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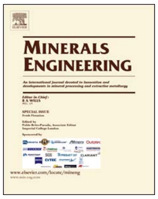

A review of pretreatment of diasporic bauxite ores by flotation separation

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ABSTRACT

The Bayer process is a conventional method for refining bauxite in the production of alumina. The Al/Si ratio in bauxite before feeding to the process must be enriched to more than eight by reducing impurities (mainly aluminosilicates). Therefore, diasporic bauxite ores (Al/Si < 6) have to be upgraded by pretreatment methods to meet the required quality for the Bayer process. Flotation separation (direct or reverse) followed by flocculation as an efficient pretreatment method is the main beneficiation technique for upgrading diaspore. Diaspore pretreatment by flotation favors several conditions and possesses certain limitations. This study has systematically explored various effective flotation factors (particle size, surface electrical charge, collectors, depressants, dispersants, flocculation and aggregation) and limitations in the pretreatment of diaspore and has compiled optimum results for its beneficiation. The summary offers various approaches for the selective flotation of diasporic ores via different conditions and suggests perspectives for further investigation.

1. Introduction

Aluminum metal, a major industrial metal, can be extracted from hydrated bauxite minerals, including gibbsite [$Al(OH)_3$], boehmite [γ-AlO(OH)], and diaspore [α-AlO(OH)] (Barbosa et al., 2016; Gen et al., 2012). The major difference between these minerals lies in their crystalline structure (Tabereaux and Peterson, 2014). Bauxite occurrence may be distributed in tropical climates (mostly gibbsite and several traces of boehmite) as well as in regions of highly weathered clay (i.e. lime clayey lithology) in rocks containing mineralogical composition of silicates (typically diaspore) (Marino et al., 2013). Around 10% of the world's discovered bauxite is found in Brazil, mainly formed gibbsite and boehmite (Liu et al., 2015), while low grade diasporic ores are found in highly weathered regions. China has about 98% of diasporic bauxite ores (Liu et al., 2016). It was reported that substantial reserves of bauxite may be located in Guinea (26.4%), Australia (19.2%), Brazil (12.1%) and Jamaica (7.1%) (Marino, 2012).

The major method of bauxite beneficiation is the Bayer process, which is leaching at 100 °C to 250 °C by a caustic soda solution (sodium hydroxide) followed by solid-liquid separation, cooling, precipitation, filtration and calcination, with alumina as the final product. The process dissolves the majority of the alumina-bearing minerals and other reactive associated minerals, such as silicates (Marino, 2012; Marino et al., 2013). Therefore, the Al/Si mass ratio of the process feed plays a critical role in the viability and economics of the process. In general, the Al/Si mass ratio for feeding to the Bayer process has to be more than eight (Marino, 2012; Marino et al., 2013). Due to the rapid depletion and limitation of high grade gibbsitic/boehmitic bauxite (Al/Si more than eight), attention has been drawn to the abundant low grade diasporic ores. As the Al/Si mass ratio in diaspore is typically less than six, upgrading of the feed has to be performed. Generally, froth flotation as an enhanced, less costly environmental achievable physical separation method has been employed to increase the mass ratio of Al/Si for adequate purification and pretreatment of diaspore before the low grade material feeds to the Bayer process (Feng et al., 2009).

Associated gangue minerals in bauxite ores are varied. Nevertheless, the general impurities associated with gibbsitic bauxite are iron oxides (Hematite, Goethite), and silicates (Marino, 2012), while gangue phases of diasporic ores are mainly kaolinite, illite, and pyrophylite (Wang et al., 2004; Liu-yin et al., 2010). Diaspore pretreatment separation may be accomplished by direct or reverse flotation (Sheng-gui et al., 2007; Sanjun et al., 2013). The purpose of this study is to provide a comprehensive review of various conditions which affect the upgrading of diaspore by froth flotation as a pretreatment process. It will discuss how different parameters (particle size, surface electrical charge, collectors, depressants, flocculation, aggregation, and water chemistry) can have effects on upgrading of flotation products. This investigation discusses ways to apply this technique and the optimum parameters for various conditions.

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2. Particle size effect

Particle size for contemporary diaspore processing is usually obtained by crushing and grinding followed by de-sliming through scrubbing, and, at intervals of the processing, wet screening may be utilized in order to remove gangue minerals (Marino et al., 2013). The size of particles in the pretreatment procedure has an essential effect on upgrading metallurgical results (Marino, 2012). As it was noted, diasporic bauxite ores (diaspore is naturally hydrophilic) have a low Al/Si mass ratio, and an extensive comminution has to be performed on the ore in order to liberate value and gangue minerals and prepare them for selective interaction with reagents (direct and reverse flotation) (Wen-li et al., 2014; Kurusu et al., 2009). It was reported that diaspore particles as coarse as 0.297 mm (Massola et al., 2009), and finer than −0.037 mm would attach to bubbles on the premise of mineral monomer dissociation (Zhang et al., 2012). However, the complexity in the structure of the aluminosilicates pose significant challenges to obtaining an appropriate liberation size and recovering the diaspore from the ore (Gen et al., 2012; Xu et al., 2014) where typically fine particles in diaspore flotation are clay minerals (mostly Kaolinite) (Marino, 2012).

It is well documented that slime beneficiation can increase the life of mines (Thella et al., 2012). On the other hand, particles less than 10 µm show low collision efficiency with bubbles and limit the probability of bubble-particle attachment (Marino et al., 2013; Zhang et al., 2016). Moreover, slime may adversely affect the processing technique and decrease the grade of the diaspore (Barbosa et al., 2016; Wang et al., 2004). Several investigations studied the role of specific surface area in determining the form of collector absorption on fine diaspore particle surfaces, and processing these particles remains a considerable challenge (Hao et al., 2011; Jiang et al., 2011; Jiang et al., 2014).

This challenge comes from the phenomenon that an increase in grinding and size reduction likely affects the shape and surface area properties, and produces a relative number of edges on both value and gangue minerals (Xu et al., 2014). Kaolinite would be affected extensively by such a process because the specific surface area of kaolinite is much larger than the value of diaspore (6–7 times for the same size fraction) (Jiang et al., 2014). The large surface area of kaolinite potentially increases its collector adsorption, and reduces the concentration of collectors on the diaspore surfaces. Furthermore, fine particles, besides their large specific surface area, have small masses, which possibly facilitate their collector adsorption (Marino, 2012). Therefore, scrubbing and de-sliming particles under 0.010 mm are necessary to avoid frothing problems (Massola et al., 2009). Several studies reported that the optimal size for diaspore pretreatment by flotation is 74 µm (Gen et al., 2012; Liu et al., 2016; Liu-yin et al., 2010; Wen-li et al., 2014; Jiang et al., 2011; Yuhua et al., 2011; Liu et al., 2011a,b; Yue-hua et al., 2008; Yu et al., 2016; Deng et al., 2015; Jiang et al., 2012a; Yi-ping et al., 2002; Deng et al., 2016; Yu-hua et al., 2008; Chuanbing and Yuhua 2008; Xue-feng et al., 2008; Yu-ren et al., 2010; Li et al., 2010; Hu et al., 2012).

3. Surface electrical charge

The collector adsorption in flotation of oxides is principally controlled by the electrical double-layer on the surface of minerals. Thus, the surface electrical charge, and most specifically the isoelectric point (IEP) of diaspore and its associated minerals, are the most important keys for the upgrading process via flotation (Laitinen et al., 2016). The surface electrical charge of diaspore can change by adsorption of OH^- or dissociation of H^+ (Eq. (1)) where its surface alters to hydroxylate in water (Hao et al., 2011).

$$-Al{-}OH_2^+ \overset{H^+}{\Leftrightarrow} -Al{-}OH \overset{OH^-}{\Longleftrightarrow} -Al{-}O^- \qquad (1)$$

Table 1
The IEP of diaspore and its associated aluminosilicates in the distil/deionized water.

Diaspore	Kaolinite	Illite	Pyrophillite	References
6.68	3.56	2.51	2.88	Yu-hua (2003)
6	3.4	3.2	2.3	Sheng-gui et al. (2007)
6.4	3.6	2.8	2.4	Hu et al. (2003)
5.4	3.2	2.9	2.3	Zhong et al. (2008)
6.2	3.4	2.4	3	Yu et al. (2016)
6.3	4.3	3.4	–	Jiang et al. (2010)
6.6	4.2	3.4	–	Jiang et al. (2011)
6.25	3.68	2.8	–	Yu-ren et al. (2010)
6.3	3.7	–	–	Liuyin et al. (2009)
6	3.1	–	–	Jiang et al. (2014)
6	4.2	–	–	Hai-pu et al. (2004)
7.3	3.8	–	–	Xu et al. (2014)
5.3	3.1	–	–	Liu et al. (2007)
4.8	3.2	–	–	Liu et al. (2011a,b)
7.8	–	–	–	Hai-pu et al. (2011)
7.8	–	–	–	Hai-pu et al. (2010)
6	–	–	–	Deng et al. (2016)
7.8	–	–	–	Li et al. (2010)

Various investigations have indicated that the IEP of diaspore in deionized water and in the absence of flotation reagents is pH 5–7.5 which is higher than its associated aluminosilicates (Table 1) (Yu et al., 2016; Deng et al., 2015; Jiang et al., 2010). The variation of diaspore IEP can be explained by the presence of silicate impurities (Hu et al., 2003). Yu-lin et al. (2011) reported that the IEP of diaspore in the presence of 5×10^{-4} mol/L cations Ca^{2+}, Mg^{2+}, Na^+, can change from 7.2 to 4.5, 8 and 6.8, respectively. Kaolinite, illite and pyrophyllite have similar chemical compositions which suggest a similar IEP with negative charge over a wide range of pH (IEP mainly at pH less than 4) (Table 1). The greater IEP value of diaspore versus aluminosilicates is the reflection of a higher number of Al–O sites in the surface of diaspore in comparison with a higher number of Si—O sites on the surface of its associate minerals (Jiang et al., 2010). On the other hand, there is a negative relationship between IEP and SiO_2 content (wt%) and a positive inter-correlation between IEP and the Al_2O_3 content (wt%) in the diaspore flotation system (Hu et al., 2003).

The surface electrical charge of diaspore (and typically its associated minerals) is positive at pH less than IEP and negatively charged at pH greater than IEP (Feng et al., 2009; Deng et al., 2015; Yu-hua et al., 2008; Li et al., 2010; Laitinen et al.,2016; Hai-pu et al., 2010; Yu-hua et al., 2003; Zhao et al., 2003a). As the IEP is dependent on pH adjustments, the presence of reagents can potentially influence the pulp pH, and their interactions on mineral surfaces can affect IEP. Reactions between the ionic reagents and ions on the diaspore surface have an effect on the hydrogen bonds (Xia et al., 2009). In general, it was reported that anionic collectors would significantly decrease the IEP of diaspore to less than pH 4, this decrease is negligible for Kaolinite (pH ∼4 to ∼3.5) (Table 2). Moreover, various investigations demonstrated that cationic collectors can shift the electrical charge on the diaspore surface towards more positive where this shift is considerable for Kaolinite (IEP at pH > 8) (Table 2).

4. Flotation

4.2. Direct flotation

4.2.1. Collectors

Several investigations have reported that floating of diaspore (direct flotation) is an effective method for the pre-treatment of the low grade ores, to increase Al/Si mass ratio and prepare the inferior feed for the Bayer process (Gen et al., 2012; Liu et al., 2016; Wang et al., 2004; Xu et al., 2014; Yu et al., 2016; Jiang et al., 2010; Xia et al., 2009; Jiang et al., 2012b; Huang et al., 2013). Various types of collectors have been categorized, synthesized, and used to efficiently increase the recovery of direct flotation (Table 3). Although direct flotation of diaspore