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Extraction of alumina from coal fly ash generated from a selected low rank bituminous South African coal

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Abstract

Vast quantities of coal ash, originating from the steam generation coal-based process have accumulated over the years. Continuous research is conducted to identify opportunities for the utilization of fly ash. This coal ash typically contains 30% alumina, 1.5% titania, 2.5% hematite, 9.5% lime and 60% silica. Due to the availability of alumina in fly ash and large quantities of alumina imported by South Africa annually, a project was initiated to evaluate the possibility of extracting the alumina from fly ash.

The mullite-containing fly ash was mixed with calcium oxide and subsequently calcined at a temperature ranging from 1000 to 1200 °C to yield acid or base soluble calcium aluminate. The calcined ash was leached with a sulphuric acid solution to produce a solution containing iron, aluminium and titanium species. An aluminium extraction efficiency of 85% was achieved when the sintered pellets were leached with sulphuric acid using an acid concentration of 6.12 $\mathrm{mol\,dm^{-3}}$ at 80 °C for 4 h. The leached residue, from the sulphuric acid leaching, could be considered as a co-product in this process and could possibly be suitable for use as a lightweight aggregate in masonry concrete applications or cement production. Purification methods such as precipitation, solvent extraction and crystallization were evaluated to selectively separate both iron and titanium ions from the aluminium containing aqueous solution.

The solvent extraction method was found to be superior for the removal of iron and titanium from the aluminium-containing aqueous solution in comparison with all of the purification methods evaluated in this study. The major final product obtained with the solvent extraction method contained approximately 99.4% alumina, whilst the minor product contained 97% titanium oxide. The alumina product can be used for the production of aluminium chemicals and in refractories, while the titanium oxide product can possibly be used as a white pigment in the production of paints.

Keywords: pH control; Leaching; Solvent extraction; Extractive metallurgy

1. Introduction

Coal ash from Sasol combustion plants typically contain 60% SiO_2, 30% Al_2O_3, 6–10% CaO and 1.5% TiO_2 (Torma, 1983; Matjie, 1997; Ritter, 1991). According to Torma (1983) and Freeman (1993), coal ash could represent a very important source of pre-mined minerals particularly alumina, which is presently extracted from bauxite resources.

In an attempt to convert Sasol fly ash into value added products thus substituting utilization for disposal, research at Sasol Technology began into the recovery of minerals from the ash. The recovery of alumina from coal ash or clay is based on the application of hydrometallurgical processes such as acid or base leaching, precipitation, solvent extraction and re-crystallization (Phillips and Wills, 1982; Seeley et al., 1981; Bohdan, 1986; Alquacil et al., 1987, Canon et al., 1979; Freeman, 1993; Burnet et al., 1984). Nitric acid and hydrochloric acid leaching processes for the recovery of alumina and other minerals have been developed a long time

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ago, however these processes found little practical application due to the highly corrosive nature of concentrated chloride or nitrate solutions (Freeman, 1993). In addition, hydrochloric acid and nitric acid are expensive lixiviants in terms of acid cost and large evaporative losses make these processes largely uneconomic. Lastly these processes also constitute an environmental hazard.

The traditional Bayer process for the recovery of alumina from Bauxite (low in silica) involves the dissolution of alumina and trace amounts of silica in sodium hydroxide. According to Burnet et al. (1984) and Jackson (1986), pressure leaching of coal ash with alkaline solutions can simultaneously dissolve silica and alumina from ash. Removal of silicon species from aluminate solution prior to the precipitation of $Al(OH)_3$ is a major concern of the Bayer process (Adrian and McCulloch, 1966; Balantseva et al., 1982; Bereza et al., 1972; Kiselev and Platonova, 1981; Shcherban et al., 1979).

In the proposed process, ash was pelletised together with fine coal and a calcium source prior to sintering in order to decompose the mullite phase present in the ash. Due to the low cost and stability of sulphuric acid, this acid has been used as a lixiviant during the recovery of alumina from calcined coal ash pellets prepared from calcium oxide sources. Alumina and $Al_2(SO_4)_3$ produced from the proposed process could be used in the production of aluminium chemicals. The leached pellets are considered as a co-product in this process and could be used as a lightweight aggregate in masonry concrete applications.

2. Experimental

The experimental procedures followed during the leaching of fly ash with sulphuric acid are described below in detail.

2.1. Fly ash

A 200 kg sample of the dry fly ash was collected for the leaching testwork. One kilogram representative sample of fly ash was obtained from the bulk sample using the cone and quartering method (England et al., 2002). Particle size distribution, chemical and mineralogical analyses were conducted on the sample. The particle size distribution (PSD) of the fly ash was derived by physically screening the samples using 75 and 38 μm screens.

2.2. Direct acid leaching of fly ash

A 100 g representative sample of fly ash obtained from a steam plant at Sasol SynFuels, Secunda was added into a 1000 ml Pyrex beaker. A 400 ml of 6.12 $mol\,dm^{-3}$ H_2SO_4 solution was carefully transferred to the Pyrex beaker containing ash. The resulting slurry was subsequently refluxed for 6 h in order to dissolve the aluminium species present in the coal ash. The leached residual ash was separated from the solution by filtration. Distilled water (about 100 ml) was used to remove all of the residual leach liquor that was absorbed by the leached ash. Subsequently, the leach liquor and wash solution were combined to produce the final leach liquor. After drying the washed leached residual ash at 95 °C for 6 h, the masses of the dried leached ash and the final leach liquor were recorded. The dry residual ash as well as the corresponding leach liquor was submitted for XRF (X-ray fluorescence), XRD (X-ray diffraction), Al and Fe analyses respectively.

2.3. Pelletisation

In the proposed process, fly ash was pelletised with fine coal and calcium oxide using a ratio of 5:4:1 to produce pellets with a strong mechanical strength. To the mixture of fly ash, calcium oxide and fine coal (100% < 1 mm size fraction), 10–30% water was added and the mixture pelletised to form 4–7 mm spherical pellets. The pellets were dried in air overnight for easy handling. To determine the effect of calcium oxide on the extraction efficiencies of the metal species during the leaching of sintered pellets, the following pellets were prepared.

The abovementioned mixtures were thoroughly mixed and subsequently pelletised with water to produce pellets for the sintering and leaching steps.

2.4. Sintering of the dry pellets

Approximately 50 g dry pellets of fly ash mixtures as given in Table 1 were placed into a silicon crucible and sintered at 1000–1100 °C for different times (in the range 30–180 min) to produce sintered pellets for the leaching step.

2.5. Leaching of the sintered pellets produced from the mixture of 10% CaO, 40% fine coal and 50% fly ash

A 100 g representative sample of the sintered pellets was leached with sulphuric acid concentrations (3.06

Table 1
The percentage of fly ash, fine coal and quicklime present in the mixtures used during pelletisation

Mixture number	% Ash	% Fine coal	% CaO
1	70	10	20
2	70	20	10
3	60	25	15
4	60	30	10