An investigation into the moisture absorption properties of thermally dried South African fine coal

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Synopsis

The aim of this research was to study the absorption characteristics of thermally dried fine coal from South African collieries. After milling to –150 µm and pressure filtration, the samples were subjected to either air drying or thermal drying at 150°C. The samples were then put into a climate box at 28°C and at three different relative humidity levels, namely 30, 60 and 94 per cent. It was found that the equilibrium moisture content of thermally dried coal at a specific relative humidity was lower than that of air dried coal. The relationship between the equilibrium moisture content and relative humidity is described by $1 - RH = \exp(-KTM_e^n)$. There was no relationship between the volatile matter content and equilibrium moisture content, but there was an increase in the equilibrium moisture content of the coal with an increase in mineral content. The moisture uptake rate increased with an increase in temperature and a decrease in particle size. A model is discussed that fitted the experimental data and gave a good prediction for changes in the conditions. There was no evidence of greater moisture absorption by thermally dried coal.

Keywords: Fine coal, thermal drying, drainage, South Africa, drying.

Introduction

Water, while being the workhorse of mineral processing, is also one of the most undesirable components in the final product. Not only does the high moisture content have an adverse influence on meeting market specifications, it can also be a nuisance in handling and add on to the expensive freight cost. Up to 50% of the moisture in a coal plant product can be present in the ultrafine fraction (-75 µm), even after being filtered. There are several ways to consider reducing the moisture content of the product like reducing the amount of fines, increasing the efficiency of the dewatering device, changing the surface chemistry of the fine coal or thermal drying[1].

Although a number of dewatering and drying technologies exist and are being practised commercially, the general perception exists in the South African coal industry that thermal drying is impractical, unsafe and/or uneconomical. The fine coal that is generated during the coal mining and processing operations has traditionally been pumped as slimes to co-disposal discard dumps. This fine coal constitutes about 10–15 per cent of annual run of mine tonnage[2]. Economically viable techniques to dewater the fine coal may result in this coal being included in the saleable fraction. This will turn a liability into an asset and could improve the income earned from coal sales by the South African industry substantially.

Background

According to Rong[3] three types of moisture can be distinguished in coal, namely:

- Surface or free water which lies on the surface of the coal particle
- Inherent or capillary water which is absorbed into the capillary structure of individual coal particles, and
- Chemical water which is chemically bound with the coal or tailings.

While the surface moisture of a solid depends on the shape and the extent of the external surface, coal being a porous material contains moisture in its sub-microscopic pores. Water micro-capillaries (mostly intra-particle) has been quantified by nuclear magnetic resonance and gravimetric sorption techniques and shown to be in the range of 3–8 per cent for bituminous coals. It is coal dependent and this moisture cannot be removed by mechanical means[4]. This is supported by Figure 1 which shows effective dewatering techniques for coal.

The relationship between relative humidity (RH) and equilibrium moisture content (M_e) for both the thermally dried and air dried samples are described by:

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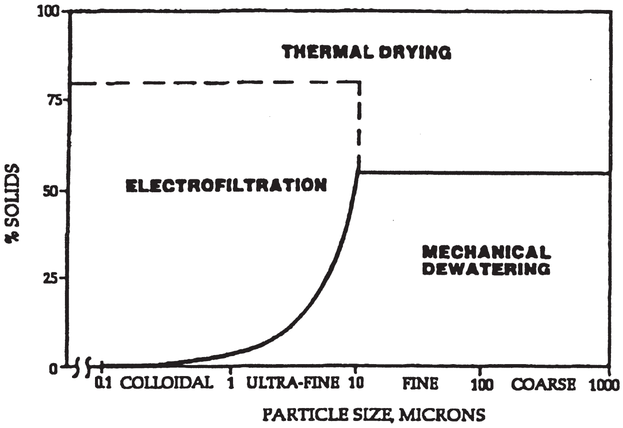

Figure 1—Effective dewatering techniques in relation to particle size[4]

$$1 - RH = \exp(-KTM_e)^n \quad [1]$$

with T as temperature (°K), K and n as material specific factors. This relationship corresponds with part of a model as described by Shadle[5].

Experimental setup

Coal from four different South African collieries was used for the absorption experiments. Table I shows the proximate analysis for the different coals.

The coal samples were milled in a ceramic ball mill and the -150 μm fraction was removed by wet screening. The samples were dewatered in a pressure filter to form a filter cake of about 0.5 cm thick. The filter cake was either thermally dried in a laboratory oven at 150°C or air dried at atmospheric conditions before being put into the climate box. A control sample also went directly from the filter to the climate box.

For the constant humidity experiments a climate box was used. A loadcell measured the mass of the sample in the climate box. The temperature and relative humidity were computer controlled and the mass recorded every second. Figure 2 is a diagram of the experimental set-up.

The temperature in the climate box was 28°C. Coal from each colliery was kept at 28, 60 and 94 per cent relative humidity respectively. The mass increase of the sample was recorded over time and used to calculate the moisture content of the sample.

Table I

Proximate analysis results for coal samples used in experiments

Colliery	Bank	Sigma	Tavistock	Zululand Anthracite
Moisture (%)	2.6	7	3.3	2.1
Ash (%)	22	28.8	19.9	18.2
Volatile matter	22.7	21.5	24.9	8.7
Fixed carbon	52.7	42.7	51.9	71
Total sulphur	0.54	0.38	0.89	0.89

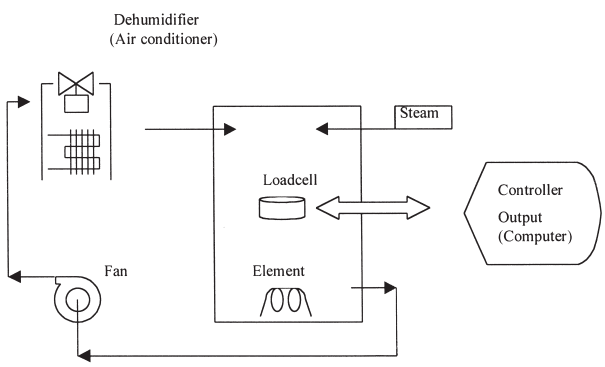

Figure 2—Diagram of experimental set-up (climate box)

Results

Figure 3 shows the experimental data for coal from Tavistock compared to the theoretical values as described by Equation [1].

Figure 4 shows the different moisture uptake curves for coal from Bank Colliery at different relative humidities. This behaviour was expected and mentioned by Suuberg and Devi[6]. Due to the higher humidity, the partial pressure of the water vapour was higher and more moisture could be absorbed. The same trend was displayed by the other coal samples.

An increase in temperature increases the moisture uptake rate but did not increase the equilibrium moisture content as can be seen from Figure 5.

There was a small difference in the equilibrium moisture content between thermally dried and air dried coal for all the samples. At the same relative humidity, the thermally dried coal displayed a lower equilibrium moisture content than the air dried samples. This was most evident for Sigma coals as shown in Figure 6. This may be due to a collapse of the micropores in the coal during thermal drying[7,8].

No relationship could be observed between the volatile matter content and equilibrium moisture content but with an increase in mineral matter the equilibrium moisture increased as well. A model described by Shadle fitted the experimental data fairly well (Figure 7). It also predicted the change in moisture uptake rate with an increase in temperature.

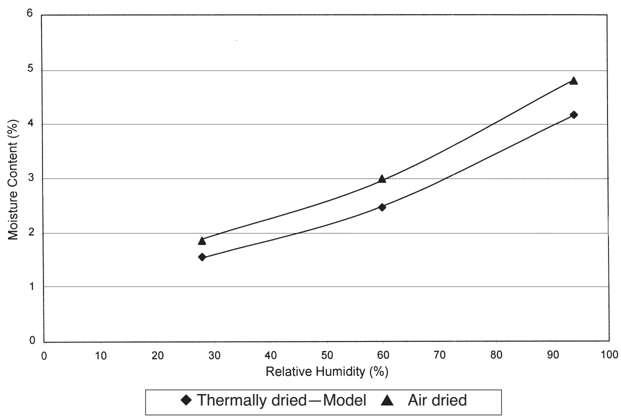

Figure 3—Comparison between experimental and theoretical values for coal from Tavistock

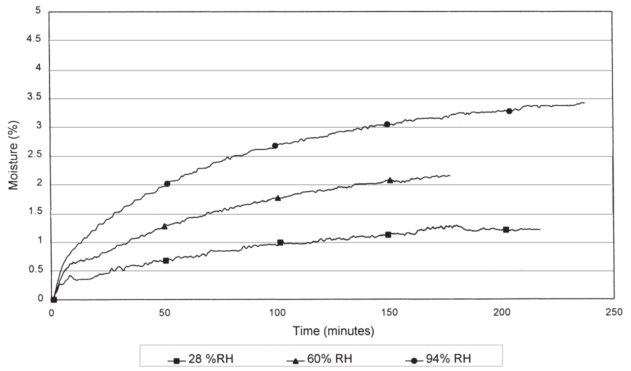

Figure 4—Moisture uptake rates for thermally dried coal from Bank Colliery at different relative humidities

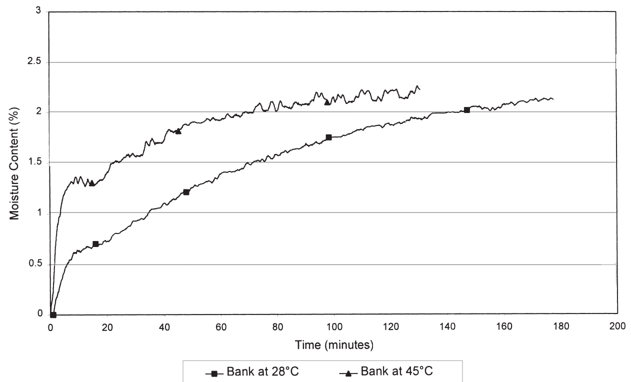

Figure 5—Influence of temperature on moisture uptake rate for coal from Bank Colliery at 94 per cent relative humidity

Conclusions

The relationship between equilibrium moisture content and relative humidity for the coal studied can be described by Equation [1]. This relationship holds for both thermally dried and air dried coal. Thermally dried coal has a lower equilibrium moisture content than air dried coal at the same relative humidity. This was observed for all the coal samples and it may be due to a collapse in the micropore structure of the coal during drying.

Coal from Sigma has a much higher equilibrium moisture content than the other coals. This may be due to its higher mineral contents. There seemed to be no correlation between the volatile content and the equilibrium moisture content. Literature suggests that mineral matter acts as a hydrophilic site and that water readily absorbs into the mineral matter's pores as well. The model described by Shadle fits the experimental data fairly good and may be used to predict the behaviour of the coal during moisture uptake.

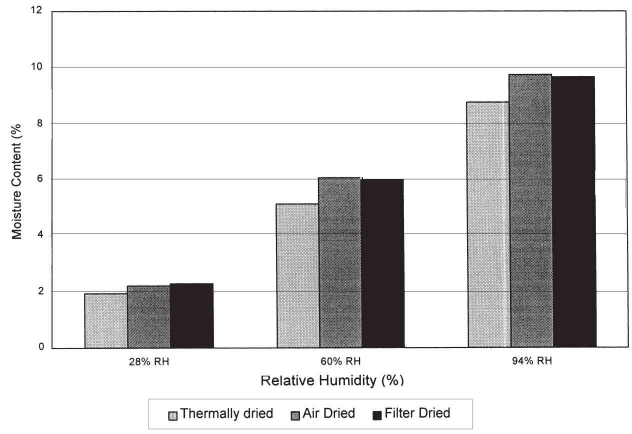

Figure 6—Comparison between different drying methods for Sigma coals

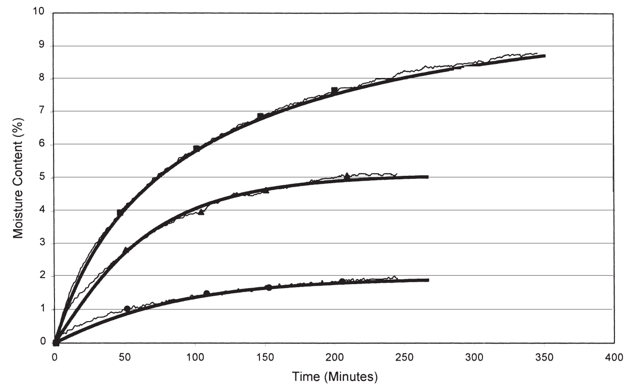

Figure 7—Model compared to experimental data for thermally dried Sigma coal

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