



Enrichment of trace elements in bottom ash from coal oxy-combustion: Effect of coal types



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HIGHLIGHTS

- We examined the enrichment of 21 trace elements from two coals.
- 10 had the same enrichment behaviour in air combustion.
- For oxy-combustion, all the 21 trace elements behaved differently.
- This was attributed to the nature of maceral-trace elements association.

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ABSTRACT

In this study, the enrichment of trace elements in two coals under air and oxy-combustion conditions was studied. Twenty-one trace elements were evaluated. The two coal samples had a different concentration for the 21 trace elements, which was due to differences in the maceral composition. Based on the Relative Enrichment (RE) values calculated for the 21 trace elements in this study, 16 of them are non-volatile and the rest (5) are semi-volatile and volatile elements. The non-volatile elements are Li, Cr, V, Mn, Sr, Ba, Cu, Rb, Co, Ni, Ga, Pb, Be, Mo and U. The semi volatile and volatile elements are Ag, Cd, Te, Bi and Ti.

In air combustion, only 9 of the 16 non-volatile trace elements have the same enrichment behaviour in the two coals when the temperature was increased from 900 °C to 1000 °C. The 9 trace elements are Cr, Mn, Cu, Co, Ni, Mo, V, Zn and Pb. In oxy combustion, only 5 of the 16 non-volatile trace elements and they are Cr, Sr, Rb, Ni and Mo. Only 3 of the 16 non-volatile trace elements have the same enrichment behaviour under both air and oxy-combustion conditions. The three elements were Cr, Mn and Mo.

For the 5 semi-volatile and volatile trace elements, only 3 had the same enrichment behaviour in air combustion in both coal samples when the temperature was increased from 900 °C to 1000 °C. The three are Bi, Te and Ti. In oxy-combustion, Bi had the same enrichment behaviour when the temperature was increased from 900 °C to 1000 °C.

The results show that the difference in the enrichment behaviour for both coal samples at different combustion temperatures is more significant under oxy-combustion conditions.

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1. Introduction

Coal is an important energy source in South Africa. It accounts for 74.1% of the primary energy in the country. The rest is supplied from: oil (12%), renewable energy (hydro, biomass, solar and wind) – (7.4%), nuclear (4.2%) and gas (2.3%) [1]. The abundant and relatively cheap coal reserves will almost certainly remain our most important energy resource for the foreseeable future. In order to secure its energy future, whilst minimising the impact on the environment, South Africa will need to investigate methods to reduce

the amount of CO₂ that is produced during coal utilisation. There are three main options for the capture of CO₂ from coal combustion. They are pre-combustion capture, oxy-coal combustion and post combustion capture. Integrated gasification combined cycle (IGCC) is a pre-combustion technology, and it involves the gasification of coal to produce CO and H₂. Steam reforming of these gases enables the separation of CO₂ for capture and storage. In post-combustion capture CO₂ is separated from flue gas using solid minerals, chemical solvents, etc. In oxy-coal combustion, CO₂ is captured as a result of the recycling of the flue gas and the use of pure oxygen instead of air as an oxidant [2]. This results in a concentrated flue gas containing 95% CO₂ which makes it easier to capture. One other advantage of oxy-coal combustion is that it can be retrofitted in existing coal

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fired power stations [3–7]. The technology also produces less NO_x and lower emissions into the atmosphere [8,9].

The oxy-combustion of coals leads to the generation of solid residues such as bottom ashes and they are a potential source of trace element pollution to the environment [10–12]. The level of enrichment of trace elements in the ash residues could have an effect on the design and effective management of pollution controls for the oxy-combustion process. Previous studies have shown that the enrichment of some trace elements under air and oxy-combustion conditions is different [11–13]. This is attributed to the lower volatilisation rate of trace elements as a result of a lower particle combustion temperature in oxy-combustion. The effect of the nature of the coal, such as the maceral-trace element association, on the enrichment of trace elements during oxy combustion has not been well evaluated. Kalkreuth et al. [14] investigated the association of trace elements with macerals. They reported that Ni, As and Hg have a strong affinity for vitrinite macerals, while Cr, Rb and Ge have partial affinity for vitrinite. Inertinite macerals have a high affinity for Sn and Li and partial affinity for Ga, Se, U and Y. The liptinite maceral did not show any association with any trace elements. The trace elements, such as Cr, that show partial affinity to macerals also have affinity for pyrite and clays. The maceral-trace element association could have an effect on the enrichment of the trace elements in the bottom ash. According to Vejehati [15], inertinite rich-coals burn slowly and this can cause the retention of some trace elements in the ash.

This study aims to investigate the effect of maceral-trace elements association on the enrichment of 21 trace elements in two different South African coals under air and oxy-combustion conditions. One of the coal samples is vitrinite-rich and the other is inertinite rich. In South Africa, there are two key coal fields that are very important for power generation. They are the Highveld and the Waterberg coal fields. Highveld coals are mainly inertinite-rich coals while Waterberg coals are mainly vitrinite-rich coals. Presently coals from the Highveld coal fields are mostly used for power generation. It is expected that in future most of the coal for power generation will be obtained from the Waterberg coals fields due to the depletion of coals from the Highveld coal fields. The distribution of trace elements in coals from both coal fields has been reported [16,17]. The concentration of the majority of the trace elements in Waterberg coals is higher than those in Highveld coals [16]. This could lead to different trace element enrichment behaviour in air combustion and oxy combustion process. A previous study showed that the enrichment of trace elements is different in air and oxy-combustion conditions [13]. The study was carried out using a coal sample from Highveld coal field. In all the 21 trace elements studied, the enrichment of most of the trace elements was lower in oxy-combustion than in air combustion at 900 °C; however at 1000 °C the enrichment behaviour was different. The enrichment of some the trace elements were now higher in oxy-combustion than air combustion while some were lower. Similar results were obtained when the oxygen concentration was increased from 21% to 50%. This study aims to investigate if similar enrichment behaviour occurs for Waterberg coals. If so, will it occur in the same trace elements? In this study, a comparative analysis of the effect of temperature and oxygen concentration on the enrichment of 21 trace elements in two South African coals with similar ash contents (37%) but different concentration of trace elements under air and oxy combustion conditions was carried out.

2. Experimental

2.1. Materials

Two coal samples from South Africa were selected for the study. The coal samples have a mean particle size of 250 μm. MM coal

sample from the Highveld coal field is inertinite-rich and GG coal sample from the Waterberg Coal field is vitrinite-rich. Their properties are presented in Table 1. These coals were selected because they are presently used as coal feeds to two power plants in South Africa. MM coal is used in Matla power station and GG coal is used in Matimba power station. Both coal power stations are operated by Eskom, which is the main electricity provider in South Africa.

2.2. Oxy-combustion test

The gas mixtures used were: 21% O₂/79% N₂ for Air-combustion and 21% O₂/79% CO₂ for oxy-combustion. The ash samples were collected from the bottom of the reactor and were analysed. The combustion tests were at 900 °C and 1000 °C in the tubular reactor. The ash residues were collected at the bottom of the reactor. The trace elements in the coal and the ash samples were analysed by Induced Coupled Plasma-Mass Spectrometry (ICP-MS) after they were digested by a mixture of acids (HCl, HNO₃, HClO₄ and HF). The ratio of the mixture was 3:2:1:1. About 0.2 g of coal and ash samples was digested in the acid mixture.

3. Results and discussion

3.1. Trace elements in the feed coal samples

Table 2 represents the elemental concentration in the inertinite-rich MM coal sample from the Highveld coal field and the vitrinite-rich GG coal sample from the Waterberg coal field. The MM coal sample has a higher concentration of Bi, Cr, Cu, Ga,

Table 1
Proximate, ultimate and ash chemistry data for MM coal and GG coal samples.

Sample	MM	GG
<i>Proximate analyses</i>		
Calorific value (MJ/kg) ad	18.11	21.40
Ash (wt.%) ad	37.15	35.70
Moisture (wt.%) ad	5.84	1.90
Volatile matter (wt.%) ad	22.24	28.30
Fixed Carbon (wt.%) ad (calculation)	34.77	35.00
<i>Ultimate analyses (wt.% ad)</i>		
C	42.58	49.20
H	2.19	3.87
N	0.89	0.97
O (Calculation)	7.54	6.79
S	0.69	1.47
<i>Ash analysis</i>		
SiO ₂	58.91	68.60
Al ₂ O ₃	28.76	20.05
Fe ₂ O ₃	2.13	5.59
TiO ₂	1.33	0.72
CaO	2.99	0.71
Na ₂ O	0.35	0.12
K ₂ O	0.76	1.25
SO ₃	1.17	0.57
P ₂ O ₅	0.22	0.08
<i>Macerals analysis</i>		
Vitrinite content %	36	83
Liptinite content %	4	5
Inertinite content %	59	12
Total reactive macerals %	56	96
Mean reflectance %	0.64	0.67
<i>Microlithotype analysis</i>		
Vitrite %	10	24
Liptite %	0	0
Inertite %	14	8
Intermediates %	24	22
Carbominerite %	24	29
Minerite %	28	17

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