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Sustainable Indian alumina refineries: Beneficiation and reuse of bauxite residue

A lumina is produced by refining bauxite, which is stripped from open-cut mines; aluminium, one of the world’s most important lightweight metals used in packaging, transportation and construction, is in turn produced by smelting alumina. About 259 million tonne of bauxite is mined annually throughout the world from a global reserve of 55-75 billion tonne, with 30% of bauxite mined in Australia (77 mt), 18% in China (47 mt), 13% in Brazil (34 mt), and 7% in India (19 mt), with the remainder mined in countries such as Guinea, Jamaica, Indonesia, Malaysia and Russia. Bauxite is either consumed by local alumina refineries or exported to the more than 100 refineries throughout the world, with the number of refineries in China alone increasing from seven in 2001 to 49 in 2011. India consumed an average of 19 mt of bauxite per year between 2008 and 2012 (including exports), and the total global demand is projected to reach 350 mt by 2018.

The most common method of digesting alumina from bauxite is the Bayer process. In this process, alumina is generated when bauxite is digested using sodium hydroxide at a moderate temperature and low pressure. The Bayer process generates a waste by-product known as “bauxite residue” (BR). For every one tonne of bauxite processed using this process, 300-500 kg of alumina and 500-700 kg of BR are generated, with alumina going to a smelter for manufacture into aluminium and BR discharged into long-term impoundments (see examples in Figure 1), the footprints of which can be significant. When discharged from the refinery, BR is highly alkaline (typically around 5,000 parts per million [ppm], but sometimes as high as 30,000 ppm or 3%, with a pH >12.0). BR is a classified “hazardous” waste in most jurisdictions due to its highly caustic nature. BR can burn skin on contact; for example, a 2010 BR spill killed ten people.

The generation of large amounts of BR presents a disposal problem to the alumina industry. Consider that at least 120 million tonne of BR per year are generated, with projections of 140 mt by 2018. As the world’s largest industrial waste by-product with about three billion tonne currently stockpiled around the world and up to four billion tonne projected by 2015-2018, the issue of safely storing, monitoring and managing BR, along with its potential environmental and social impacts, is a non-trivial

Figure 1. Photographic examples of BR impoundments in Australia (left) and Romania (right).
When factoring in legacy stockpiles of many hundreds of millions of tonne, the need for a sustainable BR future is unambiguously important. For this reason, seven governments, including India, Australia and China which account for 53% of the world’s aluminium production, have formed the Asia-Pacific Partnership for Clean Development and Climate to make BR a key policy area worthy of further investigation and investment.

Among the main challenges associated with the management of BR are its chemical properties. Untreated BR is composed of iron (25-35%), aluminium (10-20%), sodium (3-10%), titanium (5-10%), silica (5-20%) and calcium (5-10%) in oxide, hydroxide and/or oxy-hydroxide states. None of these elements constitute a particularly grave problem, but their combined caustic nature pose significant long-term environmental management and human health risks. BR can also contain heavy metals and metalloids, including arsenic, chromium, gallium and vanadium, although usually only in trace concentrations of a few parts per million. While the presence of radionuclides, such as lead, thorium and uranium, have raised concerns, these elements are almost always found in non-radioactive states. These and other findings are important when considering the possibility of reusing BR in “waste-to-resource” initiatives or when translocating it from impoundments to large-scale agricultural applications. For example, if BR is reused its hazardous chemical properties need to be ameliorated in order for it to be handled and transported safely and before it can be re-applied in industrial or municipal settings. For this reason, many alumina refineries have sought ways to modify BR by “neutralising” its alkalinity, reducing its pH and thus lowering its causticity.

A variety of different BR neutralisation methods have been identified in the last 20 years, including carbonation, seawater neutralisation, concentrated brine addition, sulphur addition and acid neutralisation; theoretically, each method renders BR safe for storage or reuse. The critical question in considering a method’s viability asks: will the BR be stored in an impoundment after modification or will it be reused? The answer to the former means that while neutralised BR can be stored safely, there can be no question of reusing it and thus the neutralisation method need not factor in specific chemical or physical features of the neutralised BR other than alkalinity, pH and causticity. The answer to the latter leads to decisions about the neutralisation method employed, particularly if reuse requires BR to neutralise acid, sequester heavy metals, bind phosphate, add macro- and micro-nutrients to soil, interact with chemical and/or biological agents, or otherwise perform specific environmental, technological or industrial functions (these modification methods are referred to as “beneficiation” because they not only neutralise the adverse properties of BR but also enhance it for later use).

Once beneficiated, this type of BR has a number of important characteristics, and these can be enhanced further by blending it with other chemical and biological additives or modifying it for other applications through specialised industrial processes. These beneficial reuse options include applications in agriculture, municipal wastewater treatment, industrial solids and sediment remediation, concrete strengthening, among many others. From this overview it is evident that beneficiated BR has an industrial, economic and environmental role to play, and for this reason its sustainable reuse in India should be examined.

Figures 2, 3 and 4 present a framework for understanding the beneficiation and reuse of BR to create a sustainable future for India. This framework has been conceived as a comprehensive...
and inclusive approach to conceptualising a future for BR; it assumes that all stakeholders can and should play a role in an open conversation about the beneficial reuse of BR. In Figure 2, four stakeholders have been identified: Stakeholder A, the alumina refinery, which plays a central role as the supplier of BR; Stakeholder B, government agencies; Stakeholder C, technology solution and service providers; and Stakeholder D, owners/managers of contaminated sites and waste producers who can benefit from the reuse of BR. These stakeholders can each contribute something to, and receive something beneficial from, a sustainable India.

For example, in contributing to the sustainability framework, Stakeholder A contributes BR, Stakeholder B approves the beneficial reuse of BR, Stakeholder C has BR beneficiation and reuse expertise, and Stakeholder D has a contaminated site which needs remediating and can benefit from the reuse of BR. Similarly, Stakeholder A benefits by reducing their long-term liability, Stakeholder B benefits from fewer environmental problems, Stakeholder C benefits with more commercial success, and Stakeholder D benefits by cleaning up their contaminated industrial site.

In Figure 3, the beneficiaries of a sustainable India are: Stakeholder E, socially responsible investors; Stakeholder F, the media, and marketing and public relations companies; Stakeholder G, the scientific research community; Stakeholder H, consultants, contractors and industry associations; and Stakeholder I, the general public. In contributing to the sustainability framework, Stakeholder E financially supports environmental projects, Stakeholder F promotes sustainable development, Stakeholder G provides research skills and resources, Stakeholder H contributes engineering and environmental expertise, and Stakeholder I includes the participation of non-governmental organisations, environmentalists, concerned citizens and community action groups in sustainable development and provides a clarification of the public will.

Figure 4 presents an example of six industries which can benefit from the application of BR and shows the interactions between them; specifically Figure 4 shows how a waste stream treated by BR in one industry can be reused as an input for beneficial reuse by another industry. Figure 4 also summarises the general sustainable outcome for each industry as it relates to waste that has been treated with BR. Figure 4 is predicated on the input of beneficiated BR into all six application areas, which

Figure 3. Sustainability framework identifying key stakeholders E-I and their contributions to, and benefits from, a sustainable India.
are: Application A. agriculture; Application B. sewerage treatment plants; Application C. composting; Application D. landfills; Application E. mine sites; and Application F. industrial waste.

For example, when applied to A, BR has been shown to help soil retain moisture, help soil retain phosphate in a bioavailable form, promote plant growth, help soil sequester heavy metals, improve crop yields as a result of greater moisture retention, leading to high crop yields. Similarly, when applied to B, BR has been shown to reduce phosphate, nitrogen, biological and chemical oxygen demand, heavy metals and E.Coli in municipal wastewater, as well as reduce the volume of biosolids, leading to better treatment outcomes and reduced volumes of waste. When BR is applied to B, treated biosolids have reuse value as a fertiliser in agriculture and at mine sites; treated biosolids can also be used in composting facilities and treated biosolids can be discharged to landfill without the long-term negative impacts of landfill sites associated with untreated biosolids. Moreover, treated municipal wastewater has value as recycled water for use in agriculture and composting facilities and at mine sites.

When BR is added to green and household waste in C, this application results in higher composting temperatures, more rapid degradation of compost, and better quality compost. Treated compost can be used as a fertiliser in both agriculture and in mine site revegetation. When solid landfill wastes in D, are treated prior to disposal to landfill, these solids can either be reclassified from “low-level contaminated” to “clean material” thereby reducing the cost of disposal or can reduce the likelihood of long-term contaminated leachate; under either condition, landfill waste can generate methane.

There are a wide variety of waste streams generated at E, including waste rock, tailings, wastewater, and fugitive emissions. When gaseous emissions are treated with modified BR, for example, they do not result in the generation of greenhouse gases or pollution of the atmosphere. Treated mine wastewater can similarly be discharged to the local environment, and sites can be rehabilitated using BR. Such programs also promote grass and tree growth, resulting in remediated mine sites. There are also a wide variety of waste streams generated from F, many of which are amendable to treatment by BR. For example, some treated industrial solids can be used in composting or go to landfill in a reclassified form, thereby reducing the cost of solid waste disposal. The result of these initiatives for mining and industrial waste is a general reduction in waste and a cleaner, more sustainable society and environment.

In conclusion, we have discussed how BR is a large-volume hazardous waste, which when modified can have beneficial physical and chemical properties. A number of important studies have shown that BR has significant reuse value, including in wastewater and solids treatment, cementitious product manufacture, metal recovery, ceramics and contaminated site remediation. The current framework will lead to on-going education by all stakeholders, with core supporters, drivers and process owners taking responsibility for key decisions and project implementation. We have seen this ideal adopted in the leadership shown by Alcoa in Australia and other refineries throughout the world, including RUSAL and Chinalco, where stakeholders actively seek to reuse bauxite residue. It is in the interests of the entire international community and the long-term sustainability of India that efforts such as these, which explore and exploit beneficial reuse opportunities for BR, continue and flourish.

Figure 4. Beneficial reuse potentials across six industry examples (A-F) when considering reusing beneficiated BR.

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