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Recovery of sodium from bauxite residue by pressure filtration and cake washing

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A B S T R A C T

Bauxite residue, the main waste fraction of alumina production, is extremely hazardous to the environment, as well as to human health. After the recovery of the pregnant liquor, the washed and thickened bauxite residue is typically pumped as thick slurry to a residue disposal area. The use of filter presses for the final washing, in order to further enhance the recovery of alkali and aluminum, together with effective deliquoring, may be beneficial in many cases. In this study, a vertical filter press ($A = 0.1$ m^2) was used for the filtration and washing of industrial bauxite residue. The effectiveness of various washing sequences, as well as variation in the local washing results in the filter cakes, was compared. The results show that Na recovery of 98% can be obtained at a wash ratio as low as 1.4. It was also observed that not only the wash ratio is important: temperature and pressure have a significant effect on the dissolution of Na.

1. Introduction

The production of alumina from bauxite ores by the Bayer process generates bauxite residue as the main waste fraction. The amount of bauxite residue (red mud) generated while producing 1 t of alumina is typically about 1–2 t, and the residue inventory is, according to numbers from the year 2007, increasing by approximately 120 Mt/a (Power et al., 2011). The increase of the residue production rate has been rapid, because only 70 Mt/a was produced in the early 1990s (Green et al., 1994). Among the most significant producers of alumina are currently Australia, China and Brazil, which together are responsible for nearly 60% of the annual alumina production globally (Sparks, 2010; Samal et al., 2013). Toxicity to the environment (Milacic et al., 2012) and risks to animals and humans restrict the use and disposal of this strongly alkaline residue (pH > 13 in many cases). Concerning waste management, dry stacking (solid content = 48-55%) and dry cake disposal (solid content > 70%) are currently regarded as the preferred disposal methods, with a share of approximately 65%. Wet disposal in large ponds (lagoons) accounts for most of the rest, while the possibilities for direct marine disposal are inevitably vanishing. Both lagooning and direct marine disposal were the primary disposal methods until the 1970s, after which dry disposal methods became more popular (Power et al., 2011; Rai et al., 2012). In the case of lagooning, the major risks are associated with the mechanical instability of old dam constructions and the hazardous properties of the bauxite residue (Lorber and Antrekowitsch, 2011).

The composition of bauxite residues varies depending on the bauxite ore and the Bayer process. Typically present are hematite, alumina, titania, silica, CaO, Na_2O, K_2O, as well as several other components (Atasoy, 2007; Liu and Wu, 2012). Rare earth minerals are also typically present in bauxite residues. The major caustic–insoluble product formed in the Bayer process is the so called Bayer-sodalite, a sodium aluminum silicate, the exact composition of which depends on the purity of the digestion liquor (Chvedov et al., 2001). Bauxite residues also have a high salt content, and therefore high electrical conductivity. Sodium (Na^+) is the dominating metal ion in the liquid phase (Gräfe et al., 2009). The solid particles in bauxite residues are fine: particles larger than 10 μm represent about 50% or less of the particles (Lorber and Antrekowitsch, 2011; Liu and Wu, 2012; Johnston et al., 2010). The bulk density and the specific surface area of bauxite residues are high (Liu and Wu, 2012; Gräfe et al., 2009, 2011).

A large number of potential applications for the residues have been recognized and demonstrated. Some studies have focused on the most

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apparent value of the residues: the metals that are present as valuable oxides and alumina (Atasoy, 2007; Zhong et al., 2009). Bauxite residue is sometimes neutralized in order to 1) reduce its environmental impact on the surroundings of the disposal area and 2) sequester CO_2 (Rai et al., 2012; Kirwan et al., 2013; Si et al., 2013; Yadav et al., 2010). Neutralization with seawater or CO_2 is probably the most promising neutralization methods to be applied in alumina refineries (Gräfe et al., 2009; Brunori et al., 2005). The utilization of bauxite residue, even after a long period of time, is enabled by proper dry disposal. In order to minimize unnecessarily waste disposal, several applications for solid residue have been suggested, including material technology (Mymrin and Vazquez-Vaamonde, 2001), chemical industry (Alvarez et al., 1999; Schwarz and Lalik, 2012), water and soil treatment (Liu et al., 2011; Sahu et al., 2010), and recovery of valuable compounds (Agatzini-Leonardou et al., 2008; Li et al., 2009; Zhu et al., 2012; Lee and Pandey, 2012; Liu et al., 2009). However, there is hardly any significant use for the residue currently (Lee and Pandey, 2012).

Separation of bauxite residue from the sodium aluminate-rich liquid phase is typically conducted in a multi-stage countercurrent washing/thickening process, using polymeric flocculants (Gräfe et al., 2011). In order to reduce the moisture content after the final washing/thickening stage, vacuum drum filters have been typically used (Sparks et al., 2010; Borges et al., 2011). Filtration is performed, because dry cake disposal of bauxite residue requires filtration of the thickened residue, to obtain a cake with significantly reduced moisture content: approximately 30–35% (most vacuum filters) and 25–28% (typical pressure filters). The recovery of alkali and aluminum can be further improved by cake washing and minimizing the residual moisture left in the cake. Hyperbaric filters operating at pressure differences of 2–6 bar have been used for this purpose for approximately two decades (Paramguru et al., 1994). The use of filter presses, demonstrated earlier by Rousseaux et al. (2008) and Kinnarinen et al. (2015), is most likely to become more popular in the future, because filter presses can operate at even higher pressure differences, which is important when the amount of cake and the loss of process chemicals are minimized.

In this study, deliquoring and washing of industrial bauxite residue are investigated by using a vertical filter press. The alkali recovery, filtration capacity and the local differences in the washing results are evaluated through three different washing sequences. Experiments without cake washing are also performed for comparison. Additionally, dissolution of sodium from the solids at various conditions is studied.

2. Material and methods

2.1. Preparation and characterization of the slurry

A slurry sample ($V = 120$ L), received from an industrial alumina production facility, was mixed with three pitched-blade turbines in a well-sealed, temperature-controlled tank at 65 °C. During the tests, four slurry samples were taken to ensure that the slurry composition did not change significantly.

The Na concentrations in the liquid phase of the slurry, measured before and after the experiments, were 15.2 and 15.9 g/kg. The pH of the slurry, measured four times during the tests, was 13.05 ± 0.01. The total solids (TS) content of the slurry was 406 g_{solids}/kg_{slurry}. The particle size distribution of the solids suspended in the slurry is presented in Fig. 1, which shows that the solid particles were relatively fine: the median particle size was 2.32 μm, and 10% of the particles were smaller than 0.87 μm. The mineralogical composition of the slurry was determined with X-ray diffraction (XRD). The most abundant mineral phases identified in the slurry were hematite, anatase, boehmite, gibbsite, silicon oxide, sodium aluminum titanium silicate, sodium magnesium titanium oxide, sodium iron titanium oxide, goethite, and faujasite.

A scanning electron microscope equipped with an energy dispersive spectrometer (SEM-EDS) was used for slurry characterization. Several SEM pictures were taken from a completely dried slurry sample (Fig. 2), in order to investigate the suspended solids and the dissolved solids, which were crystallized when the sample was dried. The elemental composition of the slurry was evaluated based on the SEM-EDS spectrum. The following elements were detected at significant amounts: O, Fe, Na, Al, Ti, and Si.

2.2. Operation of the test unit

A Larox® PF 0.1 vertical filter press (Fig. 3), was used to carry out the solid–liquid separations and to compare the performance of cake washing. The test unit contained only one filter chamber ($A = 0.1$ m^2) and there was an elastomer pressing diaphragm in the top of the chamber. The test unit was operated at a constant pumping pressure ($\Delta p \approx$ 6 bar), and the final cake squeezing was performed at 12 bar.

In addition to cake squeezing with the pressing diaphragm pressurized with water, air (5.1 bar on average) was available for the cake deliquoring in the final stage of operation. The average air flow rates in the beginning and end of air deliquoring were 250 and 270 L/min,

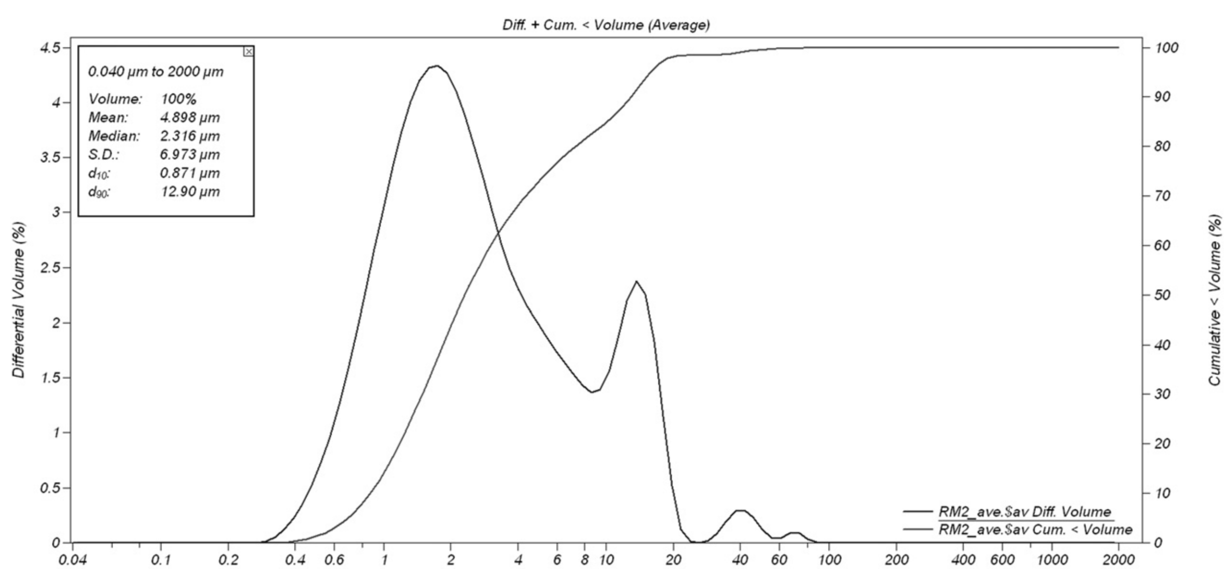

Fig. 1. Particle size distribution of slurry solids, measured with a Beckman Coulter laser diffraction analyzer.