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Improving the Sustainability of Residue Management Practices — Alcoa World Alumina Australia

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ABSTRACT

Alcoa World Alumina Australia is the world's leading producer of aluminium and alumina, with three alumina refineries in Western Australia and a further six refineries located in Europe, the Caribbean, North and South America. During the refining process, an alkaline residue is produced and is deposited in lined storage areas designed to protect ground and surface waters.

As early as 1977, Alcoa recognised the need to investigate alternative residue management strategies. The company made a significant commitment to continuous improvement in tailings management through the establishment of a focussed research and development group charged with the responsibility of "establishing Alcoa's reputation as a leading company in the management of bauxite tailings". Through ongoing research and field trials, a range of significant improvements to residue storage methods have been developed and implemented.

Recent work has focussed on investigating ways to modify the residue, in particular decreasing its alkalinity to further lessen its potential environmental impact. Residue carbonation has been developed and tested at the Kwinana refinery and is currently being expanded to a full scale operation. It is a process which is easily integrated with the current thickening and dry stacking process, offering a range of operational and environmental benefits. The potential to progressively implement the process at Alcoa's other refineries worldwide is currently being evaluated. It is anticipated that residue carbonation will become the alumina industry's best practice benchmark for residue treatment and storage worldwide.

Alcoa has also been focussed on potential re-use opportunities for the residue. A number of potential uses have been progressed through to pilot and demonstration phase, opening the way for the re-use of considerable volumes of residue.

This paper will describe these more recent developments in residue management practices, and outline the sustainability case for progressing their implementation.

1 INTRODUCTION

There are a number of indicators suggesting that industry's traditional waste management practices around the world are coming under increasing scrutiny, and that some of these practices will not be acceptable into the future. In the recently published Mining, Minerals, and Sustainable Development final report, it was noted that:

> *"Mineral products are essential to contemporary societies and economies. Many basic needs cannot be met without them. But simply meeting market demand for mineral commodities falls far short of meeting society's expectations of industry. The process of producing, using, and recycling minerals could help society reach many other goals – providing jobs directly and indirectly, aiding in the development of national economies, and helping to reach energy and resource efficiency targets, among many others. Where industry is falling far short of meeting these objectives, it is seen as failing in its obligations and is increasingly unwelcome" (MMSD, 2002).*

In a truly sustainable global society we will take far fewer minerals from the earth. Instead of requiring ever-growing amounts of minerals and fuels, a sustainable economy will use materials much more efficiently, reduce waste to a minimum, and rely more on recycling, re-use and renewable energy technology.

If resource stewardship is to move toward sustainability, there will need to be an increasing focus on areas such as:

- Maximum incorporation of renewable and recycled materials.
- More benign reagents to replace toxic or non-degradable ones.
- Modification of wastes to a more benign form, lessening the potential for environmental impacts.
- Restricted net volumes of emissions.
- Maximum utilisation of 'waste' streams for products.

The retiring executive secretary of the UN Framework Convention on Climate Change, Michael Zammit Cutajar, told the 2002 Marrakesh conference of parties that the convention and its offspring, the Kyoto Protocol, we're *"not about conservation and pollution abatement"* but about *"the transformations that will bring about greater efficiency in the use of resources and greater equity in access to them"* (Cutajar, 2002).

> *Environmental impacts tend to be closely linked to material and energy intensities. Steel, aluminium and cement represent 73% of total value and 98% of total mass production of the world's mined and chemically transformed minerals. While aluminium is a truly recyclable material, with some 440 million tonnes of the 680 million tonnes ever produced still in use, the production of aluminium via alumina does produce large volumes of residues (red mud). In terms of processing waste and residue production (excluding tailings from mining operations), steel (70%) and aluminium (23%) are the major sources globally (Herbertson, 2001).*

In 1991, the United Nations Industrial Development Organization (UNIDO), commissioned a study into the alumina industry, which was presented and discussed at the UNIDO Conference on Ecologically Sustainable Industrial Development, held in Copenhagen in that same year. The study (Siklosi et al., 1991) concluded that: *"The most important ways of reducing the negative environmental impacts of the alumina industry are;*

- *Reduction of the amount of natural resources (firstly of energy) consumed per unit amount of alumina produced,*
- *Reduction of the residual discharges (effluents, dust, stack gases) per unit amount of alumina manufactured, and*
- *Environmentally sustainable discharge and storage of digestion residue".*

As early as 1977, Alcoa recognised the need to investigate alternative residue management strategies. The company made a significant commitment to continuous improvement in residue management through the establishment of a focussed residue research and development group charged with the responsibility of "*establishing Alcoa's reputation as a leading company in the management of bauxite tailings"* (Cooling, 1997). Through research and field trials, a range of significant improvements to residue storage methods has been developed and implemented over the past two decades. However, through recent long-term planning for residue storage, it has become increasingly apparent that community and government expectations are changing, and that further improvements to the way residue is managed into the future will be needed (Alcoa World Alumina Australia, 2002).

A vision for future residue storage practices can be described pictorially as shown in Figure 1.

Described is an overall transition to a more sustainable method of residue storage, where the potential for environmental impacts is being progressively reduced, with the ultimate aim of reducing the volume of residue being stored through the use of the residue in value adding products. Following is a discussion of the desired overall transition to a more sustainable method of residue storage, where the "area of impact" is being progressively reduced.

The incorporation of an underdrainage system offered a number of advantages. Pumping of the sump maintained a low hydrostatic pressure on the base seal reducing the potential for seepage. Base drainage also improved consolidation of the fine grained material and proved an efficient means of recovering alkali for re-use by the refinery. Monitoring of the trial deposit showed an improvement in the density from 55% solids (0.9 t/m^3 dry density) achieved in the conventional storage area to 62% solids (1.08 t/m^3 dry density) thereby providing a 20% improvement in storage efficiency during the operating life of the area (Cooling, 1985).

This improved density increased the strength of the fine grained material providing a more stable deposit which in turn aided surface reclamation. It was thought that long-term rehabilitation would also be enhanced by gradual downward leaching of the deposit. New containment areas at Kwinana were also constructed with a composite clay/synthetic membrane seal which, when installed with a drainage layer placed above this composite seal, provided a very high factor of safety against any seepage.

However, there were a number of environmental and process reasons why the storage of low density "wet" tailings in large impoundments was not the preferred technique for future tailings storage.

Mining companies started investigating sloped deposition of residue many years ago as an alternative to wet disposal. In 1975, Robinsky described what he called "Thickened Tailings Discharge Method" which he helped establish at the Kidd Creek Mine of Texasgulf Canada Limited in Ontario, Canada (Robinsky et al., 1975). In 1987, Chandler outlined the solar drying of red mud residue at Alcan's alumina refinery at Ewarton, Jamaica (Chandler, 1987).

Alcoa began development work on alternative residue management techniques in the early 1980s and in 1985 "dry stacking" was adopted for Alcoa's Western Australian refineries. Dry stacking utilises a large diameter gravity thickener, called a superthickener, to de-water the fine tailings and produce a thickened slurry. This slurry is then spread in layers over the storage areas to de-water by a combination of drainage and evaporative drying. By utilising the coarse fraction of the tailings for construction of drainage layers and upstream perimeter embankments, the storage area can be constructed as a progressive stack, thus avoiding the need for full height perimeter dykes and allowing continued stockpiling on areas which were previously "wet" impoundments. The following figure describes the overall stacking process.

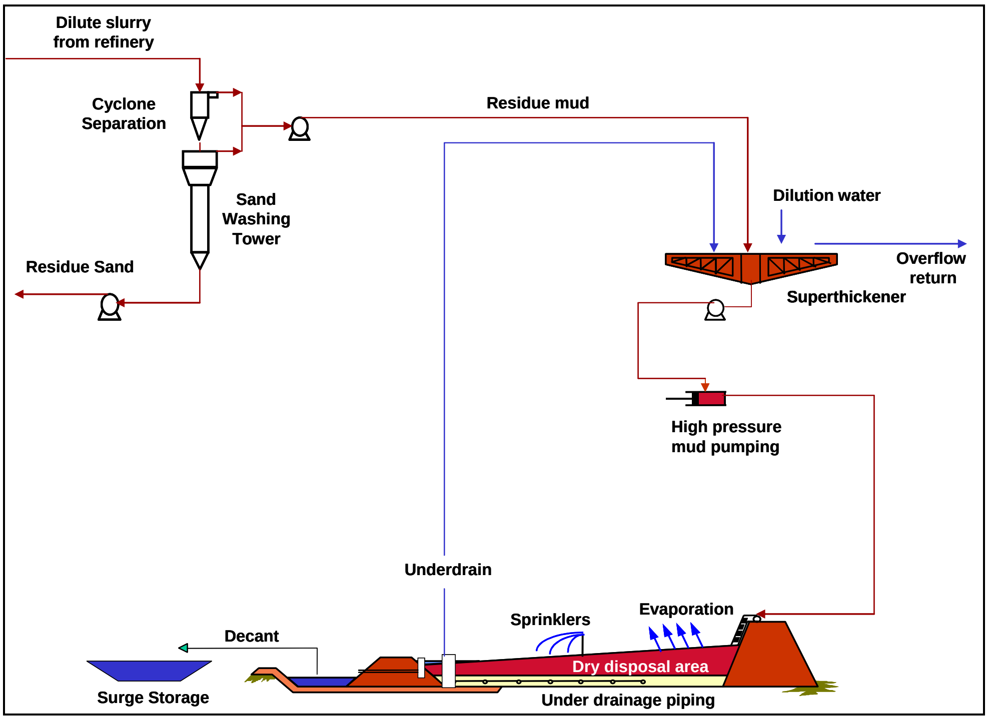

Figure 2 **Schematic of the dry stacking process**

The residue from processed Darling Range bauxite is characterised by a high coarse fraction (nominal particle size > 150 micron). This coarse fraction can be considered as a fine to medium grained sand. The fine fraction of the residue (nominal particle size < 150 micron) is silt to clay sized material and is commonly

This is generally done using a low ground pressure swamp dozer. An Archimedean screw vehicle, called an Amphirol, is also used at times. This allows a storage rate of between 13000 and 14500 t/yr/Ha to be sustained.

Routine ploughing of the mud with mechanical equipment has been termed "mud farming". Mud farming helps achieve a maximum density which allows the dry stack to be developed with maximum outer slopes (a minimum strength of 25 kPa is achieved allowing an outer slope of 6:1 to be maintained), and maximises the storage efficiency of the stack (Cooling et al., 1994).

Mud farming also minimises the potential for dust generation, which is important given the location of the refineries close to residential areas. Ploughing the surface presents a wet surface, buries carbonate, and provides a surface roughness that prevents dust lift-off once the tailings have dried.

Figure 3 Spreading the slurry, and ploughing using a D6 Swamp Dozer to enhance the drying rate

Dry stacking bauxite residue is now fully operational at all three of Alcoa's Western Australian refineries. A number of operational techniques have been developed to optimise the slurry distribution and drying processes, and these have now become standard practices. The advantages of reduced environmental risks and lower overall storage costs are now being realised. Alcoa is now looking toward treatment of the residue to reduce the pH as the next step in improving the sustainability of residue storage practices. A number of neutralisation options have been investigated over the past two decades.

4 RESIDUE NEUTRALISATION

Residue neutralisation will help reduce the potential for environmental impacts from residue storage activities, and will reduce the need for significant levels of ongoing management of the deposits after closure. Neutralisation will also open opportunities for re-use of the residue which to date have been prevented because of the high pH. The cost of neutralisation will, to some degree at least, be offset by a reduction in the need for long-term management of the residue deposits. Instead of accruing funds to deal with a future liability, the funds can be invested in process improvements, which reduce or remove the liability.

4.1 Sintering

Sintering of residue is one option investigated which resulted in fixation of all leachable alkali, however the cost was found to be very high, primarily due to the high energy consumption, making the process far from economically viable (Clyde-Carruthers, 1981).

During 1994, CSIRO prepared an overall summary report into the various residue treatments options they had investigated for Alcoa over several years. The report compared residue treatment using acid, seawater and carbonation (Cardile et al., 1994). Table 1 provides a good overview of the treatment comparison.

Table 1 Comparison of the treatment of last washer underflow with CO_2, seawater, and mineral acid (Cardile et al., 1994)

	CO_2	Mineral Acid (e.g. HNO_3)	Seawater	Deionised Water
Minimum pH value achievable	7	Any value, pH=7 achievable	8.5	11
PH after equilibrium with atmosphere	10.2	Any value, pH=7 achievable	8.5	11
Minimum pH after extended water washing without air equilibrium	9.7	Any value, pH=7 achievable	10.2	11
Minimum pH after extended water washing with air equilibrium	9.8	Any value, pH=7 achievable	8.2	11
Alkaline solution species removable	OH^-, $[Al(OH)^4]^-$	OH^-, $[Al(OH)^4]^-$, CO_3^{2-}	OH^-, $[Al(OH)^4]^-$, CO_3^{2-}	OH^-, $[Al(OH)^4]^-$, CO_3^{2-}
Alkaline solid species removable	TCA, DSP caged OH^-	TCA, DSP, calcite	TCA, DSP caged OH^- CO_3^{2-}	'adsorbed' OH^- and CO_3^{2-} only
Species controlling pH value after treatment	$NaHCO_3/Na_2CO_3$ plus resulting mud solids	Mud solids – alkaline components removed	Solution Mg^{2+} and resulting mud solids	Mud solids containing TCA, DSP
Major species introduced or greatly increased by reagent	HCO_3^-/CO_3^{2-}	Inorganic anion e.g. NO_3^-	Cl^-, Mg, Ca, Na	None
Major species leached from the solids	SO_4^{2-}	Depends on pH. At pH=7: Na, Ca, SO_4^{2-}, Cl^-	Ca	Na
Trace elements leached from the solids	P, Sr, U, Zr	No data	No data	No data
Major solution non-alkaline species reduced by treatment	Al, TOC, Na	Depends on pH. At pH=7: Al	Al	TOC
Trace non-alkaline species removed from solution	Cu, Ga, Pb	No data	No data	No data
Increase in mud volume after treatment without settling	0	Depends on acid concentration	9 times	100 times
Increase in mud volume after settling	0	Depends on pH. At pH = 7: close to zero	1.3 times	Close to zero

recommissioned to treat 100% of Kwinana's residue full time. Full operation started in 2006 using waste CO_2 from another industry in the Kwinana Industrial strip.

The technology is also being further developed, focussing on the direct use of flue gas (high purity CO_2 is currently being used and can either be sourced from other industries or extracted and concentrated from flue gas). If flue gas can be used efficiently, carbonation could be implemented at all of Alcoa's refineries, without relying on synergies with any other industries or having to install additional extraction and concentration technologies This significantly increases the adaptability and generic applicability of the process.

5 USE OF THE RESIDUE AS A PRODUCT

The ultimate aim in terms of sustainability of residue management, and in turn the sustainability of bauxite refining, is to have no residue to store. This might be achieved partly through beneficiation of the ore (leaving part of the ore in the mine rather than taking it through the extraction process to end up with it as residue), interception of value products currently within the processed ore that to date have simply passed through to the residue, or finding alternative uses for the residue produced. The move to dry stacking was a critical step along the pathway toward re-use, as it produced a readily accessible residue (through excavation from the drying beds) at a relatively low cost. Neutralisation of the residue is seen as a similar step along this same pathway, as the more significant hazard associated with the residue (its high pH) has been removed.

Alcoa continues to support a large amount of research into potential beneficial uses of residue. Potential uses that have been identified and continue to be investigated include:

- Use as a soil amendment to help retain nutrients and adjust soil pH.
- Use as a neutralising agent for treatment of acid mine drainage and amendment of acid producing soils.
- Use as a filtration medium to remove phosphorous and nitrogen from sewage effluent in domestic and industrial septic systems.
- Use as an additive to fertiliser to improve phosphorous retention in soils.
- Use as an additive to compost to aid the retention of trace metals.
- Use in brick and tile manufacture, both fired and non-fired.
- Use as a filler for plastics, to impart strength, resistance to UV, heat and chemicals, and colour.
- Use as road base, either using the sand fraction directly, or the mud as a component of a composite with gypsum or fly ash.
- Use as raw materials for the production of cement alternatives, such as mineral polymers and ceramics.
- Use as a pigment for a range of applications in coatings and materials manufacture.

Three of the more promising re-use opportunities that Alcoa believes hold the greatest potential for large volume re-use of the residue include use of the coarse residue fraction (Red Sand) as a general-purpose fill and construction medium, use of the solar dried fine mud fraction (Alkaloam) as a soil amendment, and use of lime residue (Red Lime) as an agricultural liming agent (Cooling et al., 2003).

5.1 Red Sand

The residue from processed Darling Range bauxite is characterised by a high coarse fraction (nominal particle size > 150 μm). This coarse fraction can be considered as a fine to medium grained sand. The fine fraction of the residue (nominal particle size < 150 μm) is silt to clay sized material and is commonly referred to as 'red mud'. The mud and sand fractions are separated to aid the washing for soda and alumina recovery, and are handled within the residue storage area as separate residue streams. The separation is not complete with around 10-15% of the fine mud remaining with the sand and similarly 10-15% of the coarse