and void monitoring.
- Meteorological monitoring.
- Dust monitoring

Annexure –VII

Decision Tree Chart for Soil Amelioration



Total Potentially Toxic Elements (PTE) – To include: Arsenic, Cadmium, Chromium (Total), Chromium (VI), Lead, Nickel and Cobalt

PTE (SOIL) - Total Potentially Toxic Elements in Soil

PTE (RM) - Total Potentially Toxic Elements in Red Mud

Annexure –VIII

Red Mud Generation and Disposal Status Report

Financial Year………………..

1. Name and Address of the Alumina Production Facility:
2. Google Location of the RMDA:
3. Contact Person Responsible for Management of RMDA:
    a) Name and Designation:
    b) Mobile Number:
    c) Email ID:
4. Status

Financial Year	**Quantity of Red Mud Utilized before beginning of financial year (MT)**	**Quantity of Red Mud Stored in DSF at the beginning of financial year (MT)**	**Red Mud Generated during the year (MT)**	**Red Mud Utilized during the year**		**Quantity Stored in the DSF during the Year**	
				Use Type	**Quantity (MT)**	**DSF Number**	**Quantity (MT)**