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The solid-liquid separation behaviors of the typical leach slurries in the alkaline processes for alumina

Zehao Zhang [a,b,c], Fangfang Chen [b], Shaotao Cao [b,*], Yi Zhang [b]

[a] School of Chemical Engineering, Tianjin University, Tianjin 300072, China
[b] National Engineering Laboratory for Hydrometallurgical Cleaner Production Technology, Key Laboratory of Green Process and Engineering, Institute of Process Engineering, Chinese Academy of Sciences, Beijing 100190, China
[c] National Engineering Research Center of Distillation Technology, Tianjin 300072, China

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ABSTRACT

The filtration kinetics and the cake properties of the alumina leach slurry were investigated. Four kinds of alumina leach slurry were prepared by the hydro-chemical process to treat the bauxite, the Bayer process, the Bayer process with less lime, and the hydro-chemical process to treat the Bayer red mud. The filtration kinetics was regressed by filtration test method at constant pressure. The diversity of the solid-liquid separation behaviors indicates that the digestion conditions play an important role in the filtration process. The composition and phase, the size distribution, the shape and the surface properties of the solid particles as well as the viscosity of filtrate were measured, and their effects on the filtration resistance and the cake compressibility were confirmed. Results indicate that the fine size and the broad size distribution of the particles lead to a high cake resistance. And the substances containing Fe or Ti exhibit a noticeable influence on the cake characteristics. Methods of filtration optimization through changing digestion conditions were recommended.

1. Introduction

Solid-liquid separation is essential for many processes. In alumina plant, it's of great value to improve the separation of the red mud and the sodium aluminate liquor from the leach slurry. The separation performance strongly depends on the particle properties such as the size distribution, the shape as well as the properties of liquor, which are mainly determined by the conditions of the previous digestion process (Clarke and Rantell, 1985; Delrue et al., 2011; Wakeman, 2007).

In China, the bauxite resources are nearly all of the diaspore type, and the majority is with low A/S (the weight ratio of Al_2O_3 to SiO_2 in the bauxite). Accordingly, the hydro-chemical process for alumina production is valuable to digest the diasporic bauxite and the typical red mud from refinery in a mild and green way (Cao et al., 2012, 2013; You et al., 2014; Zhong et al., 2009; Zhang, 2003; Zhang et al., 2008). In the hydro-chemical process, high concentrated caustic liquor was used to reduce the digestion temperature of diasporic bauxite, expedite the extraction of alumina even in the absence of lime (Zhang et al., 2008; Zhang, 2003). The previous results have proved that the comprehensive recovery of alumina can be elevated through a secondary digestion. In order to realize the efficient secondary digestion through an economic method, the Bayer process with less lime before the hydro-chemical treatment was proposed. However, the target solid is not cancrinite but sodalite in the Bayer process with less lime, which is more active and favorable for the secondary extraction.

In the alkaline processes for alumina above, the filtration of leach slurry is used to be considered as the major bottleneck, which limits the productivity of alumina. The primary feature of the hydro-chemical process is the adoption of high caustic concentration (Na_2O, 40–60 wt%) in liquor (Zhong et al., 2009; Zhang et al., 2008; Zhang, 2003). And the large amount of Na_2O in liquor not only promotes the extraction of alumina but also the solution of other minerals, which gives rise to the liquor with a high viscosity (Bi and Yu, 2006). Moreover, the red mud formed in the hydro-chemical process appears as fine particles of micron-size, which increases the difficulty of separation. The filtration difficulty for the Bayer process has been acknowledged, but the filtration problem for the hydro-chemical process is even more intractable. Many studies about digestion in the hydro-chemical process for alumina production have been carried out (Rayzman et al., 1998; Yang, 1993), but how the leach slurry affects the subsequent filtration has not yet been investigated. So this paper is aimed to study the solid-liquid separation behaviors and to confirm the effects of the particle or the liquor properties on filtration.

The size and the shape of the particles have critical influences on the filtration behaviors, especially the cake resistance and the cake

* Corresponding author at: National Engineering Laboratory for Hydrometallurgical Cleaner Production Technology, Institute of Process Engineering, Chinese Academy of Sciences, No. 1, Beiertiao, Zhongguancun, Beijing 100190, China.
E-mail address: stcao@ipe.ac.cn (S. Cao).

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compressibility, and the relevant influence during filtration has been extensively investigated (Bourcier et al., 2016; Beck and Andreassen, 2012; Beck et al., 2009; Wakeman, 2007; Häkkinen, 2009). To minimize the specific cake resistance, the ideal properties for particles are thought to be with large size, the monosized distribution and the spherical shape (Wakeman, 2007). The solid particles in red mud primarily include sodium aluminosilicates and some other insoluble residues like iron oxides, titanium dioxide and quartz. The sodium aluminosilicates are also called desilication products (DSPs), and the potential DSPs include sodalite, hydrogarnet and cancrinite (Barnes et al., 1999a). Researchers have found that the sodalite has a cubic structure and the cancrinite presents a hexagonal structure (Smith, 2009). The iron-bearing residues are present in the form of hematite, magnetite and andradite, which are converted from goethite or alumogoethite in bauxite at high temperature (Basu, 1983; Hind et al., 1999; Murray et al., 2009; Xu and Smith, 2012). Therefore, the structure variation of these products from the digestion of bauxite can effectively control the phase and the morphology of the red mud. The iron oxides are usually of nanoscale and with colloidal properties, which easily lead to the flocculation and the coagulation in liquor (Hind et al., 1999; Smith, 2016). And the cake compressibility is closely related with the colloidal properties and the size distribution of the particle, and is also strongly dependent on the chemical properties of the liquor, especially the ionic strength of the solution. Normally deformable particles or soft colloids exhibit high compressibility, and particles with an extended size distribution probably lead to a cake made up of uneven layers containing different-sized particles (Bourcier et al., 2016). Smaller particles can move into the channel through the cake pore and the cake tends to be compressed as the filtration pressure increases. As a result, during filtration the smaller particles not only decide the specific surface area and thus the specific cake resistance, but also introduce the compressibility effect by interacting strongly with ions or other substances in the solution (Wakeman, 2007). Even slight increase in the number of these fine particles can significantly reduce the filtration rates. In order to control the composition and the structures of the red mud, the formation of particles with large size and monosized distribution will facilitate the filtration in alumina production.

The properties of particles and liquors are essentially determined by the digestion conditions. Therefore, the digestion process should be firstly studied to clarify these properties. Though many studies about the bauxite digestion have been conducted, how the digestion condition affecting the filtration behaviors is rarely reported. In practice, the digestion process includes the desilication and the transformation of the iron-bearing minerals, which was proposed to be a dissolution-reprecipitation mechanism (Barnes et al., 1999b; Murray et al., 2009; Pan et al., 2016). And precipitation is influenced by the reaction temperature, the medium concentration, the fluid hydrodynamics, and the additives such as the lime added before leaching, resulted in variation of the size and the shape of the final particles. It is thus considered by adjusting the digestion conditions to favor the growth of the DSP crystals, to reduce the amount of colloid iron in slurry, to contribute to a low dynamic viscosity, and to control the size and shape of particles, especially the spherical shape (Barnes et al., 1999b; Smith, 2016; Wakeman, 2007).

Efforts for enhancing the filtration capacity are focused on the chemical agents to alter the surface characteristic of the red mud or the slurry rheology, the optimization and improvement of the filter equipment or the filtration media, and the design of process to improve the separation efficiency (Fernando Concha, 2014; Rushton et al., 2008; Tarleton and Wakeman, 2006). Before applying these methods, it's necessary to test the filtration behaviors of the alumina leach slurry to obtain the properties of the slurry and the filtration parameters, which can provide theoretical guidance for the optimization of the digestion and the design of the filtration. In this study, the alumina leach slurry was prepared by the hydro-chemical process to treat the Chinese typical diaspore, the Bayer process, the Bayer process with less lime, and the hydro-chemical to treat the Bayer red mud. The filtration behaviors were tested at a constant pressure in laboratory. The properties of the slurry were measured, and the red muds were investigated in detail. The factors influencing the filtration were analyzed and the approaches of enhancing filtration were proposed to deal with the challenges for the filtration of the hydro-chemical process and the Bayer process.

Table 1
Chemical compositions of bauxite and red mud.

Raw materials	Contents (wt%)								
	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	A/S
Bauxite	62.20	13.92	3.86	3.00	0.73	\	\	1.05	4.47
Red mud	24.67	19.88	5.12	4.81	19.46	0.65	6.76	\	1.24

2. Theory for filtration

Simplified as the viscous liquid fluid through a porous medium, the cake filtration is described by the Darcy's law with two assumptions that the flow velocity is slow and the particles and the bed are incompressible (Coulson and Richardson, 1968; Fernando Concha, 2014).

$$\frac{dV}{dt} = \frac{A\Delta p}{\mu R} \tag{1}$$

where dV/dt is the volumetric rate of the filtrate flowing through a bed, A (m^2) is the filter cake area, Δp (Pa) is the pressure drop across the filter cake, μ (Pa·s) is the dynamic viscosity of the filtrate, and R (m^{-1}) is the filtration resistance consisting of the medium resistance R_m and the cake resistance R_c.

When the filtration pressure is kept constant, the filtration is expressed by the Ruth's filtration equation (Ruth, 1946):

$$\frac{t}{q} = \frac{\mu c a_{av}}{2\Delta p} q + \frac{\mu R_m}{\Delta p} \tag{2}$$

where t (h) is the filtration time, q ($m^3 \cdot m^{-2} \cdot h^{-1}$) is the filtrate volume per unit filter area, c ($kg \cdot m^{-3}$) is the solids concentration in the slurry (dry mass per unit volume of the filtrate), and α_{av} ($m \cdot kg^{-1}$) is the average specific resistance of the cake. The solids concentration in slurry can be calculated by the following equation derived from the mass balance:

$$c = \frac{w\rho_l}{1-mw} \tag{3}$$

where w ($kg \cdot kg^{-1}$) is the mass fraction of solids in the slurry, ρ_l ($kg \cdot m^{-3}$) is the filtrate density, and m ($kg \cdot kg^{-1}$) is the mass ratio of the wet to the dry cake. Thus, Eq. (2) can be rewritten as:

$$\frac{t}{q} = \frac{\mu w \rho_l a_{av}}{2\Delta p(1-mw)} q + \frac{\mu R_m}{\Delta p} \tag{4}$$

All the parameters could be determined by experiment, except that the α_{av} and the R_m were obtained from the intercept and the slope of the t/q vs. q plot, respectively.

As for the situation affected by the filter pressure, the α_{av} is often described by the following empirical equation:

$$\alpha_{av} = \alpha_0 \left(\frac{\Delta p}{p_0}\right)^n \tag{5}$$

In Eq. (5), α_0 ($m \cdot kg^{-1}$) is the cake specific resistance, and p_0 (Pa) is the reference pressure set as 0.1 MPa in this work, which is used to make a dimensionless pressure. The exponent n is the factor of the filter cake compressibility.