



# Extraction of alumina from coal fly ash using an acid leach-sinter-acid leach technique



A. Shemi\*, S. Ndlovu, V. Sibanda, L.D. van Dyk

School of Chemical and Metallurgical Engineering, University of the Witwatersrand, P/Bag 3, Wits 2050, 1 Jan Smuts Avenue, Johannesburg, South Africa

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## ABSTRACT

In this paper, a two-step acid leach process for the extraction of aluminium from coal fly ash has been conducted using an acid leach-sinter-acid leach technique. The technique was formulated based on the dissimilar response characteristics of the amorphous and mullite alumina phases present in coal fly ash. The amorphous phase is reactive and soluble in inorganic acids while the mullite phase is refractory, not amenable to inorganic acids, and requires phase transformation before leaching. Sintering of the coal fly ash residue from the first leaching stage was carried out using a mixture of CFA with calcium carbonate. Results presented in this paper show that, sintering of coal fly ash residue from the first leaching stage successfully transformed most of the mullite phase alumina into a leachable plagioclase phase which completely dissolved in sulphuric acid during the second leaching stage. The results further show that the two dissimilar alumina phases can be processed separately by a novel acid leach-sinter-acid leach technique for alumina extraction from coal fly ash as investigated in this work. This study has also revealed that by employing this technique, coal fly ash can be optimally leached. The implications of the findings are that this could provide an alternative economic process for recovering alumina from readily available secondary resources such as coal fly ash.

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## 1. Introduction

The global demand for metals (Halada et al., 2008) and continual build-up of secondary resources such as coal fly ash (CFA) has motivated studies into metal recovery from such materials recently. CFA, formed as a result of coal combustion in coal-fired power plants, typically contains about 26–31% alumina ( $\text{Al}_2\text{O}_3$ ). Attention has been given to research connected to the recovery of alumina from CFA using a variety of alternative hydro and pyrometallurgical routes such as bioleaching (Seidel et al., 2001), alkaline leaching (Murtha and Burnet, 1983; Habashi, 2005), acid leaching (Nayak and Panda, 2009; Matjie et al., 2005; Shcherban et al., 1995; Kelmers et al., 1982) or a combination of processes (Yao et al., 2014). These works are an effort from the scientific community to develop and propose an economically viable process for recovering alumina from large quantities of unexploited CFA.

For the extraction of aluminium from non-bauxitic high silica materials such as CFA, acid leaching is generally preferred because acid routes have the advantage of silica being substantially insoluble in acid (Gabler, 1982; Gilliam et al., 1982; Shcherban et al., 1995; Nayak and Panda, 2009) unlike alkaline routes (Habashi, 2005). Process schemes that involve roasting of CFA with soda followed by water leaching have shown potential for high aluminium extraction (McDowell and Seeley, 1981; Gabler, 1982; Kelmers et al., 1982).

However, in spite of the high extraction efficiencies from salt-soda-sinter processes, the high reagent consumption rate seems to outweigh the advantages. The acidic route includes processes such as bioleaching, nitric acid leaching, hydrochloric acid leaching, sulphuric acid leaching and several variations of the sinter method (Seidel and Zimmels, 1998; Seidel et al., 1999, 2001; Padilla and Sohn, 1985; Abdul Wahab, 2006; Murtha and Burnet, 1983; Murtha, 1983; Yao et al., 2014). Non-sinter methods have been found to be largely uneconomical due to limitations such as slow kinetics, insufficient metal selectivity, low extractions and high lixiviant cost due to high evaporative losses. In more recent work, Yao et al (2014) reviewed several alumina recovery technologies involving sinter and non-sinter methods. In their review they recommended that research in the field of alumina recovery from CFA be enhanced by use of a combination of processes including sinter and acid leach routes.

It is important to note that CFA contains two dissimilar phases, amorphous and mullite, which play a key role in alumina dissolution kinetics (Loubser and Verryn, 2008; Nayak and Panda, 2009; Matjie et al., 2005). The amorphous phase is reactive and soluble in inorganic acids. The mullite phase is refractory, not amenable to inorganic acids and requires pre-treatment and phase transformation into an acid-soluble plagioclase phase prior to leaching. The two dissimilar alumina phases can be processed separately by a novel acid leach-sinter-acid leach technique for alumina extraction from CFA as investigated here. A flow diagram of the proposed acid leach-sinter-acid leach process is presented in Fig. 1. The first acid leach step is targeted at the alumina

\* Corresponding author.

E-mail address: [alanshemi@yahoo.co.uk](mailto:alanshemi@yahoo.co.uk) (A. Shemi).

## Nomenclature

Raw-CFA Coal fly ash as received from the thermal power plant.  
Residue-CFA Coal fly ash solid remains separated by filtration from the leached slurry mixture.  
Sintered residue-CFA Heat-treated residue-CFA at high temperature (1150 °C) using a muffle furnace

in the acid-soluble amorphous phase. The leaching of the amorphous phase in the first leach step exposes the mullite phase, alters the CFA morphology (Nayak and Panda, 2009) thus increasing chances of mullite transformation. The second acid leach step is targeted at the post-sinter acid-soluble alumina phases (plagioclase).

Although the acidic and alkaline single-step leaching of CFA and other alumina bearing materials has been a subject of much study in recent years, information on the separate leaching of the amorphous and mullite alumina phases in CFA is limited. This study is based on the concept that the two dissimilar alumina phases present in CFA when leached separately, using sulphuric acid in an acid leach-sinter-acid leach process, will improve aluminium extraction efficiency from both phases.

## 2. Materials and methods

### 2.1. Coal fly ash

The CFA material used in this study was provided by Kendal Power Plant, a division of Eskom, South Africa. The CFA sample contained 30.52 wt.% alumina. Representative samples used in all experiments were prepared using a riffler splitter (Model: 15A, Eriez Magnetics, South Africa).

The CFA was characterized by investigating the surface morphology, phase mineralogy, particle size and chemical analysis. The particle size analysis was done by physically screening the samples using test sieves (Fritsch, Germany) of various screen sizes within the range of 38 µm and 212 µm. The CFA surface morphology analysis was carried out using a Scanning Electron Microscope (Model: Quanta-400F, FEI, USA). The CFA phase mineralogy analysis was carried out using an X-ray diffractometer (Model: X'Pert, PANalytical, Netherlands) operated with Co-K<sub>α</sub> radiation generated at 40 kV and 50 mA after addition of 20% elemental silicon (Aldrich 99.9%) for quantitative determination of

amorphous compounds and micronizing in a McCrone micronizing mill. The relative phase amounts (weights %) were estimated using the Rietveld method (Autoquan Program). The chemical composition analysis was carried out using Wavelength Dispersive X-ray fluorescence (XRF) spectrometer (Model: Axios, PANalytical, Netherlands) operated with a Rhodium tube excitation source. Filtrates were analyzed for aluminium using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) analyzer (Model: SPECTRO GENESIS, Spectro Analytical Instruments, Germany).

### 2.2. Reagents

All reagents used in this study were of analytical grade. Sulphuric acid (98% w/w) was purchased from Merck (South Africa). Calcium carbonate was purchased from Sigma Aldrich (South Africa). All the reagents were used as received without further purification. Distilled water was used in the experiments.

### 2.3. Coal

Coal used in this study was obtained from Matla Collieries, South Africa. It was crushed and finely ground to 100% passing 212 µm (similar grind as CFA). The coal sample contained 4.32%

moisture, 20.25% volatiles, 68.20% fixed carbon, 7.23% ash and 1.05% Al. The Thermo-gravimetric analysis (TGA) was used to determine the contents of the coal.

### 2.4. Identification of influential parameters and optimization tests

In order to identify and optimize significant factors influencing the aluminium extraction process, leaching using a statistical design of experiments (DOE) and optimization tests using the response surface methodology (RSM) were carried out.

A detailed experimental procedure, the subsequent results obtained and analysis and discussion of the results have been documented in a previous study (Shemi et al., 2014). The optimization experiments showed that an optimum aluminium extraction efficiency of 24.8% could be achieved at an optimal leaching temperature of 82 °C and a leaching time of 10.2 h (Shemi et al., 2014). The identified optimum parameter levels were thus subsequently treated as the leaching conditions for the first and second leaching stages. These values are given in Table 1.

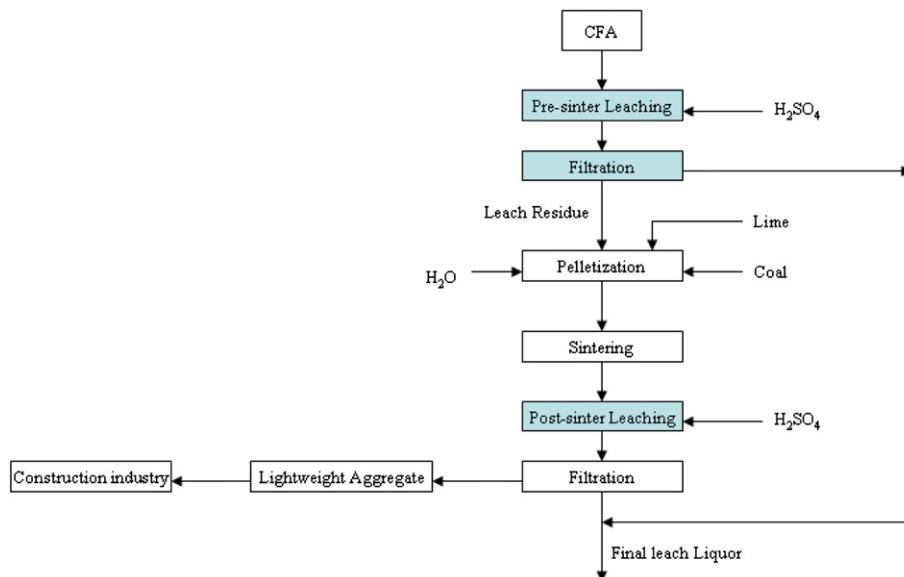


Fig. 1. A flow diagram of the proposed acid leach-sinter-acid leach process for extracting alumina from CFA.

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