Compaction of coal mine rejects to limit the potential for spontaneous combustion

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ABSTRACT

In the Hunter Valley Coalfields of New South Wales, Australia, in which the rejects produced by the washing of the certain coals are prone to spontaneous combustion, the South African practice of compacting the rejects has been adopted in an effort to limit oxygen ingress. The paper describes the results of field and laboratory studies of the evolving rejects at a particular Hunter Valley mine, aimed at characterising the materials, understanding the compaction problems encountered, and assessing the effectiveness of compaction in limiting the risk of the spontaneous combustion of these coal rejects.

1 INTRODUCTION

Considerable research has been carried out on the potential for spontaneous combustion of coal discard (rejects) in South Africa, where it is a well-known problem. South African practice has been to compact the rejects to 95% Standard compaction, wrap the sides of the rejects emplacement with 1.5 m of compacted clay to limit wind-driven oxygen ingress, and cover the top of the emplacement with a nominal 1 m thickness of compacted clay to limit oxygen diffusion. However, the results of recent South African research by Vermaak et al. (2006) involving instrumented test cells indicate that the compaction of fine coal rejects (coarse-grained SAND to fine-grained GRAVEL size) is ineffective in limiting oxygen ingress, with both uncompacted and compacted rejects allowing a ready and constant supply of oxygen at near-atmospheric concentrations.

A particular mine in the Hunter Valley Coalfields of New South Wales initially exploited a coal seam (Seam A) that produced coarse-grained rejects, which were relatively easy to handle and compact. Towards October 2003, mining of a second coal seam (Seam B) commenced, which produced finer-grained rejects that were difficult to handle and compact due to their high fines and moisture content. The placed layer thickness was reduced, lime was added, and the compaction requirement was lowered. There was insufficient area available to work the Seam B rejects and a temporary storage for wet Seam B rejects was established. Fine rejects filter presses were later commissioned to overcome this problem, but there remained a number of issues to address arising from the Seam B rejects already placed.

1.1 Coal seams processed and rejects produced

The now mined-out Seam A Run-of-Mine (ROM) coal was clean and coarse-grained, with most of the fines comprising product coal. The ROM Seam A coal was crushed to pass 125 mm and passed over 12 mm and 1.4 mm sieves to gravity-separate the coarse and intermediate coal fractions, with the -1.4 to 0.1 mm fine coal fraction separated on spirals. The average ash content of the Seam A product coal was about 11%.

The subsequent Seam B ROM coal was dirtier and finer-grained than the Seam A ROM coal, with considerable fines reporting as ash, which averaged about 20%. The fine rejects (-1.4 mm fraction) were passed through a thickener and along a Delcor vacuum belt filter to dewater them, with the belt filter delivering them to a conveyor where the coarse rejects (+1.4 mm fraction, comprising about 25% of the total rejects stream) were added, prior to disposal to a stockpile. Both Cationic and Anionic polymer flocculants were added, before and after the thickener and before and after the belt filter, at a dosage rate in excess of 600 g/tonne of dry feed in total. The Cationic polymer added to the thickener input stream improved water clarity, while the Anionic polymer added to the thickener underflow stream reduced settling time. The pH of the process water was 9.3±0.2.

1.2 Disposal of rejects

The rejects produced were placed in a surface emplacement, where they were required by the licencing conditions to be compacted in 600 mm thick layers to at least 95% Standard compaction. The purpose of the compaction was to reduce the ingress of oxygen, and hence reduce the potential for self-heating on oxidation and the risk of spontaneous combustion.

1.2.1 Seam A rejects

The rejects from the Seam A ROM coal were relatively easy to handle, they formed at a steep angle of repose of about 35° on deposition, and the compaction specification was achievable.

1.2.2 Seam B rejects

The Seam B fine rejects on the vacuum belt filter appeared to have a relatively low clay content and appeared to dry well on the belt. If they were squeezed they formed a compact lump, but a significant amount of water was expelled. The process water felt slimy, indicating a high polymer flocculant content. The polymer flocculant appeared to both temporarily stabilise the rejects and entrain water. After vacuum belt filtering, the fine rejects fell about 10 m onto a conveyor belt, where they appeared wetter than they did at the end of the belt filter. It is likely that the polymer flocculants unwrapped somewhat due to rapid shear disturbance from the fall, releasing some water.

The coarse and intermediate rejects were added to the conveyor and the total rejects deposited on a stockpile, prior to transfer by truck to the rejects emplacement about 500 m away. On stockpile deposition the total rejects formed a "cow pat" at a shallow angle of about 15% or 8°. The deposited total rejects appeared even wetter than the fine rejects, despite the addition of the coarser rejects fractions, with considerable water being released. It is likely that the polymer flocculants were by that stage rendered largely ineffective due to disturbance. On excavation from the stockpile by front-end loader and dumping into a truck for transport to the emplacement the total rejects slumped further.

The emplaced Seam B rejects were not trafficable. They were dumped from the truck in thin (200 to 300 mm) layers on top of the emplacement, spread by dozer, and left a few days to dry. From January to September 2004, lime was applied at a rate of about 10% (in up to three applications) to aid in drying the rejects and to facilitate compaction, and the specification lowered to 90% of Standard compaction.

Due to the thin layers in which the Seam B rejects had to be placed, and the need to leave them to dry prior to lime addition and compaction, the working area required increased dramatically to the point that the mine was running out of permitted disposal area. Subsequent to September 2004, filter presses were used to dewater the fine rejects, removing the need to add lime.

2 CHARACTERISATION OF REJECTS

2.1 Particle size distribution

The particle size distributions of the rejects show that the Seam A rejects classified as a well-graded Silty Sandy GRAVEL (GW), while the Seam B rejects classified as a well-graded, low plasticity, Gravelly Silty SAND (SW), as shown on Figure 1.

2.2 Compaction of rejects

2.2.1 Laboratory Standard compaction

Laboratory Standard compaction tests carried out on the Seam A rejects, and the Seam B rejects with and without lime addition, gave the average Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) values given in Table 1. Also given in Table 1 are the range of field dry density (FDD, obtained by the sand replacement method) and gravimetric moisture content (FMC) for the different materials. The specific gravities of the Seam A and B rejects were found to be 2.33 and 1.90, respectively, reflecting the relatively high content of carbonaceous shale in the Seam B rejects. The compacted Seam A rejects field data correspond to an average degree of saturation of about 33%, while the compacted Seam B rejects field data correspond to an average degree of saturation of about 67%, and the uncompacted Seam B rejects were near-saturated.

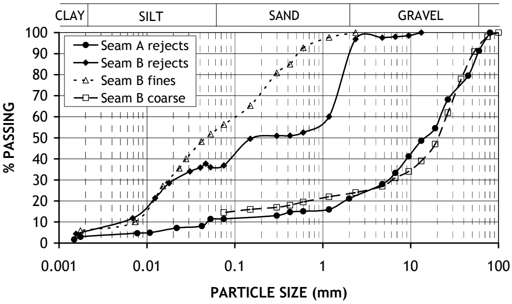

Figure 1: Comparison of particle size distribution curves for Seam A and B rejects

Table 1: Compaction results for rejects

Rejects	MDD (t/m^3)	OMC (%)	FDD (t/m^3)	FMC (%)
Seam A	1.87	9.5	1.63-1.87	7.6
Seam B without lime	1.29	20.0	1.43-1.62	15.5
Seam B with lime	1.27	23.9		

2.2.2 Compaction control data

For compaction control purposes, nuclear field densities and laboratory-determined field gravimetric moisture content determinations were carried out on the rejects over time, as shown on Figures 2 and 3. Also shown on Figures 2 and 3 are the change-over from Seam A to Seam B rejects around October 2003, the duration of lime addition to the Seam B rejects from January to September 2004, the subsequent commencement of filter pressing of the Seam B fine rejects, and typical specific gravities for the two rejects. Figure 4 shows the corresponding HILF density ratios obtained, which bottomed out during the period that lime addition was required, but rose again after the commencement of filter pressing. The moisture content of the Seam A rejects was fairly consistent, averaging about 7.6%, and that of the Seam B rejects rapidly rose with time to about 20% by July 2004. A density ratio 90% was generally achieved throughout, with the majority of the data achieving 95%. The polynomial trend lines show that the commissioning of the Seam B fine rejects filter presses reversed the downward trends in wet and dry field densities and HILF Density Ratio, and the upward trend in field gravimetric moisture content.

2.2.3 Possible effects of lime addition

Soil water characteristic curve and saturated hydraulic conductivity testing of the compacted Seam A rejects and the compacted, lime-treated Seam B rejects was carried out, from which their unsaturated hydraulic conductivity functions could be derived. The compacted, lime-treated Seam B rejects were inferred to have an unsaturated hydraulic conductivity of about 5 x 10^{-7} m/s in situ, which is a relatively high value, capable of drainage. However, the unsaturated hydraulic conductivity of the underlying compacted Seam A rejects was inferred to be about 10^{-12} m/s in situ, equivalent to 0.3 mm/year, or practically impermeable. As a result, the compacted, lime-treated Seam B rejects would drain to the underlying compacted Seam A rejects, and would not be drawn to the surface of the rejects emplacement through evapotranspiration. The underlying compacted Seam A rejects would not pass any significant seepage from the overlying compacted, lime-treated Seam B rejects, but would instead store it. The overall effective lime dosage to the entire rejects emplacement was less than 0.5% by mass, which would have a negligible effect on its overall pore water alkalinity and pH. The lime addition to the placed Seam B rejects has not had a measurable impact on the overall pore water quality of the emplaced rejects, and is not expected to impact seepage water quality or subsequent revegetation of the surface of the rejects emplacement.

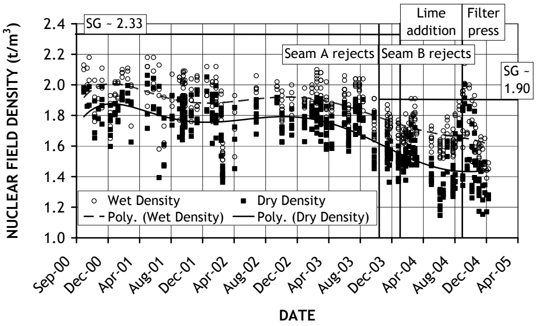

Figure 2: Field wet and dry densities of rejects versus time

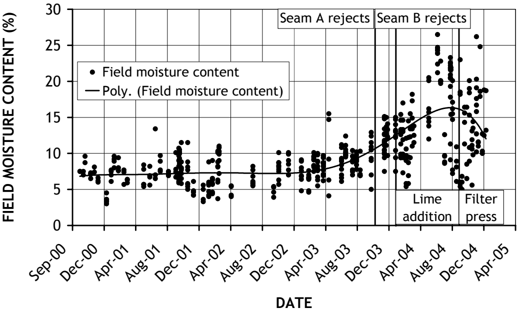

Figure 3: Field gravimetric moisture content of rejects versus time

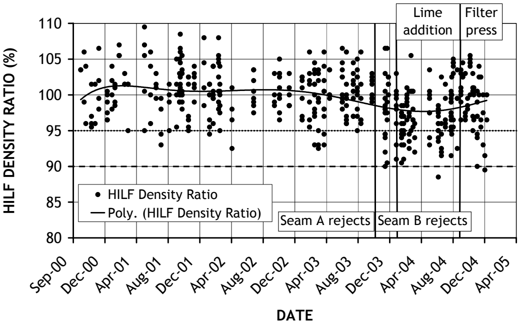

Figure 4: HILF density ratio of rejects versus time

3 HEATING OF REJECTS

In the following sections data on the heating of the rejects emplacement are presented, together with worldwide experience of the heating of coal rejects.

3.1 Rejects emplacement data

Stage 1 of the rejects emplacement was constructed with 300 mm thick compacted clay layers above each 3 m height of compacted Seam A rejects, which were compacted to 95% Standard compaction in nominal 600 mm high lifts. The final surface of Stage 1 was capped with 500 mm of clay compacted to 95% Standard compaction. Stage 2 comprised Seam A rejects compacted to 95% Standard compaction in nominal 600 mm thick layers, without intermediate compacted clay layers. The final surface of Stage 2 was capped with 500 mm of clay compacted to 95% Standard compaction. Stage 3 was active and remained uncapped.

Both the Seam A and B coals were known to have a potential for spontaneous combustion and hence the rejects produced from them do also. Thermocouples for measuring temperature within the emplaced rejects were installed in each of the first three stages of the rejects emplacement (four in stage 1, three in Stage 2 and two in Stage 3), at depths of about 8 m below the rejects surface and at least 25 m in from the edge of the emplacement. A further thermocouple was used to measure the ambient air temperature.

The thermocouples have been read approximately monthly since January 2001, and the resulting temperatures (averaged for each of the three stages) are plotted against time on Figure 5. The ambient temperature plot reflects seasonal changes, with the three sets of averaged thermocouple data showing a very subdued reflection of ambient temperature changes (summer heating and winter cooling). All three of the stages showed some minor heating over time, with Stage 2 showing the most significant heating, but none showed a rapid escalation in temperature with time that would indicate the likelihood of spontaneous combustion occurring within the emplacement.

Heating above 50°C is the trigger level for further investigations to be undertaken. There exists a threshold temperature of about 70°C above which the heating of susceptible coal or coal rejects rises rapidly (Beamish, 2004). A progression to spontaneous combustion would be marked by the possibility of steam venting at the surface as the internal temperature reached about 100°C, followed by a very rapid rise in temperature to about 400°C, at which spontaneous combustion would occur.

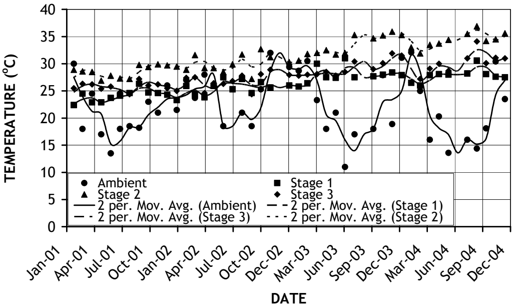

Figure 5: Temperature monitoring within the rejects emplacement

3.2 Worldwide experience of heating of coal rejects

The air permeability of unsaturated soils is described in Fredlund and Rahardjo (1993), who suggested a reduction in the air permeability of soils whose degree of saturation (volume of water/volume of voids, expressed as a %) exceeded 60%. Fredlund and Rahardjo further suggested that for an unsaturated sandy soil with a matric suction of less than about 2 kPa, the soil would have a very low air permeability. This is backed up by Fredlund and Rahardjo, who showed a very low air permeability for soils with a gravimetric moisture content of 15% or greater, rising to reasonably high air permeabilities for soils with a gravimetric moisture content of 5% or less.

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However, the results of recent research by Vermaak et al. (2006) involving instrumented test cells indicate that the compaction of fine coal rejects (coarse-grained SAND to fine-grained GRAVEL size) is ineffective in limiting oxygen ingress, with both uncompacted and compacted rejects allowing a ready and constant supply of oxygen at near-atmospheric concentrations (17 to 21%). A 0.3 m thick uncompacted clay cap over the rejects reduced the oxygen availability to between 14% and 18%, a 0.5 m thick compacted clay cap reduced the oxygen availability to between 0 and 11%, and a 1.0 m thick compacted clay cap reduced the oxygen availability to generally below 5%.

The oxygen diffusion coefficient for a given soil is very strongly a function of its degree of saturation (Figure 6, after Millington and Quirk, 1959), and shows low values for a degree of saturation above 85%, at which the soil would have continuous water-filled porosity. Environmental Geochemistry International Pty Ltd of Sydney used this relationship to calculate the effectiveness of a compacted clay cover (with a nominal saturated hydraulic conductivity of 10^{-8} m/s) in reducing the acid generation rate of underlying oxidising material (Figure 7). To achieve a 90% reduction for no cover, the material would need to maintain a degree of saturation of greater than about 80%. A 1 m thick compacted clay cover would need to maintain a degree of saturation of greater than only 62% and a 2 m thick compacted clay cover a value of greater than only 53% to have the same effectiveness. Clearly, compacted clay has a far higher water-holding capacity than coal rejects, and doesn't need to remain as saturated to be effective in limiting oxygen ingress.

4 WATER LEVEL AND QUALITY

Piezometers for measuring water table elevations beneath the emplaced rejects were installed in Stages 1 and 2 in January 2002, and have shown negligible change in water table elevations over time, with the average elevation of the water table 1.3 to 4.6 m below the base of the rejects. This indicates negligible seasonal effects and no water table mounding due to the placement of the rejects.

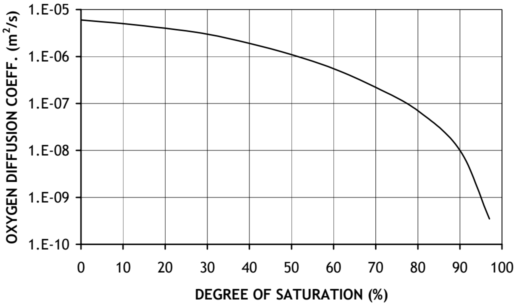

Figure 6: Oxygen diffusion coefficient versus degree of saturation

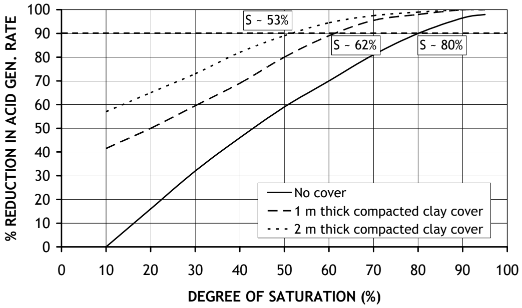

Figure 7: % reduction in acid generation rate versus saturation and compacted clay cover thickness

The stored process water contains about four times the alkalinity of the natural groundwater, having a pH about two pH units higher, being a logarithmic scale), with about twice the salinity and suspended solids. Water quality monitoring has shown that the downstream groundwater quality has been maintained and has shown negligible variation over time, indicating that it has not been impacted by the washery, rejects emplacement or the stored process water. The seepage flows from the rejects emplacement are small, which is consistent with the low unsaturated hydraulic conductivity of the compacted rejects (see Section 2.2.3). The excess process water is not discharged to the environment, being removed through evaporation.

5 CONCLUSIONS

The paper presents data on the characterisation of the rejects from a particular mine in the Hunter Valley Coalfields as they evolved from the mining of Seam A to the mining of Seam B, and on their compaction and self-heating. The transition from Seam A rejects to the much finer-grained and hence much wetter Seam B rejects created difficulties in meeting the licencing condition that the rejects be compacted to limit oxygen ingress and to reduce the risk of spontaneous combustion of the emplaced rejects. This difficulty was addressed as an interim measure by treating the Seam B rejects with lime, achieved without environmental impact, before the commissioning of filter presses to dewater the Seam B fine rejects.

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