



Local properties of filter cakes formed from pH-adjusted bauxite residue slurries



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ABSTRACT

Solid-liquid separation of bauxite residue is a topical issue in the alumina industry, not least due to the great quantity and problematic properties of this highly alkaline residue. The objective of this contribution is to provide deeper knowledge about the solid-liquid separation of pH-adjusted (pH 11) bauxite residue by investigating the local filtration properties of filter cakes produced with a piston press. Two bauxite residue samples having different particle size distribution were investigated. Measured local data of the hydrostatic pressure and solidosity was used together with flow rate data to calculate local specific filtration resistance as well as compressibility data. For the investigated pressure range (0.2–2 MPa) it was found that the residue formed slightly/moderately compressible filter cakes with a specific cake resistance between $5 \cdot 10^{11}$ to $1.5 \cdot 10^{12}$ m/kg. The sodium recovery and final cake solidosity were strongly dependent on the applied pressure, but only to a minor extent on the particle size reduction obtained by the applied mechanical treatment. The filter cakes formed from the mechanically treated samples did, however, display a somewhat higher pressure dependence for the local specific filtration resistance compared to the non-ground samples.

1. Introduction

Safe disposal of bauxite residue is a huge challenge for the alumina industry. For each ton of alumina produced, approximately 1–1.5 tons of bauxite residue are generated [1,2], in some cases even more [3,4]. Bauxite residues have high alkalinity, buffering capacity and electrical conductivity, and they contain large quantities of dissolved metal ions, especially sodium [5,6]. The mineralogical composition of the solid phase varies depending on several factors, but most typically Fe_2O_3 , FeOOH , SiO_2 , TiO_2 , CaO and sodium aluminium silicates as desilication products are present at high amounts [7–9]. Due to the adverse properties and the excellent availability of bauxite residues, several utilization methods have been proposed in the literature, although the utilization in industrial scale is still scarce. Potential future applications can be found e.g. in the construction industry [10,11], various fields of metallurgy [12,13], agriculture [14], production of ceramics, pigments and catalysts [15], as well as treatment of contaminated liquids [1]. Practical challenges are caused by the chemical composition, for instance by the Cl content, which is often too high for cement production [16].

Disposal of bauxite residue in the alumina industry is typically performed after thickening the residue slurry in a countercurrent

thickening/washing train at a total solid content of < 60 wt% [17], retaining the residue in pumpable form for transport to the disposal area (dry stacking). Alternatively, disposal is performed after increasing the total solid content by pressure filtration to approximately 70–75 wt % [18–21], and in this case the residue is transported to the disposal area as compact cakes (dry cake disposal). Currently, these two treatment and dry disposal methods are the most recommendable options for bauxite residues, unlike a couple of decades ago, when alumina refineries relied on marine discharge and lagooning [21]. The main reason for the implementation of dry disposal methods is the toxicity of bauxite residue to the environment [17] and the apparent risks caused for the local environment by large disposal ponds [22]. Neutralization of the residue prior to disposal by using for instance seawater, acids or CO_2 may reduce the risks caused by its high alkalinity further [23]. Additionally, gypsum may be applied as a surface layer at the dry disposal areas of the residue to facilitate revegetation [24].

The filtration behavior of slurries is today still normally investigated by examining average filtration properties, followed by modeling based on these average properties by using the classical filtration equation based on Darcy's work [25]. However, this approach has several limitations. For material that forms compressible filter cakes, i.e. cakes where the local cake structure varies over the height of the filter cake,

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Nomenclature			
A	filtration area (m^2)	TC	total caustic
c	mass of solids in the filter cake per volume of filtrate ($\text{kg}_{\text{dry}} \text{solids}/\text{m}^3_{\text{filtrate}}$)	v	superficial flow velocity of the liquid in the z-direction (m/s)
d_v	inner diameter of the filter cell (m)	V	volume of filtrate or slurry (m^3)
h	height from the filter medium (m)	V_c	volume of cake (m^3)
n	parameter (-)	V_{ss}	volume of suspended solids (m^3)
n_v	number of counts for the filter cell with cake (-)	z	distance from the filter medium (m)
$n_{v,0}$	number of counts for an empty filter cell (-)	α	local specific filtration resistance (m/kg)
Δp	pressure difference (Pa)	α_0	parameter (m/kg)
p_0	parameter (Pa)	α_{av}	average specific filtration resistance (m/kg)
p_c	pressure drop over the cake (Pa)	β	parameter (-)
p_L	hydrostatic pressure (Pa)	μ	viscosity of the fluid (Pa s)
p_s	solid compressive pressure (Pa)	$\mu_{v,l}$	attenuation coefficient of the liquid phase (m^{-1})
R_m	resistance of the filter media (m^{-1})	$\mu_{v,s}$	attenuation coefficient of the solid phase (m^{-1})
RSD	relative standard deviation	ρ_s	solid density (kg/m^3)
t	time (s)	Φ	local solidosity (-)
T	temperature ($^{\circ}\text{C}$)	Φ_0	parameter (-)
		Φ_{av}	average solidosity (-)

these kinds of average measurements and models are not sufficient. Furthermore, investigation of local properties can be very valuable when detecting cake cracking behavior, skin formation and other changes in the cake structure and cake resistance [26]. In the literature, several examples of studies of local filtration properties can be found. Local hydrostatic pressure has been investigated by using pressure probes in different configurations (e.g. [27–30]), while local solidosity of filter cakes or sediments has been measured with different techniques, including cake dissection [31,32], nuclear magnetic resonance [33,34], conductivity measurements [27,28], and γ and X-ray attenuation [30,35,36].

In spite of the emerging research activity on the topic of bauxite residue filtration [18–20,37,38] no information is available about the local filtration properties of bauxite residues. The purpose of this paper is to investigate how the local properties of filter cakes formed from pH-adjusted bauxite residue slurry are influenced by particle size and filtration pressure. The local cake properties are investigated in-situ by using a piston press equipped with pressure capillaries to measure the local hydrostatic pressure within the cake, and a γ -ray attenuation system used for measuring the local solidosity at certain heights of the cake. The final properties of the filter cake, including e.g. the residual sodium and moisture contents and the average solidosity, are also discussed.

2. Materials and methods

2.1. Slurry preparation

Bauxite residue slurry of industrial origin was used in the filtration experiments. At the refinery, the sample was taken from the underflow pipe of the last thickener of the bauxite residue washing train. The primary sample ($V = 0.3 \text{ m}^3$) was kept mixed overnight in a large mixing tank. A significantly smaller sub-sample of approximately 15 dm^3 was taken from the mixing tank. Part of the sample was then

ground in a vertical stirred media mill (Vollrath-Salomix, $P = 0.75 \text{ kW}$): rotation speed = 700 rpm, grinding time = 30 min, mass of slurry = 4 kg, vessel volume = 5 dm^3 , mass of beads = 2 kg, diameter of beads = 2 mm. Glass beads were used as the grinding media. The objective of experiments with ground samples was to investigate the influence of particle size distribution on the filtration properties. The aim was to obtain a better understanding of the effect of particle size distribution on the specific cake resistance, solidosity and compressibility. These experiments were considered important, because the particle size distributions may vary significantly in industrial treatment of bauxite residue solids. After grinding, the beads were separated from the slurry by pouring the slurry through a sieve with an opening 1.4 mm in diameter. The dimensions of the stirred media mill have been described in detail by Kinnarinen et al. [39].

The density of the slurry was determined by taking a certain volume of slurry in a graduated glass cylinder and measuring its mass. The slurry sample was dried in an oven at $105 \text{ }^{\circ}\text{C}$ to determine the total solids content. The concentration of total dissolved solids in the liquid phase of the slurry was measured by drying the sample of centrifuged supernatant in the oven at $180 \text{ }^{\circ}\text{C}$ to dryness. A Metrohm 859 thermometric titrator was applied for the determination of the total caustic, comprising the free hydroxyl ion content and one mol OH^- per mol aluminate. The particle size distributions of the original and ground slurries were measured with a Malvern Mastersizer 3000 laser diffraction analyzer. The main properties of the slurry are presented in Table 1.

Before the filtration experiments, the pH of the slurry was reduced to pH 11 by using hydrochloric acid. To adjust the pH, a slurry sample with a mass of 0.830 kg was poured in a 3-liter jacketed feed tank, which was cooled by passing $10 \text{ }^{\circ}\text{C}$ water through the jacket. The required HCl (37% solution) dosage was $0.095 \text{ kg}_{\text{HCl}}/\text{kg}_{\text{slurry}}$, and the addition rate was $0.1 \text{ dm}^3/\text{min}$. The slurry was kept mixed during the pH reduction. Due to the exothermic neutralization reactions, the temperature increased temporarily to approximately $40 \text{ }^{\circ}\text{C}$. Mixing and

Table 1

Properties of the diluted bauxite residue slurry at pH 11, $20 \text{ }^{\circ}\text{C}$.

Slurry(-)	ρ_{slurry} (kg m^{-3})	Total solids ($\text{g kg}_{\text{slurry}}^{-1}$)	TDS* ($\text{g kg}_{\text{liquid}}^{-1}$)	TC** ($\text{g kg}_{\text{liquid}}^{-1}$)	D_{10} (μm)	D_{50} (μm)	D_{90} (μm)	$D[3,2]$ (μm)	$D[4,3]$ (μm)
Original	1400	417	99	2.2	1.5	18	138	4.2	47
Ground					1.4	3.7	18	2.0	8.8

* Total dissolved solids in liquid phase.

** Total caustic as Na_2O with respect to liquid phase.

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