Cover Trials on Tailings Storage Facilities in Arid Hypersaline Regions

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Abstract: A field study was established in 2001 to evaluate a range of cover designs for the rehabilitation of tailings storage facilities in arid hypersaline regions. The success of a cover system in this environment is dependent on the extent to which the cover limits the upward evaporation-driven migration of salts from the tailings into the cover. A "discontinuous cover" (that is, cover mounds) is one particular system that was trialled. Aside from being a cost-effective alternative to placing a conventional continuous cover, the concept of a discontinuous cover system was built on the idea that water rising to the surface due to capillary action would not rise further than the low points between the cover mounds, as the cover materials are far coarser than the tailings. The sides and tops of the mounds would then in theory be suitable for the growth of vegetation, while the low points would become salinas where vegetation could not grow, mimicking a natural salt pan.

The current research has demonstrated that the development of a salt crust on the bare tailings surface has reduced the rate of evaporation from the bare tailings, to the point where there is evidence of lateral migration of salts from beneath the bare tailings surface into the adjacent cover mounds. This has resulted in higher salt concentrations within the cover mounds than within a continuous cover of corresponding materials and cross-section. This outcome questions the potential effectiveness of a discontinuous cover system for hypersaline areas where revegetation is the aim. Further trials are recommended to further understand the mechanisms limiting the success of the current discontinuous cover system design. A key element in developing a vegetated cover on hypersaline tailings in an arid climate is an effective and sustainable capillary break between the tailings and the growth medium.

INTRODUCTION

The Kalgoorlie mining region of Western Australia is underlain by hypersaline groundwaters, which due to the shortage of good quality water in the region are used as process water. As a result, the tailings formed on processing the ore have highly saline pore water. Highly saline tailings are analogous to the natural salt pans that exist in the region.

The high salt content of the tailings has a number of effects. The formation of a salt crust on the surface of the tailings on evaporative desiccation tends to close off further desiccation, while at the same time limiting dusting. However the salt crust also makes revegetation problematic.

Where tailings contain highly saline pore water, a continuous cover will require a capillary break to prevent saline water rising to the vegetation root zone within the cover. An alternative notion, which is being trialled as part of this study, was to construct discrete cover mounds to act as island sanctuaries for vegetation. In between the mounds the tailings are left bare. The mounds are limited in size, which was thought to limit the extent to which the highly saline tailings pore water would be drawn up into the cover. Infiltrating rainfall would then form a fresh water source above the saline pore water to supply any vegetation on the mound. The performance of the discontinuous cover system is discussed herein, and compared with that of a conventional continuous cover system.

DETAILS OF TAILINGS COVER TRIALS

Study Objectives

The key project objectives pertinent to the cover trials at WMC Resources Mount Keith Nickel Operation (MKO) are as follows, with the third-listed objective being the key focus of this paper.

- To assess the rate and extent to which the high salinity of the tailings is migrating into the cover material, driven by soil suction effects, involving both solute (due to salinity) and matric (or capillary) suctions.
- To gauge and compare the performance of the different cover materials used in the cover trials; viz.: course quarry rock versus hard pit rock versus caprock versus oxide waste rock.
- To assess whether a "discontinuous cover system" presents a viable, cost-effective alternative cover solution.
- To compare and contrast the characteristics of the tailings cover trials and the state of a natural salt pan (Lake Miranda), located south of the mine.

Cover Trial Design and Philosophy

Figure 1 presents the general layout of the cover trials at MKO. On the western side of the central decant accessway, is a 60 m x 60 m continuous cover. This main pad is split up into four 30 m long square segments. This was done so that four different cover material types could be trialled simultaneously.

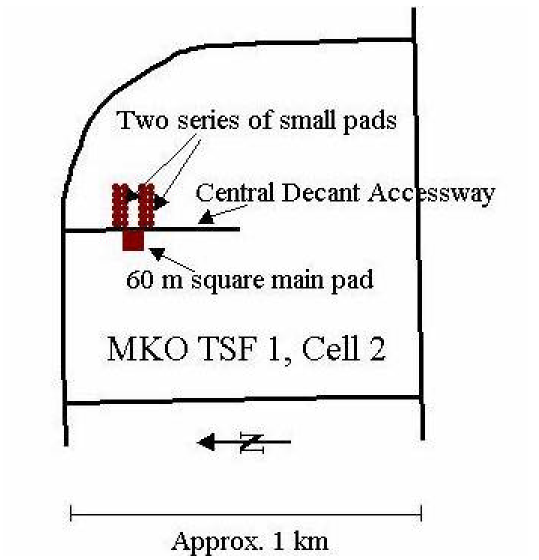

Figure 1: *Cover trial layout at MKO TSF 1, Cell 2*

The cover/tailings cross-sectional profile is shown in Figure 2. For a cover in an arid hypersaline region to sustain vegetation, a "capillary break" is required to prevent the upward migration of salts into the growth medium (topsoil), due to the excessive evaporative conditions. Hence it was deemed necessary to trial and compare a range of materials (typical of what would be available at most mine sites) to serve as a "capillary break." The different materials being trialled comprise the following:

1. Coarse quarry rock
2. Hard pit rock
3. Caprock
4. Oxide waste rock

The nominal thickness of the capillary break layer for the current trials is greater than the theoretical height to which water could rise to under the effects of capillary action, for all of the materials trialled; this height being governed by the materials particle size distribution. It is important that the capillary break is much thicker than it theoretically needs to be, to allow for the infiltration of fines from the overlying topsoil/growth medium, which is inevitable without having some sort of filtering mechanism in place, such as a graded soil filter, or a geomembrane (which is generally prohibitively expensive due to the large area involved). In addition to the above, the capillary break layer should be thicker than it theoretically needs to be to allow for the effects of root penetration by vegetation.

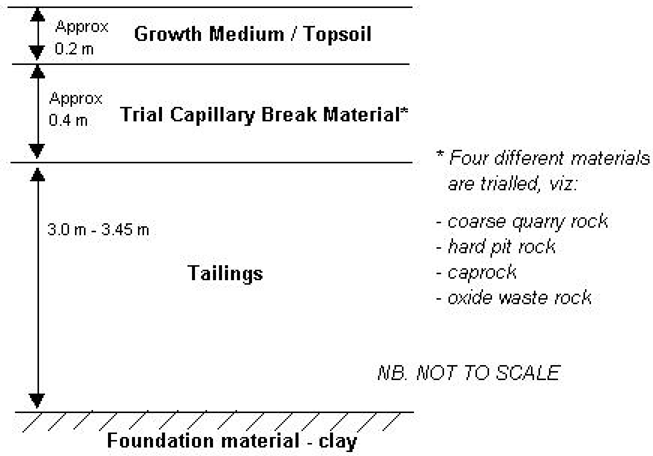

Figure 2: *General cross-sectional profile of trial covers overlying tailings*

The concept of a discontinuous cover system

As an alternative to placing a conventional continuous cover (with a necessary capillary break) on top of the TSF, the trials also involved a series of smaller pads, or "mounds" (a "discontinuous cover system") on the eastern side of the central decant accessway (refer to Figure 1). The mounds are approximately 10 m in diameter and 10 m apart.

The original notion was that by not having a continuous cover, perhaps the need for a capillary break (to limit the uptake of salinity into the cover) could be avoided; however the mounds were still constructed with a capillary layer (as per the main pad), with a plan to gauge relative performance. In addition to this it was also expected that the "micro-climates" created by the mounds would facilitate revegetation. The mounds also had a range of slightly varied shapes to assess what works best from a wind erosion standpoint with regard to seed germination.

Sampling and Testing Methods

The cover trial testing involved hand augering through the full depth of tailings or natural soils (in the case of the natural salt pan analogue) to obtain closely spaced samples, and the sampling of the cover materials from the sides of test pits. The test holes were located to be representative of conditions around and under the trial covers. All test holes were taken through the tailings to the underlying foundation at a depth of 3.2 to 3.8 m below the tailings surface.

The gravimetric moisture content (ratio of the mass of water tot the mass of dry solids, expressed as a percentage) of the recovered samples was determined in the mine site laboratory, and selected samples were subjected to total suction (using a portable psychrometer), pH, Electrical Conductivity (EC) and salinity (Total Dissolved Solids, TDS) testing. The pH, EC and TDS determinations were carried out on a paste formed by adding distilled water to the moist sample in a nominal water (distilled water plus pore water) to dry solids mass ratio of about 5 to 1, as recommended by Hunt and Gilkes (1992). The distilled water had a neutral pH and negligible salinity. As a result, the pH of the samples was not affected by the addition of distilled water. The EC and salinity of the samples were determined on a solids dry mass basis. The amount of distilled water added was sufficient to ensure that all soluble salts on the tailings particles were dissolved, yielding the total dissolved solids (Hunt and Gilkes, 1992).

The EC values in µS / cm were approximately twice the numerical TDS values in ppm. The EC may then be correlated with osmotic suction, which when subtracted from the total suction values gives the matric suction. Only the osmotic suction values are plotted herein, as a relative representation of salinity within the different cover profiles.

RESULTS AND INTERPRETATION

The test results to date generally present little variation in engineering performance for the different cover materials trialled. While from a capillary break standpoint the hard pit rock has performed better than the other materials trialled, it hasn't been completely successful as a capillary break, with salt still breaching this layer and migrating into the overlying growth medium. However, when the performance of the continuous cover is compared with the discontinuous cover for the same material type, a much more interesting disparity emerges, as discussed in the following subsections.

Salt Crust Development

The osmotic suction depth profiles for the caprock continuous cover system, as a function of time, are shown in Figure 3. At depth, there is little shift in profile. However, within the cover the osmotic suction varies largely between the test times. November 2002 presented significantly higher osmotic suction values at the surface, when compared with May 2002, which is likely to be attributed to the particularly dry period leading up to this investigation. A salt crust was noticed during the course of the November 2002 visit, and the increase in osmotic suction for the surficial tailings from approximately 3,500 kPa in May 2002, to nearly 9,000 kPa in November 2002, confirms this crust development. The salt crust has continued to amass salt, climbing to an osmotic suction of 9,600 kPa in October 2003.

Wilson, Fredlund *et al*. (1997) discussed the significant effect that soil suction has on evaporative fluxes from soil surfaces, observing that the rate of actual soil evaporation declined when the total suction in the soil surfaces that were tested exceeded approximately 3,000 kPa (at Mount Keith, the osmotic suctions alone far exceed this value). Unique relationships for the different soil types were developed from their research, but they had very similar trends. It is this phenomenon that is also coming into play in the performance of the discontinuous cover system (or cover mounds), as discussed below (Wilson, Fredlund *et al*., 1997).

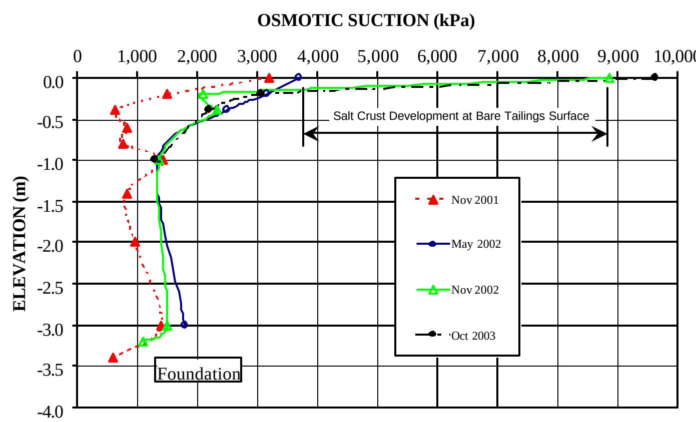

Figure 3: *Osmotic suction depth profiles (main pad/continuous cover, caprock)*

Cover System Comparisons

The caprock and hard-pit-rock cover types were both studied during the October 2003 investigation in order to compare the performance of the main pad (continuous cover) with that of the mounds (discontinuous cover). The covers were compared by way of moisture content, matric suction and osmotic suction. The moisture content and matric suction plots showed very little variation between the main pad and the mound for both cover types (Figure 4 presents the matric suction profiles for the caprock cover).

The osmotic suction plots tell a different story. The cover mound for both material types presented a much higher value of osmotic suction at the cover surface, than the main pad. Figure 5 presents the osmotic suction depth profiles for the caprock material. The hard rock cover presented similar trends to the caprock cover, for moisture content, matric suction and osmotic suction.

These results indicate that the salt is well and truly migrating to the surface of the mounds, but more importantly salt is migrating at a faster rate through the mounds than through the main pad.

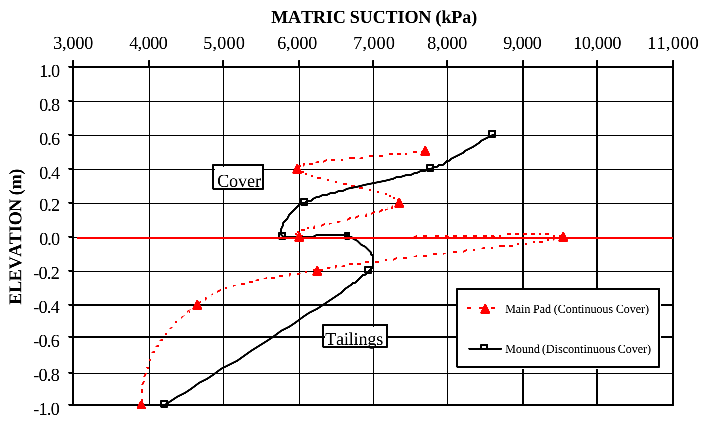

Figure 4: *Matric suction depth profiles for the continuous and discontinuous cover systems (caprock) – October 2003*

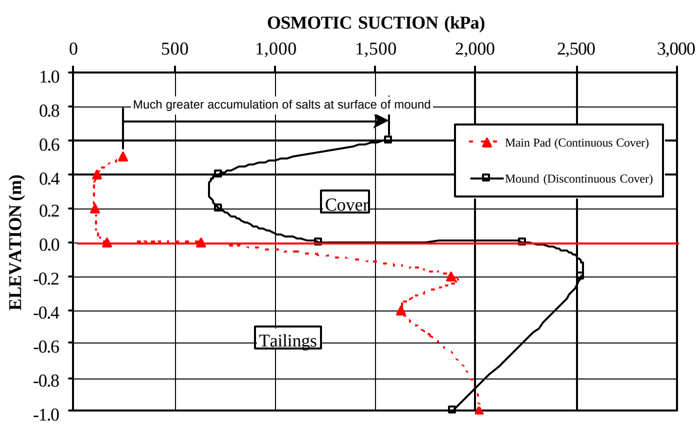

Figure 5: *Osmotic suction depth profiles for the continuous and discontinuous cover systems (caprock) – October 2003*

This behaviour goes against what was originally expected to happen, and is a very important outcome. There is a number of processes that could be driving this behaviour:

- The development of a salt crust has greatly reduced the actual rate of evaporation from the tailings surface (as suggested by Wilson, Fredlund *et al*., 1997), to the extent that it has led to evaporation occurring preferentially through the cover system, as opposed to from the bare tailings.
- The fines from the overlying topsoil layer have tended to erode their way downslope over time resulting in a thin layer of finer material forming around the full perimeter of the capillary break layer (refer to Figure 6). This renders the capillary break useless, since the sides of the mound provide an alternate access route for the saline pore water.
- The tailings underlying the salt crust, as well as the cover materials nearer the tailings interface, are much wetter than the cover materials near and at the top of the mounds. Earlier research by Thorpe and Barbour (1991) found that for a given water flux, the velocity of advective sodium (Na) transport increases as the water content decreases. The low water content in the topsoil results in the rapid movement of Na to the evaporative front where it is concentrated as a result of evaporation. Secondly, the lower water content of the surface topsoil allows more rapid increases in Na concentration as a result of diffusive transport or as a result of evaporative water losses (Thorpe and Barbour, 1991).
- A combination of any or all of the above.

Extensive numerical modelling is currently in progress, in an attempt to reproduce the behaviour observed in the field, and to subsequently provide further insight into the complex mechanisms at play.

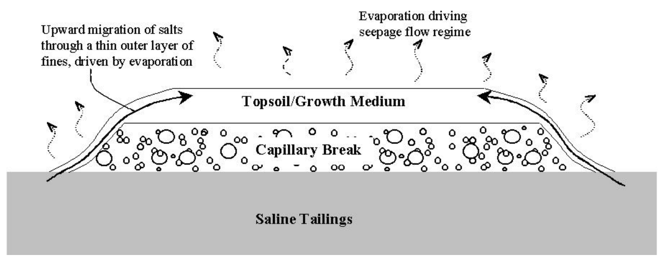

Figure 6: *One likely mechanism responsible for higher salt levels in the cover mounds (cf. the main pad)*

CONCLUSIONS

The results of the field investigations have questioned the potential effectiveness of a discontinuous cover system for hypersaline areas where revegetation is the aim. However, a discontinuous cover system may still be an option under the following circumstances:

- In areas where a salt crust is unlikely to form due to more manageable levels of salinity, or where salt leaching occurs either naturally (that is, by means of regular rainfall), or by manual means (which implies post-mining maintenance, which may be impractical).
- The situation depicted by Figure 6 is somehow avoided in the design and construction of the discontinuous cover system by incorporating an effective capillary break into the design.

The costs associated with placing a continuous "advanced" (that is, comprising a properly engineered capillary break, or multiple layers) cover system are very high. A discontinuous cover system, which is somewhat akin to an elevated salt pan, with some topographic relief, presents a potential cost-effective alternative. Accordingly, it is recommended that further field trials and numerical modelling be conducted to test the above conditions and move a step closer towards finding a viable and sustainable rehabilitation solution for TSFs in arid hypersaline regions.

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