RECENT ADVANCES IN THE TREATMENT AND REUSE OF BAUXITE REFINERY RESIDUES (BAUXSOL™)

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Abstract

At the previous Alumina Quality Workshop (Brisbane, 2002) we described a cost effective new procedure (the Basecon™ process) for treating caustic red mud residues from alumina refineries such that they were safe to store and revegetate, or to reuse in a wide range of environmental applications. The mineral cocktail (Bauxsol™) prepared by the Basecon™ process is now in commercial production at several sites around the world and has been registered as a safe new product by regulatory agencies in both North America and Europe. Furthermore, Bauxsol™ reagents have now been used successfully in large-scale trials and commercial applications in many countries and a lot more has been learned about their geochemistry and how to use them.

In this paper we report on the outcomes of further research into the properties of Bauxsol™ reagents and on the results of several large-scale trials and commercial applications. Examples involving the use of these reagents to treat acid rock drainage and pit lake water; tannery, wood treatment and electroplating plant effluents; acid sulphate soils, sulfidic waste rock and mine tailings; effluents from sewage and organic waste processing facilities; discharge water from power stations and ash ponds; and to remove arsenic and fluoride from human drinking water will be presented. These examples have been selected to illustrate important aspects of the geochemical processes involved when Bauxsol™ reagents are used in practical applications; this knowledge is necessary to improve their performance still further and to identify potential new applications.

1 Introduction

Globally, alumina refineries produce about 70 million tonnes of highly caustic (pH > 13) red mud residues each year and although some is neutralised by various means or dumped in the sea, most of this potentially hazardous material is stored in large red mud dams. The use of large storage facilities involves capital costs for land purchase and containment facility construction and operational costs for maintenance, site security, public safety, environmental protection, leachate management, ultimate site rehabilitation and other costs such as insurance that will only increase in the future. Given that no lined and capped impoundment can remain secure forever, the only effective permanent solution must involve some form of reuse or reprocessing of the stored residues and for most potential reuse applications, the residues will first have to be treated in such a way that basicity is converted to solid alkalinity (e.g. McConchie et al., 1999, 2002; Menzies et al., 2004; Hanahan et al., 2004) and the material becomes non-hazardous.

The concept of sustainable development, which is currently popular with politicians, planners and environmentalists, involves maximising resource use efficiency and minimising waste production. Demands for economic efficiency in the mining and mineral processing sectors have led to considerable improvements in resource use efficiency, but there has been comparatively little progress toward minimising (or preferably eliminating) wastes. Perhaps an important step in addressing this deficiency must involve thinking about industrial residues as potential resources rather than as wastes to be disposed of and the large volumes of residue generated by the alumina industry would be an excellent place to start.

At the previous Alumina Quality Workshop we described (McConchie et al., 2002) a new cost-effective procedure for converting red mud residues from alumina refineries into a non-hazardous near-neutral product (Bauxsol™) that can be safely reused in a wide range of industrial and environmental management applications. The treatment is achieved using readily available reagents, such as seawater or other natural or industrial waste brines, with or without the addition of magnesium and calcium salts; the optimum treatment for residues from each refinery depends on several factors as described by McConchie et al. (2002). Such production of useful substances from mineral processing residues illustrates the type of 'green technology' required to ensure a sustainable future for mining and mineral-processing industries.

2 Bauxsol™ and its derivatives

Since developing the treatment procedure described by McConchie et al. (2002) we have investigated other red mud treatment options and have not found any cost-effective alternatives that preserve the properties that make the treated material (Bauxsol™) useful. However, we have developed an effective way to prepare porous pellets from Bauxsol™ (see Clark et al. in this volume) for treating contaminated water using flow through reaction cells or sub-surface permeable reactive barriers. As a spin-off from this work, a method has also been developed for using Bauxsol™ to produce high strength (uniaxial compressive strengths greater than 50 MPa), low permeability, acid and salt resistant concretes that also have other useful properties; work on these specialist concretes is continuing in collaboration with the European Concrete Research Laboratories in Belfast. Work with North American researchers on using Bauxsol™ to extract radioisotopes from contaminated water and then using the spent material to make highly durable concretes that can be safely disposed of is also showing very promising results.

New Bauxsol™ blends that enhance its effectiveness for treating particular types of contaminated water or potentially acid-generating waste rock have been developed. However, although the mineral cocktail in Bauxsol™ (McConchie et al., 2000, 2002, 2003; Davies-McConchie et al., 2002) simultaneously provides both positively and negatively charged binding sites on particle surfaces at all pH values between about 3.0 and 9.0, it was never very effective at removing oxy-anions (e.g. arsenate, molybdate, selenate, etc.) from near neutral or slightly alkaline water; there was no problem if the water was initially acidic (e.g. see the results for arsenic in Table I) because more positively charged sites were available. This limitation was overcome by develop-

Table I: Data for the treated waste rock trench at the Gilt Edge Mine, South Dakota, USA

Analyte – Units	Control 2003	Result 2001	Result 2002	Result 2003	Result 2004
pH	1.93	7.9	7.96	8.35	8.62
Acidity (mg/L as $CaCO_3$)	49,000	4	≤ 5	≤ 5	≤ 5
Alkalinity (mg/L as $CaCO_3$)	≤ 5	90	62	66	72
TDS (mg/L)	77,000	11,500	8,300	3,000	NA
Sodium (mg/L)	9,300	2,970	2,990	570	250
Sulfate (mg/L)	55,000	6,000	5,800	2,200	NA
Ag (μg/L)	150	≤ 1	1.1	≤ 5	≤ 5
Al (μg/L)	1,200,000	≤ 50	10	66	≤ 50
As (μg/L)	35,000	3.1	3.7	≤ 10	≤ 10
Ba (μg/L	99	155	27	35	68
Be (μg/L)	56	≤ 0.4	0.34	≤ 5	≤ 5
Cd (μg/L)	630	0.41	0.4	≤ 1	≤ 1
Co (μg/L)	2,200	1.5	11	≤ 10	≤ 10
Cr (μg/L)	390	≤ 1	12	≤ 10	≤ 10
Cu (μg/L)	33,000	8.2	7.2	≤ 10	≤ 10
Fe (μg/L)	21,000,000	≤ 25	18	120	210
Hg (μg/L)	0.2	≤ 0.1	0.2	≤ 0.2	≤ 0.2
Mn (μg/L)	34,000	17	0.3	≤ 10	≤ 10
Ni (μg/L)	1,600	2.1	1.4	≤ 10	≤ 10
Pb (μg/L)	390	≤ 2.2	2.9	≤ 10	≤ 10
Sb (μg/L)	500	≤ 3.7	48	≤ 10	NA
Se (μg/L)	102	41.4	3.9	< 8.5	NA
Tl (μg/L)	200	≤ 5.2	3.1	≤ 5	NA
V (μg/L)	1,700	≤ 0.9	1.0	≤ 10	≤ 10
Zn (μg/L)	29,000	42	21	≤ 10	≤ 10

Data for water leaching from sulfidic waste rock that had been treated using ViroMine™ reagent in the Trench Trial at the Gilt Edge Mine site; the data span the four years since the single treatment was carried out in 2001. The control data were obtained for leachate emanating from the same type of waste rock that had not been treated with ViroMine™ reagent. ≤ indicates that the concentration is below the detection limit for the analytical procedure used; the number shown is the lower limit of detection. NA indicates not analysed. **Note:** Data up to and including those for 2003 have been validated by CDM, but the data for 2004 have not yet been validated under the QC/QA procedures.

ing activated and acid washed forms of Bauxsol™ (Genc et al., 2003; Genc-Fuhrman et al., 2004a,b) that are much more effective than activated or acid treated red muds. The acid washed Bauxsol™ is one of the most effective materials known for binding arsenate (see Genc-Fuhrman et al., 2004b) and the arsenate is bound sufficiently tightly that spent sorbent does not require disposal in a hazardous waste repository; the modified Bauxsol™ can also bind large quantities of phosphate (≈50g phosphate/kg of Bauxsol™).

As a component of the ongoing evaluation of the properties of Bauxsol™, it has been subjected to a range of eco-toxicological tests in Italy (Brunori et al., 2005) and the USA and it has been found to be non-toxic. Similarly, a study of the effect of spent Bauxsol™ on earthworms (Maddocks et al., 2005) showed that if worms were fed soil containing up to 80% Bauxsol™ loaded with 6,450 mg/kg of contaminant metals for 28 days, all worms remained healthy and active and bioaccumulation remained well below the toxicity threshold indicating that most metals bound to Bauxsol™ are not bioavailable. Bauxsol™ is now registered as a product in Europe and the USA and is approved by the regulatory authorities for use in a wide range of environmental and other applications.

3 Bauxsol™ applications

Acid rock drainage (ARD) water (or contaminated water from mineral processing operations, electroplating and wood treatment plants, tanneries, etc.) can be treated by direct addition of Bauxsol™-based reagents or by passing flowing water through a bed of pelletised reagents (McConchie et al., 1999, 2003; Davies-McConchie et al., 2002; Munro et al., 2004; Lapointe et al., 2005). The effectiveness of this treatment for a wide range of inorganic contaminants has been demonstrated for numerous contaminated waters and several large water bodies (>500 ML) have been successfully treated to the stringent standards for the protection of aquatic ecosystems; the procedure is currently being used successfully at several tanneries and electroplating plants for waste water treatment. However, although often necessary at mine sites, these methods treat the symptoms rather than the cause of environmental problems and a better solution would to treat the sulfidic waste rock or tailings to stop the production of acidic metal-rich leachates; sulfide oxidation needs to be slowed to a rate that can be accommodated by normal environmental processes. Storing sulfidic wastes permanently in lined and capped impoundments is not a solution because all caps and linings will eventually fail creating a nasty surprise for some future generation. Adding lime also has major problems because it can readily leach from the treated material before all potentially acid forming minerals have oxidised; lime treatment often appears to be effective for a few years and then fails. Hence, there has been a strong research focus on using Bauxsol™, which is dominated by very low solubility minerals, to treat sulfidic waste rock and soils and large scale trials conducted by the US EPA at the Gilt Edge Mine site in South Dakota have clearly shown (Table 1) that treating highly sulfidic waste rock with Bauxsol™ can result in successful management of leachate quality. These trials also showed that even when only a single treatment is applied, leachate quality will continue to improve for at least four years. All the evidence currently available suggests that Bauxsol™ offers a highly effective long-term solution for the management of ARD and a computer model has been developed to determine the blend compositions and application rates required to control both actual and potential acidity to ensure that no acidic metal-rich water can ever escape from the site.

Bauxsol™ reagents can be physically mixed with sulfidic waste rock or soil as was done at the Mt Carrington mine site in NSW, Australia (Lin et al., 2002; Maddocks et al., 2004) and at the Tomei Prawn Farm, Qld., Australia, or they can be injected into waste rock piles as a slurry as is being done for the I-99 road cut in Pennsylvania, USA. In addition, pelletised Bauxsol™, or a mixture of waste rock with excess Bauxsol™ reagents (e.g. in the trench trial at the Gilt Edge mine, Table I), can be used to form permeable reactive barriers (PRBs) down the hydraulic gradient from sulfidic waste rock; this procedure also offers a solution to the problem of treating highwall runoff. Furthermore, if organic matter and fertiliser are also added to sulfidic waste rock, tailings or soil being treated, the treated material can be immediately and effectively revegetated (e.g. Maddocks et al., 2004).

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