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Trace element concentration reduction by beneficiation of Witbank Coalfield no. 4 Seam

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ABSTRACT

South Africa remains the 5th largest producer and joint 4th largest exporter of coal in the world. It is also a major supplier of coal to the European Union. This is significant as the European Union has recently supported the environmental lobby that threatens the combined full scale use of coal in Europe and other first world countries. This promotes the development of clean coal technologies in order to counter the ever increasing number of environmental constraints threatening the export market. One critical development in clean coal technologies is coal beneficiation, which allows the reduction of mineral content. Permian coals from South Africa have characteristically high ash and inertinite contents and therefore require further beneficiation. The no. 4 Seam in the Witbank Coalfield is no exception, and it can be described as containing higher inertinite content and minerals compared to the no. 2 Seam in the same Coalfield. Beneficiation, therefore, is an important requirement for improving the quality of the coal, especially for export purposes.

With the increase in environmental legislation and the drive towards “clean coal” a concern is raised in terms of the performance and marketability of export coal produced from the no. 4 Seam in the Witbank Coalfield. This seam is economically significant and remains an important source of export steam coal.

Due to the nature and composition of the no. 4 Seam, coal beneficiation is essential to reduce the mineral content to be in line with export quality specification levels. This paper focuses on the association of the trace elements within the seam with the organic and inorganic components and possible methods of trace element reduction by removal using coal beneficiation techniques. The techniques investigated include reduction by dense medium beneficiation and flotation. The associated mineral reducibility investigations included mineralogical distribution and liberation analysis. By studying the relationship between coal mineralogy, petrography and trace element distribution, methods of optimum trace element reduction established. Furthermore, the distribution of mineralogical and organic components of sulphur in the Witbank Coalfield No. 4 seam was found to bear unique relationships with trace elements of special concern. By assessing the distribution and occurrence of trace element concentrations during washability and floatability tests, data was produced which could now be used in the promotion of saleable coal products from no. 4 seam in the Witbank Coalfield.

1. Introduction

According to the latest report by the Department of Minerals and Energy [1], the Highveld and Witbank coalfields account for approximately 66% of the remaining coal reserves in South Africa. Historically, the no. 2 Seam in the Witbank Coalfield was the main target for exploitation, but its reserves have declined significantly over the last 2 decades, leading to the no. 4 Seam becoming increasingly the main source of export products. The no. 4 Seam in situ coal is known to be higher in ash and inertinite, or “dirty” as described by Lurie (2000), when compared, for example, with the no. 2 Seam. Therefore, beneficiation of the 4 seam is imperative and its upgrade to yield an export grade product has been successfully achieved over the years, through incremental improvements in techniques and equipment. The export product is mainly used as solid fuel for pulverised fuel combustion in utility boilers. With the advent of new and improved technologies and expanding opportunities for exporting to foreign markets, and with requirements from recent environmental legislation, the availability of trace element washability and floatability data could play a major role in promoting the utilization of coal products from no. 4 Seam in the Witbank Coalfield.

The risk associated with trace element emissions lies both in health risks and in financial cost implications when seeking to remain within legislative measures. Certain trace elements such as HAP (Hazardous Air Pollutants) can have substantial implications, and according to James and Hower [2] the US Clean Air Act Amendments of 1990 specifically identified As, Be, Cd, Cr, Co, Hg, Mn, Ni, Pb, Sb, Se, and U as potential HAP's. These trace elements are known to be toxic and have adverse effects on humans, plants and animals as identified by Dale [3].

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There is limited data available on the matter of trace elements in South African coals The trace elements Hg, Zr, Zn, Cd, As, Pb, Mn, and Mo are concentrated in the mineral matter in the coal [5]. For this reason, beneficiation by density separation should be able to assist in reducing not only the mineral content of a coal, but also the trace elements associated with such minerals. Legislative measures in most developed countries are increasingly strict and South African coal exporting companies are interested in contributing to finding solutions to reducing or eliminating dangerous emissions. Cairncross et al. [4] has reported that the mercury content in South African coals is, for instance, higher than the global average, but subsequent work by Ruch et al. [5] and Wang et al. [6] it seems as if coal beneficiation can reduce the mercury content significantly by the removal of the related minerals.

Most significant in the study of trace elements, is the association of these elements with either the epigenetic or syngenetic minerals. The latter form is typically finely disseminated in the coal matrix, therefore extremely difficult to fully separate from its organic substrate. Given that Gondwana coals particularly those in South Africa, India and Brazil characteristically contain high quantities of inherent minerals and near gravity material, coal producers often find themselves constrained in attempting to achieve the desired product through conventional beneficiation. In contrast, epigenetic or extraneous minerals are successfully liberated from the coal matrix by a relatively straightforward separation process.

Published research on trace elements in coal and more especially in South Africa has not been extensive because up until recently with the advent of the current strict environmental policies they have been of little more than academic interest. Trace elements in coal have been investigated by various mining companies, but this info is propriety and not available for review. Furthermore because the trace elements occur in such small amounts their determination is both costly and difficult.

The concentrations of most of the trace elements in coal are lower than the average concentration of the trace elements in the earth's crust, although there are exceptions. Previous work done by Cairncross et al. [4] on a variety of South African coals and Wagner and Hlatshwayo [7] specifically on the Highveld coals gave a good indication of the likely concentrations of the trace elements in South African coals. What is quite significant in those South African coals is that in situ they have higher ash and hence mineral contents on average than our counterparts in the Northern hemisphere. Despite this South African and other Permian coals of the southern hemisphere also contain lower concentrations of sulphides, halogens, and trace elements relative to their northern hemisphere Carboniferous coals [7].

The trace element concentrations in coal mineral matter (extraneous, epigenetic and inherent) vary to a greater extent than the trace elements found in the organic fractions where the concentration variation is much narrower (Gluskoter, 1974).

Due to the variations in mineral content complications exist where the concentrations of trace elements can vary for coal from the same seam classification. In the experience of Valkovic [8], to get the best repeatable results, the bottom and top of the seams have to be sampled since higher trace element concentrations could be found in these areas. He also found that the lowest concentrations also gave the highest variations as expected. To evaluate a coal reserve quantitatively with confidence a vast majority of the borehole samples have to be taken and analysed. In evaluating the washability characteristics of the trace elements a borehole sample will not suffice; however it will give a better indication of the depositional aspects of the seam which can be related to the mineralogical occurrences of the particular seam.

The leading work done by Finkelman et al. on the occurrence of trace elements in coal was paramount in the partitioning investigations undertaken. Mineral identification and correlation to minerals is discussed in great detail. Most of the work done by Finkelman is related to SEM (Scanning Electron Microscopy) mineral investigations. The coal in South Africa is very unique and the SEM mineral investigation is critical in evaluating the liberation of the minerals and their occurrence. In relation to beneficiation this plays a major role and will indicate the capacity for trace element reduction with reference to the characteristics of the associated minerals.

Partitioning of trace elements of a Chinese coal at different size fractions from beneficiation was done by Wang et al. [6]. The research by Wang et al. [6] did not report on extensive mineralogical analysis and float-sinks analysis.

The work done in the United States has not been performed on South African coals. With the specialised characteristics of the mineral and maceral content in South African coal, these investigations are critical, Gondwana coal compared to Carboniferous coal specifically have distinct differences. In essence the comparison between the washability index of the US coals and coals from South Africa indicates that a specialised approach has to be implemented.

2. Experimental

2.1. Sampling

A series of no. 4 Seam run of mine (ROM) coal were collected. These samples were taken over a period of 24 h with the aid of an automated mechanic sampler. The samples were taken in accordance to the SANS ISO 13909-2 Standard [10].

Slurry samples of flotation plant feed; product and tailings were also collected by means of mechanical samplers. These samples were taken in accordance to SABS ISO 20904 [9]. The flotation plant feed slurry samples were used to do bench scale froth flotation tests.

2.2. Sample preparation

The ROM samples were suitably prepared by homogenizing several times prior to any reduction in mass or in nominal top size, then cone and quartered to produce a single set of samples for washability analysis. The samples were transported to Anglo Coal Central Laboratories (ACCL) within 2 h where the remaining sample preparation and analyses took place. When stored, the samples were kept in a controlled environment indoors.

2.3. Float and sink washability analysis

Float and sink densimetric separation was carried out with the use of Zinc Chloride (ZnCl) as dense medium [11]. Each resulting density fraction and the sinks were suitably prepared for all planned laboratory analyses. Proximate analysis and calorific value analysis was done on each density fraction.

2.4. Froth flotation – floatability analysis

For the bench scale tests a conventional Denver froth flotation cell was used. A combination of 200 g of no. 4 Seam flotation plant feed ultra-fines at −200 μm and 3 l of water were preconditioned without air and reagent. The reagents used in the test work were a combination of 80% collector (mainly kerosene) and 20% frother (glycol and emulsifiers), 0.3 ml reagent was dosed into the slurry and further conditioning time of 30 s was allowed. Upon the addition of air, a further 2.5 min was allowed for flotation with scraping done every 20 s. Proximate and calorific value analyses were carried on each of the flotation fractions feed, tailings and product.

2.5. Trace element analysis

Trace element analysis, and forms of sulphur (organic, pyritic and sulphate) were outsourced to UIS (Unique Innovative Scientific) analytical. Trace element analysis was conducted at UIS analytical