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Recovery of alkali and alumina from bauxite residue (red mud) and complete reuse of the treated residue

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ABSTRACT

Bauxite residue is an alkaline solid waste produced during the extraction of alumina from bauxite, which causes serious environmental problems and safety risks. In this study, alkali and alumina were recovered from Bayer bauxite residue using a novel calcification-carbonisation process. This produced a non-hazardous and near-neutral residue (C-C residue), the properties of which facilitated its subsequent reuse. After the calcification-carbonisation treatment, 46.5% of the alumina was extracted and the Na_2O content in the final residue (C-C residue) dropped to less than 0.3%. In addition, the feasibility of using C-C residue in the production of cement and the preparation of soil was analysed. The results showed that the chemical composition of C-C residue is very close to that of Portland cement clinker, which allows the dosage of bauxite residue in cement production to be increased. A comparison of the C-C residue with a general soil showed that the former performed well for many soil parameters, such as alkalinity and salinity, and has great potential for application in soil preparation. Thus, the calcification-carbonisation method, combined with cement production or soil preparation, is a sustainable process for completely reusing Bayer bauxite residue and facilitating bauxite waste minimisation.

1. Introduction

Bauxite residue is the polluting alkaline solid waste produced during the industrial process of alumina extraction. For each tonne of alumina, 1–2 tonnes of solid waste (bauxite processing residue) is produced from different sources and production processes (Jones et al., 2012; Liu et al., 2014). As the global alumina industry has developed rapidly in recent years, the amount of bauxite residue produced by alumina production has also increased. At present, the global inventory of bauxite residue stored in land-based impoundments is estimated at over 3.4 billion tonnes, with an annual growth rate of approximately 0.12 billion tonnes (Brunori et al., 2005; Gunning et al., 2010; Klauber et al., 2011). Unfortunately, the average utilisation factor of global bauxite residue is only 15%, and that of China is only 4% (LÜ et al., 2013).

Worldwide, more than 90% of alumina is produced via the Bayer process, and thus Bayer bauxite residue accounts for a considerable percent of the by-products of alumina extraction. As bauxite ore is mined and then refined using the Bayer process, in which Al-containing minerals are dissolved in hot alkaline solution, the composition of alkaline materials in bauxite residue is very complex. The alkaline content of the Bayer process is also much higher than that of other production processes (Jones et al., 2012; Liu and Naidu, 2014). In Bayer bauxite residue, the alkaline materials include not only soluble NaOH, Na_2CO_3, $NaAlO_2$, and Na_2SiO_3, left over from the solution phase, but also a zeolite sodium aluminosilicate hydrate ($Na_2O \cdot Al_2O_3 \cdot xSiO_2 \cdot mH_2O$) and metastable, amorphous non-soluble alkaline substances (Wang et al., 2016, 2017) generated from the reaction between the bauxite and strong alkaline solution (Liu et al., 2007; Wang et al., 2013). A wash process cannot easily remove the alkaline compounds, which exist in a non-soluble structure. It takes a long time to achieve solubility equilibrium between the bauxite residue particle surface and the solution interface, causing alkali to dissolve slowly from the inside out. This causes great difficulty when it comes to the subsequent use of Bayer bauxite residue, such as for producing building materials or preparing growth media. As a result, most bauxite residue has to be deposited in impoundments surrounding the alumina refineries. Huge piles of bauxite residue occupy a lot of land, and extensive labour and material resources are required to build bauxite residue disposal dams and for their management and

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maintenance. Bauxite residue can also contaminate air, water, and soil, posing a serious risk to the surrounding environment.

Despite the many attempts that have been made to utilise bauxite residue (Fig. 1), the residue does not offer beneficial properties as a raw material for these applications (Hamdy and Williams, 2001; Liu and Wu, 2012).

Producing building materials (such as cement, brick, and road base material) with bauxite residue is a direct, simple, economical, and quick way to consume a large amount of the substance (He et al., 2007; Pappu et al., 2007). However, cement preparation requires strict quality control on its components. If the alkali content of the cement is too high (>1%), an alkali-aggregation reaction will occur in the concrete, resulting in low strength and inadequate durability, which may cause serious project quality or safety issues and accidents. If wall bricks are made from Bayer bauxite residue, alkali efflorescence is a problem on the wall surface. As alkali efflorescence occurs gradually and consistently, the wall materials expand in size and become crispy, easily falling off, which leads to a decrease in the building's service life (Huang et al., 2014).

Apart from the alkaline restriction, bauxite residue used for building material production is also limited by haul distance (Graefe and Klauber, 2011; Graefe et al., 2011). On-site reclamation can eliminate the high cost of red mud transportation. Queensland Alumina Ltd. carried out research on bauxite residue neutralisation with seawater. First, excess water was added into bauxite residue reservoirs to neutralise residual alkali. Then, the surface properties of the bauxite residue were modified with sludge. Finally, a layer of 100 mm thin aggregate soil was added, and grass reaped in existing reclamation areas was spread onto the bauxite residue surface after intensive cropping. These three steps turned the original saline-alkaline bauxite residue into a near-neutral soil that supports plant growth (Guo, 2005; Yin et al., 1995). Unfortunately, most countries do not have the coastal advantage of Australia, so an economical and effective means of dealkalisation and desalination is the key to large-scale utilisation of bauxite residue.

Studies also exist in which bauxite residue was used to prepare adsorbents, flocculating agents, soil conditioners, and catalyst carriers. For these applications, less residue is usually consumed. Some of the accompanying problems have not been fully considered. In addition to improving the adsorption performance of bauxite residue, further research is needed into the follow-up disposal of the disused adsorbent. Bauxite residue is a resource rich in useful mineral elements, such as Al, Fe, Ti, Sc, Ga, and Ge. Thus, it is possible to extract and recycle valuable metals from bauxite residue (Paramguru et al., 2005). To decrease the volume of bauxite residue, the recovery of valuable metals should be technically and economically feasible if conducted at a major industrial plant. Recovering as much of the metals as possible from a process serves to increase profits, and thus is encouraged. The residue that remains after processing should also be used, in order to make full

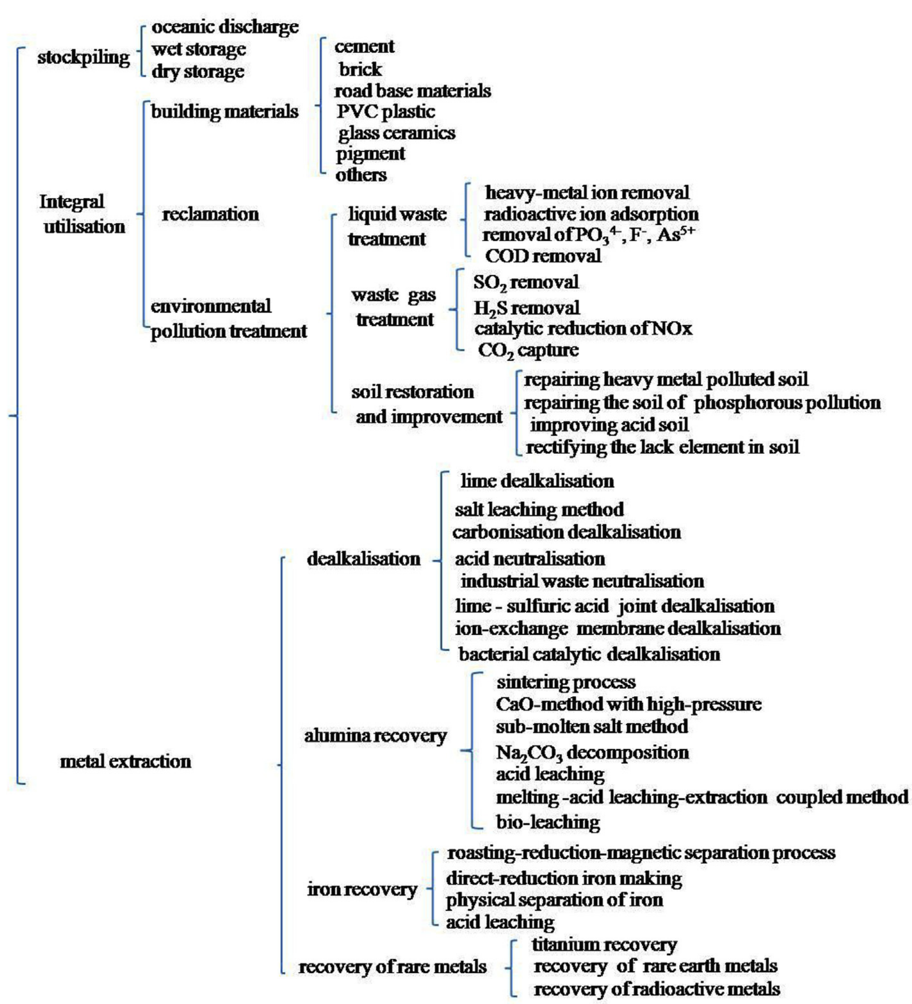

Fig. 1. Classification of current disposal methods for bauxite residue.