Coal product moisture control using stockpiles

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Abstract

The moisture content of product coal is a major factor influencing the efficiency of downstream coal utilization processes. Product stockpiles are often used as a control measure to regulate the moisture content of the coal by gravity drainage and evaporation. An understanding of the mechanisms of water migration and retention in coal stockpiles are required to optimise the management of these stockpiles. Apart from the process water carried over into the product after beneficiation, additional water due to rainfall can add to the total moisture contained in a stockpile. When the rain falls on the stockpile, it either runs off the surface or infiltrates the stockpile. The infiltrated water can evaporate from the surface (down to a certain depth), drain through a saturated toe, or remain within the stockpile to add to the total final moisture content. To study these mechanisms, laboratory scale experiments were designed. A drainage column was used to simulate the percolation of water in a stockpile, and the data verified that particle size, especially the -0.5 mm fraction, had the most significant influence on both the drainage rate and the water retained in the bed. The ratio between run-off water and infiltration water during rainstorms were also quantified, and it was shown that compaction of the bed had a major influence on infiltration. Evaporation from a coal bed surface was tested by measuring the mass loss from coal beds exposed to the atmosphere, while measuring weather conditions like temperature, relative humidity and wind speed. The average evaporation loss was about 0.8 L per m^2 per day.

Key words: coal, stockpile, moisture, moisture control, rainfall, evaporation, drainage, percolation

Introduction

Stockpiles are often used for product quality control, for example to reduce the total moisture content of a product. Because of more stringent quality requirements, an improvement in stockpile management is required (Keleher et al., 1998). Excess moisture in coal results in increased transportation costs, handling problems and a decreased calorific value (Rong, 1997; Leader et al., 1997). The need for moisture control has an influence on the method of the construction, maintenance and reclamation of stockpiles (Boyapati & Oates, 1994).

The free moisture content of a stockpile is increased by water carried over from the wet processing of the coal and by rainfall. During these events, water can either run off the surface of the stockpile, or it may ingress into the pile. On the other hand, the moisture content in a stockpile is reduced by natural gravity drainage or by evaporation from the surface (Brookman *et al*., 1981; Eckersley, 1999). To understand these processes, the phenomena of rainwater run-off versus ingress, gravity drainage and evaporation must be separately considered.

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Table 1: Proximate and CV analysis

	Value	Standard
% Inherent moisture content (air-dried)	2.5	ISO 11722: 1999
% Ash content (air-dried)	35.6	ISO 1171: 2010
% Volatile matter (air-dried)	19.0	ISO 562: 2010
% Fixed carbon (air-dried)	42.9	
Calorific value (MJ/kg) (air-dried)	19.24	ISO 1928: 2009

The relation between rainwater run-off and ingress depends on the paticle size, the rainfall intensity and duration, the stockpile slope and the degree of compaction of the stockpile surface (Curran *et al*., 2002; Wels *et al*., 2015). The proportion of rainfall that infiltrates a stockpile also depends on the infiltration capacity of the coal sample (Brookman *et al*., 1981). As the stockpile becomes more saturated, a steady final infiltration rate is reached, and any higher rainfall intensity will result in an increased amount of run-off water (Huang *et al*., 2012).

The process of gravity drainage is influenced by factors such as particle size (De Korte & Mangena, 2004), stockpile height (Curran *et al*., 2002), degree of compaction, and coal type (Eckersley, 1999). The bottom layer in the stockpile becomes saturated, allowing excess water to flow in the lower permeability outer "shell" to eventually seep through the stockpile toe. This seepage starts between 1 and 3 days following the construction of the stockpile, and it may continue for a number of weeks (Eckersley, 1999). It was found that coal with less than 10% fines (generally defined as smaller than 0.5 mm) is usually free draining. With fine coal, the voids between the particles are sufficiently small that they can act as capillary cavities that become filled with water. A study by the Fuel Research Institute of South Africa in 1964 found that the removal of the -0.5 mm particles had the most significant impact on the static drainage characteristics of a column of coal.

A number of studies have been done on evaporation from flat water surfaces (Finch & Calver, 2008). Many factors influence the rate of evaporation, especially those affecting the vapour pressure in the air, since evaporation is due to the difference in the vapour pressure at the surface of the evaporative medium and in the bulk atmosphere (CSEM-UAE, 2010; Headrick, 1967). The most important influences are wind speed, humidity, temperature and solar radiation (The University of Arizona, 2014; Headrick, 1967). When considering evaporation rates from moist coal particles rather than water surfaces, major differences can be expected, since attractive forces between the coal surface and the water tend to reduce evaporation. The fact that the coal particles are dark, and have uneven surfaces, can also affect the evaporation rate (TRC Environmental Consultants, 1983). It was also reported that evaporation rate from a bed of smaller particles is higher than from larger particles (CRA Limited, 2010).

Experimental

Coal from the #4 seam of the Witbank coalfield in South Africa was used for all experiments. The proximate analysis is given in Table 1. To investigate the effect that particle size may have on the different mechanisms, three size classes of coal were considered: a coarser fraction where the 6.7 mm was screened out, a finer fraction consisting of only 6.7 mm material, and the un-sized sample covering the entire range of sizes. The top size was 50 mm.

For the drainage experiments, a 2 m long x 0.385 m diameter column was constructed (figure 1a). The column was fitted with a mesh at the bottom supporting the packed coal bed inside. A distributer enabling an even distribution of feed water was fitted to the top of the column. The drained water was collected at the bottom and continuously weighed by a scale connected to a data logger. The column was equipped with four sampling ports on the side of the column, where local samples could be taken for size and

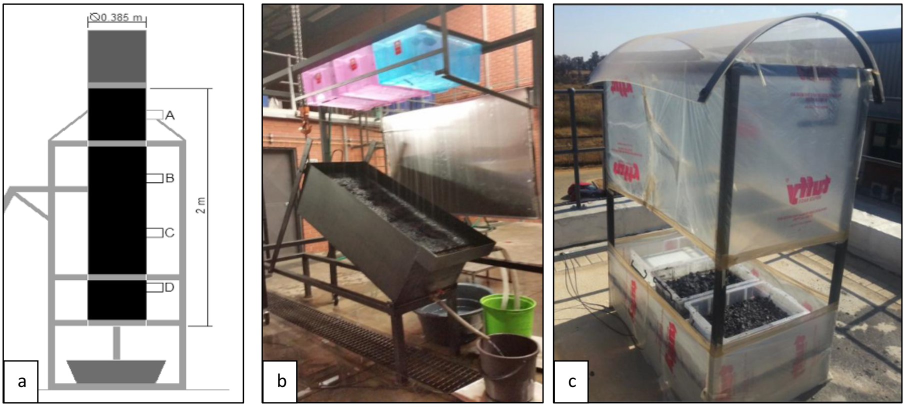

Figure 1: Equipment to determine the behavior of moisture in a coal stockpile: a) drainage column to determine drainage rates, b) inclined box to determine run-off versus infiltration, and c) open vessel evaporation determination.

moisture analysis. A measured amount of water was added in one step and allowed to drain through the column for a number of days, while the drained water mass was continually measured. Samples were taken through the ports at predetermined intervals, usually 2 to 3 days.

The run-off versus infiltration experimental setup consisted of a 1.24 m x 0.50 m x 0.55 m rectangular steel box filled to the brim with coal (figure 1b). The entire box could be tilted to simulate different stockpile angles. Rainfall could be simulated by adding water at controlled flow rates from overhead water reservoirs. This water either flowed across the inclined surface or infiltrated the bed. The run-off water overflowed via an overflow gutter, while the permeated water drained through a mesh-covered outlet at the bottom lower edge of the box. Both the run-off and permeated water was collected in containers that were continuously weighed. Coal loads with different particle size distributions, as well as at different degrees of compaction, were investigated.

Evaporation from a coal bed surface was measured by recording the mass loss from open containers exposed to the atmosphere (figure 1c), while simultaneously measuring weather conditions such a temperature, relative humidity and wind speed. Coal samples with known mass and particle size distributions were loaded into the containers to a depth of about 250 mm and saturated with water. The excess water was drained off, and a sample was taken to define the starting point moisture content. One container was filled with water only to act as a control. The experiment was allowed to run for two weeks while the mass and weather data was recorded, and the evaporation rates were determined from the mass loss information. After completion of the run, a final sample was taken for total and inherent moisture analysis. The actual moisture content over time was back calculated.

Results and discussion

An extensive set of results was generated during this project, of which only selected highlights are presented here.

From the drainage column test work, the drainage rate through beds of different particle sizes factor was firstly considered. Figure 2 illustrates how much of the added water was retained in the bed over time, and how the drainage rate through the coal bed was influenced by the presence of 6.7 mm material: the

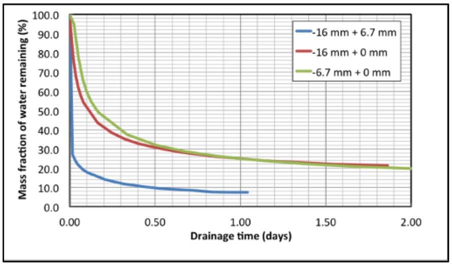

Figure 2: Drainage curves for differently sized coal samples obtained in a column over 2 days.

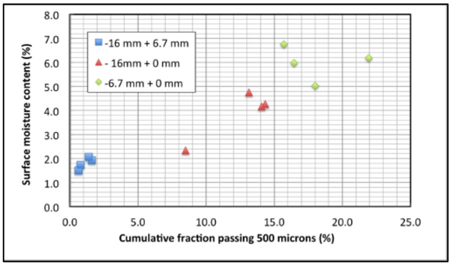

Figure 3: The relationship between the 500 µm content and surface moisture content at various positions in the column.

drainage rate was much faster for the cases where the 6.7 mm material was removed. There was no significant difference between beds containing this finer fraction, or whether it contained a full particle size distribution that included the fines. Thus any particle size above 6.7 mm did not influence the drainage rates significantly. Secondly, evidence of the importance of the ultrafine (-500 µm) material on the moisture retention is shown in figure 3, where the moisture content and ultra-fines sampled at the various sample ports are shown. This confirmed the finding in literature (Eckersley, 1999). This relationship is independent of the distribution of coarser particle sizes.

Coal with a size distribution of -19 mm + 0 mm was loaded into the run-off test box and was subjected to low, medium and high rainfall intensities. The ratio between run-off water and infiltration water was determined for a number of angles. Figure 4 confirms the concept of the infiltration capacity described by Brookman *et al*. (1981), where at a low slope angle any water addition higher than about 0.3 – 0.35 kg/s simply ran over the inclined surface. This value decreased for higher slope angles, while surprisingly the water infiltration deceased slightly with higher rainfall. This may be due to a higher kinetic energy of the falling drops that caused the water flow to deflect down the surface. The marked effect of bed compaction is illustrated by figure 5, where the infiltration capacity could be reduced from 0.38 kg/s to 0.12 kg/s by increased compaction, and even lower at high slope angles.

Figure 6 shows a typical mass loss trace for a period of 9 days for a -13 mm coal sample exposed to the atmosphere, compared to that of an open water surface. The first feature is the cyclical response of the coal mass illustrating the capacity of the coal to lose and re-adsorb moisture from the atmosphere. The

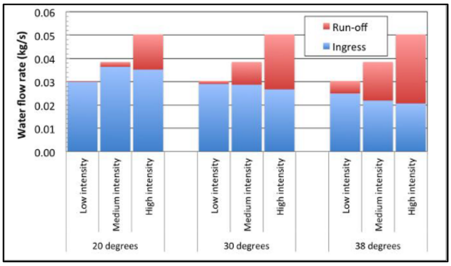

Figure 4: The run-off and infiltration rates for different rain flow rates at varying slope angles.

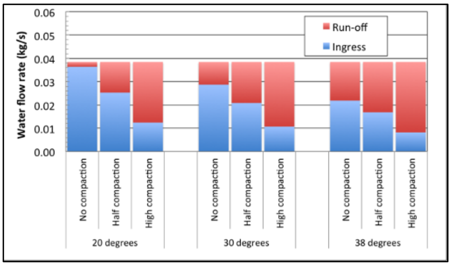

Figure 5: The run-off and infiltration rates for different degrees of compaction at varying slope angles.

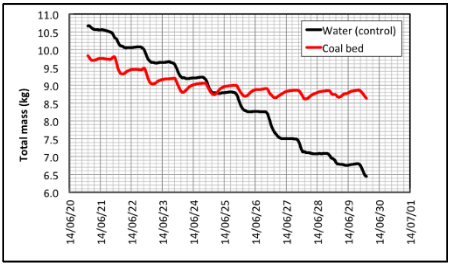

Figure 6: Mass loss of water due to evaporation for a coal bed and a control water surface.

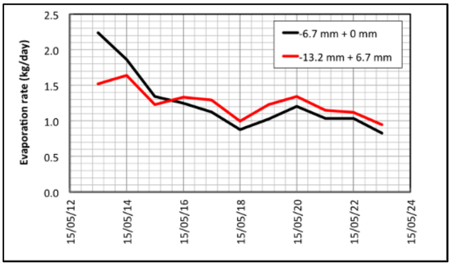

Figure 7: Daily evaporation rates for coal with and without the 6.7 mm fraction.

mass increased due to moisture adsorption in the early morning when the relative humidity of the atmosphere is the highest, and decreased during the late afternoon when evaporation was higher due to a lower relative humidity and higher temperature. With open water evaporation, the evaporation rate also varied with the time of day, with virtually no evaporation in the early morning. Under favourable conditions, the evaporation rate can initially be as high as 0.8 L per m^2 per hour, settling to equal absorption and desorption periods after 4 or 5 days. The effect of particle size on evaporation is shown in figure 7, where the coal that contained some 6.7 mm material showed a higher moisture loss for the first 1 – 2 days only, after which the evaporation rate became similar to that of the sample where the 6.7 mm material was screened out. It is assumed the higher initial moisture content in the finer fraction caused this.

Conclusions

This paper investigated the mechanisms involved in the water retention, drainage and evaporation in coal stockpiles. During the study the drainage through a stockpile could be simulated using a 3 m long column. The effect of the particle size distribution could be quantified. The effect of slope angle, rain flow rate, and degree of compaction on the water infiltration into stockpiles was determined. The evaporation rates of water from stockpile surfaces could be quantified. All of this information can be used to determine what the water drainage and retention properties of a large coal stockpile will be – this will be investigated in a follow-up study

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