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A new apparatus to establish the spontaneous combustion propensity of coals and coal-shales

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ABSTRACT

Coal and coal-shale both tend to undergo spontaneous combustion under favourable atmospheric conditions. The Wits-Ehac index has been developed in South Africa since the late 1980's to test the spontaneous combustion liability of coal. However, in some cases, the Wits-Ehac index fails to produce tangible results when testing coal-shales. To overcome this problem, a new apparatus has been developed to test carbonaceous materials such as coal and coal-shale under chemical reactions with oxygen and an index has been obtained. This index is called the Wits-CT index. The equipment emulates the influence of oxygen adsorption on carbonaceous material for a period of 24 h without a heating system. The Wits-CT index uses the total carbon content of the sample and the temperature variations obtained from the samples during reaction with oxygen to predict the spontaneous combustion liability. Eighteen samples have been analyzed using both indices and the results are in-line. It was found that coals and coal-shales with higher values of the Wits-CT index are more liable to spontaneous combustion. Further research on different coal-shales is underway in order to establish an extensive database for coal and coal-shales, together with known incidences of self-heating.

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1. Introduction

The occurrence of spontaneous combustion is one of the major challenges faced by the South African coal mining sector. The physical and chemical reactions between oxygen and external active structures of coal particles which releases heat are behind the event of spontaneous combustion. These incidents occur naturally due to the chemical reactions and oxidation of coal and coal-shales. The spontaneous combustion characteristics of coal may be influenced by the natural convection within a coal seam, spoil heaps and other mining piles [1]. Sasaki and Sugai studied the effects of chemical and oxidation reactions to measure the characteristics of temperature distribution within a stockpile [2]. Premature combustion temperatures at different points in a coal reaction vessel were reported by Gray and Lee [3].

The spontaneous heating of coal arises under definite atmospheric conditions. Coal oxidation occurs in an environment where there is sufficient oxygen. The oxidation rate of coal cannot be easily detected due to the reaction being very slow. In an open cast mining, the ingress of oxygen in the air into discontinuities and exposure of the highwall for long periods are among the factors affecting spontaneous heating. In underground coal mines, the combination of an insufficient ventilation system and self-heating areas of coal can cause spontaneous combustion. It is known that coal, roof shales, mining piles and other carbonaceous materials become self-heated and liberate heat naturally when subjected to atmospheric conditions for a long time as shown in Figs. 1 and 2. The heat generated may become faster than the heat dissipated to the surrounding.

The experience of spontaneous combustion has approached into a phase that makes practical illustrations feasible as a result of the re-established awareness of self-heating of coal and coal-shales in coal mines. Past researcher's efforts to measure the liability of coal stockpiles were primarily based on laboratory tests of one or more of the coal characteristics associated with the self-heating behavior. A limited number of medium-large scale tests on coal have been carried out in the past. However, such tests have not been conducted frequently due to the high cost and long period of time required and the difficulties in interpretation of the results.

Experimental investigations on spontaneous combustion of bulk coal samples have been carried out under a medium-large scale test with a heating system used to initiate the self-heating process [4–10]. Studies on spontaneous combustion of coal

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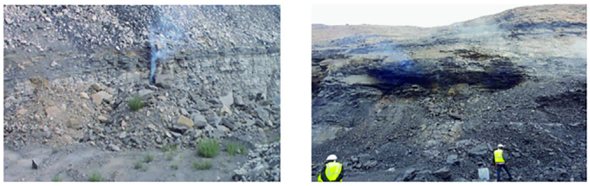

(a) Self-heating of inseam shale at Goedgevonden

(b) Burning coal seam at Khwezela Mine(Bokgoni Pit), Witbank, South Africa

Fig. 1. Self-heating of inseam shale and burning coal seam in Witbank, South Africa.

Fig. 2. Burning spoil heaps at Tweefointein Mine, Witbank, South Africa.

stockpiles under the influence of atmospheric conditions have been reported [11–15]. However, no previous studies reported experimental methodologies to emulate the effects of atmospheric conditions on coal spontaneous combustion in the laboratory without an applied heating system. An acceptable standard widely used in South Africa to predict the propensity of coal to spontaneous combustion, known as the Wits-Ehac index has been in existence and used for more than 30 years [16–18]. The test involved the use of a relatively small amount of pulverized, dry samples to determine liability of coal to spontaneous combustion. The performed laboratory small-scale studies carried out in degrees and the influence of limiting factors can only be evaluated only under the available experimental conditions, unlike the medium-large scale test that considered the self-heating of a substantial coal mass under atmospheric conditions. Spontaneous combustion is dependent on the composition of the material, air temperature, sample temperature and mine environment. It has been indicated that the ignition temperature tests are at high temperatures where an external source of heat has been applied at the surface of the coal particles [16,17]. The effects of oxygen, moisture and temperature variations within a coal mass under sluggish airflow conditions, i.e., the most likely scenario at a mine, cannot be integrated into the small-scale test.

The self-heating characteristics of some coal-shales in this study could not be determined by the Wits-Ehac index because of their low reactivity under the available experimental conditions. This motivated the need to develop a device that can measure the self-heating of coal, coal-shales and other carbonaceous materials under the influence of oxygen, which can produce similar results compared to the existing Wits-Ehac index. The use of realistic medium experimental scale tests that imitate the influence of atmospheric conditions on the various coal, coal-shale types to predict self-heating is important. The principal argument against laboratory testing in predicting the tendency of coal to spontaneous heating is that the process is unlike the natural conditions under which self-heat takes place. On the basis of these criteria, a medium scale laboratory apparatus has been developed to model and predict the occurrence of spontaneous combustion in coal mines. The model considers number of parameters such as airflow rate and temperature variation. The need for a reliable method to capture the large volume of data used to predict the occurrence of spontaneous combustion motivates this new apparatus. This current work presents the results of self-heating tests carried out on highly reactive coal and coal-shales in South African coal mines using the Wits-Ehac test and also the new apparatus (Wits-CT). Eighteen carbonaceous materials were tested with the new apparatus. The method is reliable, accurate and provides the required information on the effects of oxygen on self-heating of coals and coal-shales under field conditions.

2. Materials and methods

2.1. Sample collection

The coals and coal-shales used for this research were collected from two different coal mines in the eMalahleni area of South Africa and kept in airtight bags to avoid oxidation. Twenty representative in situ coal and coal-shales samples were obtained from the affected areas (highwalls and overburden shales). The samples subjected to the Wits-Ehac tests and tests in the newly developed apparatus.

2.2. Sample preparation and characterisation

The samples were reduced using a crusher and ball mill to suitable specify sizes as required for each test. The determinations of the moisture, ash, volatile matter and fixed carbon contents were carried out according to the American Society for Testing and Material (ASTM) standards [19–21]. Fixed carbon was obtained by subtracting the sum of the percentage of volatile matter, ash and moisture from 100. The carbon content were determined using a LECO TruSpec CHNS analyser (Fig. 3) after calibration with sulfamethazine based on the International Standard Organisation Standards [22]. The results were given in weight percent of air-dried (%, by weight, ad). The results for proximate and total carbon content and spontaneous combustion tests carried out on the coal and coal-shale samples are given in Tables 1 and 2, respectively.

2.3. Wits-Ehac test

The Wits-Ehac tests at the School of Mining, University of the Witwatersrand is a small-scale test in which freshly pulverized (<212 μm) and dried coal samples of 20–25 g in weight is used. The Wits-Ehac index has been developed in South Africa in the late

Fig. 3. Leco TruSpec CHNS analyser.

Table 1
Risk rating classification for coal, coal-shales and other carbonaceous materials to spontaneous combustion.

Wits-CT Index	Risk rating
<2.5	Less reactive
2.5–5	Moderately reactive
5–7.5	Reactive
>7.5	Highly reactive

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