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Migration and distribution of saline ions in bauxite residue during water leaching

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Abstract: Bauxite residue, a highly saline solid waste produced from digestion of bauxite for alumina production, is hazardous to the environment and restricts vegetation establishment in bauxite residue disposal areas. A novel water leaching process proposed here was used to investigate the dynamic migration and vertical distribution of saline ions in bauxite residue. The results show that water leaching significantly reduced the salinity of bauxite residue, leaching both saline cations Na^+, K^+, Ca^{2+} and anions CO_3^{2-}, SO_4^{2-}, HCO_3^-. Na^+ and K^+ migrated from 40−50 to 20−30 cm of the column, presenting a high migration capacity. The migration capacity of Ca^{2+} was lower and accumulated at 30−40 cm of the column. CO_3^{2-} initially distributed at 20−30 cm of the column, subsequently transported to 30−40 cm of the column, and finally returned to 20−30 cm of the column along with evaporation. SO_4^{2-} was originally distributed at 40−50 cm, but finally migrated to 20−30 cm of the column. Nevertheless, HCO_3^- remained at the bottom of the column, and its migratory was less affected by evaporation.

Key words: bauxite residue; salinity; ion migration; column stimulation; water leaching

1 Introduction

The alumina industry has developed rapidly due to the requirement for aluminum. Unfortunately, such rapid development has brought about multiple environmental problems that profoundly influence the sustainable development [1−3]. Bauxite residue (BR, or red mud) is a highly saline solid byproduct generated during alumina extraction from bauxite using Bayer, sintering and combined Bayer-sintering processes in alumina refineries. The volume of BR generated while producing 1 t of alumina is typically 0.5−2 t [4−7]. The cumulative global inventory of BR has reached an estimated 4 billion tons, and is still increasing [8−10]. Many efforts have been made to find suitable uses for BR, but as yet no economic method has been extensively applied [11−13]. Therefore, almost all BR continues to be disposed in BRDAs [14,15], which requires sustainable efforts to manage the waste [16,17]. Furthermore, freshly formed saline dusts on the surface of BRDA containing large concentrations of salts are harmful to the surrounding environment [18−20]. The elevated salts mean that BR is a hazardous waste, which limit its safe disposal and revegetation.

High salinity is a result of using sodium hydroxide for extracting alumina from the ore and the formation of a complex-saline mineral. The residual sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$) that can not be completely separated by counter-current decantation (CCD) water washing before disposal partly remain in BR, and are responsible for the soluble-sodic salinity [21,22]. Additionally, potash (K_2CO_3) and Na_2SO_4 commonly exist in BR. Furthermore, The formed solid phase of tri-calcium aluminate (TCA, $Ca_3Al_2(OH)_{12}$), cancrinite ($Na_6Al_6Si_6O_{24}\cdot 2CaCO_3$),

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sodalite ($Na_6Al_6Si_6O_{24}\cdot Na_2CO_3$), and hydrogarnet ($Ca_3Al_2(SiO_4)_x(OH)_{12-4x}$) are typical buffering minerals [23,24], which act as another source of salinity.

The removal of BR salinity is therefore critical. Nevertheless, many efforts are to remove or transform the alkalinity of BR, which are commonly applied by alumina refinery to treat with BR prior to store and ameliorate for revegetation at BRDAs [25,26]. The addition of gypsum, organic matter and fertilizer, seawater neutralization, waste acid interaction and carbon dioxide sequestration have been attempted to reduce and/or remove the high alkalinity [27,28]. Nevertheless, removal and separation of salinity have only been minimal. Water washing is a promising way forward in an attempt to reduce the strong alkalinity and remove the high salinity; this may leach approximately 70% alkaline Na whilst also reducing a large proportion of salts [29]. However, information on migration behavior of saline compounds and their subsequent distribution is absent, but is significant if a well-founded transportation-migration theory is to be understood. Furthermore, less concern has been paid to saline migration in BRDAs. Indeed, lack of understanding of dynamic migration and vertical distribution of saline ions in BR during water leaching is a knowledge gap that requires attention.

The objectives of the present study are to investigate leaching and migration behaviors of saline cations and anions in bauxite residue using a column leaching study, and to research the vertical distribution of saline ions in residue during long-term leaching.

2 Experimental

2.1 Field sampling and sample preparation

In October 2015, a raw BR sample, used throughout this study, was collected from an Aluminum Refinery Corporation of China. The freshly stored BR was collected from the surface of BRDA's. Three sub-samples were collected with a distance of 10 m from each other to obtain a uniform sample (Fig. 1(a)). Samples were stored in polyethylene bags, returned to the laboratory and subsequently air-dried for 4 d, and then sieved to retain the <2 mm fraction. SEM image of the sample (Fig. 1(b)) showed that it consisted of 0.1−0.5 μm particles in 2−10 μm aggregates, which was poorly-crystallized. Compositions of BR are presented in Table 1.

2.2 Long-term leaching experiment

The leaching experiment was conducted using a column (Fig. 2) to simulate long-term leaching by rainfall in a BRDA. Two half-cylinders were bonded to create the column with an outer diameter of 14 cm, an inner diameter of 12.6 cm and a height of 95 cm, and 36 sample holes were pre-drilled and arranged on the outer wall for convenient sampling at various time during the investigation. The column base was mesh, being supported with a 5 cm depth of sand. Subsequently, the column was filled with BR, and Milli-Q water was supplied slowly from the bottom of the column. After 2 d of saturation, Mill-Q water was then supplied slowly

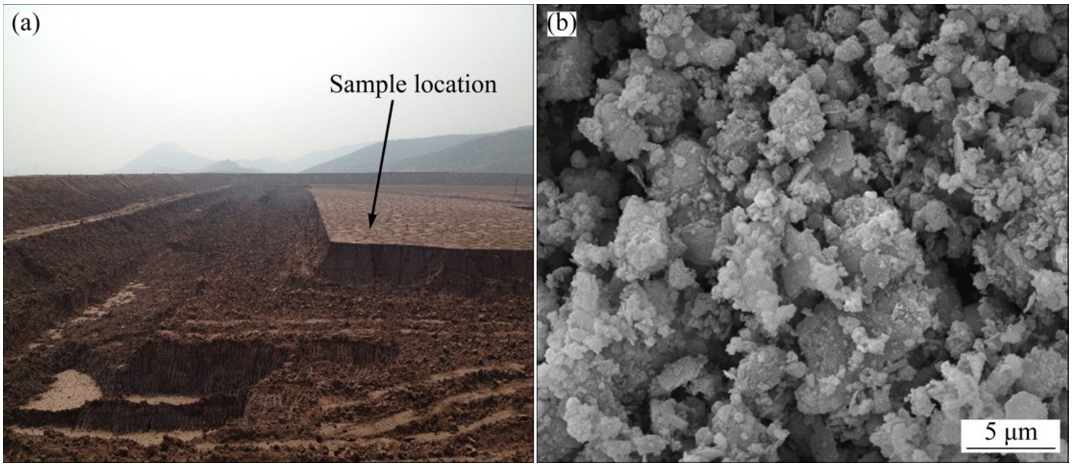

Fig. 1 Bauxite residue sample collected from surface of BRDA (a) and SEM image of bauxite residue (b)

Table 1 Initially saline composition of bauxite residue in water leaching column experiment

Concentration of saline cations/(mmol·kg^{-1})				Concentration of saline anions/(mmol·kg^{-1})			Electric conductivity/(mS·cm^{-1})	pH
Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	SO_4^{2-}		
132.16	10.72	0.30	−	57.00	6.53	7.51	1.80	11.05

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