Innovative Liner Design for Brine Evaporation Ponds

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ABSTRACT
The Emalahleni Water Reclamation Plant which treats polluted mine water from underground workings of coal mines in Witbank into a portable water standard was commissioned in October 2007. The first of its kind, the project set a benchmark for sustainable acid mine water management. The biggest challenge identified by the project was to develop a cost effective means of disposing the residue streams of the treatment process, namely brine and sludge. The brine liquid stream, which is classified as hazardous due to its high concentration of salts (especially Na, S, Ca and K) and metals (such as Fe, Li, Mn and Sr), had to be disposed of in a lined evaporation pond. According to the South African Department of Water Affairs and Forestry's Minimum Requirements, such a pond should have a liner system equivalent to that of a hazardous waste lagoon - a double composite liner system with a leakage detection and collection layer separating the primary and secondary composite liners. This prescriptive liner system recommends the use of either compacted clay liner (CCL) or geosynthetic clay liner (GCL) as part of each composite liner. Neither of these clay liners could be used due to unavailability of suitable clay in the case of CCL and chemical incompatibility of the brine with the bentonite in the case of GCL. The design and construction of an alternative liner system that takes into account these limitations are detailed in this paper.

1. INTRODUCTION

Mining activities generally result in the accumulation of large volumes of water in the underground workings and voids. The quality of the water is often poor, predominantly characterized by low pH, high metals concentrations and/or high salinity. Such affected water is increasingly becoming a problem to manage in the Highveld Coalfields of South Africa by contaminating groundwater, posing safety risks for operating mines and decanting at surface in an uncontrolled manner. In addition, the water in the Witbank dam which supplies water to the Emalahleni Municipality works is also contaminated as a result of upstream mining activities, such that the water cannot be treated to potable water quality standards in the existing biological treatment works.

Four mines in the vicinity of Witbank took the initiative to treat the polluted acid mine water to potable water quality using a reverse osmosis membrane treatment technology and to supply the treated water to supplement the Emalahleni Municipality water supply, and so improve the quality of the water through mixing and dilution. Construction of the water treatment plant commenced in November 2005 and the plant was commissioned in October 2007.

The membrane treatment process generates brine and sludge as waste streams which require responsible disposal. The brine is to be disposed of in evaporation ponds and the dewatered sludge in purpose built landfill cells within an existing mine residue co-disposal facility. This paper addresses the design and construction challenges of the liner system for the first brine evaporation pond constructed adjacent to the treatment plant (Figure 1).

The evaporation pond was constructed partly below ground (a maximum of 3 m) and partly above ground (a maximum of 10 m) through a cut to fill operation. The walls of the facility have an outer slope of 2H:1V and an inner slope of 2.5H:1V. The facility occupies a total footprint area of about 7 ha and has a storage capacity of about 330 000 m^3.

Figure 1. Aerial view of the brine evaporation pond and the water treatment plant

2. REGULATORY REQUIREMENTS

The regulatory requirements for management and disposal of residue emanating from treatment of acid mine water are not well defined. However, the permitting is governed by the following regulatory requirements: Environment Conservation Act No 73 of 1989; National Water Act No. 36 of 1998; Water Services Act No. 108 of 1997; and Mineral and Petroleum Resources Development Act. No. 28 of 2002.

An integrated approach to licensing and permitting was employed that involved all regulatory authorities. The authorities collectively agreed to use the Department of Water Affairs and Forestry's "Minimum Requirements – Waste Management Series" as the principal guideline for the engineering and development of the brine and sludge disposal facilities. This series of documents include:

- Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste.
- Minimum Requirements for Waste Disposal by Landfill.
- Minimum Requirements for Monitoring at Waste Management Facilities.

The brine disposal facility was designed based on a precautionary approach of total containment, whereas the sludge disposal facility was designed based on a risk assessment approach of co-disposal with coal residue.

3. CHARACTERISATION OF THE BRINE STREAM

The brine waste stream was found to have high concentrations of salts (especially Na=2 361 mg/ℓ, S=2 030 mg/ℓ, Ca=973 mg/ℓ, K=481 mg/ℓ and Mg=40 mg/ℓ). The waste stream was also found to have metals such as Fe=9.5 mg/ℓ, Li=1.1 mg/ℓ, Mn=1.85 mg/ℓ and Sr=4 mg/ℓ, all of which exceeded the acceptable risk levels set by the "Minimum Requirements". Based on these concentrations the brine waste stream was classified as Hazardous (Class 6) with a Hazard Rating 2. The brine containment facility would therefore have to comply with the prescribed "Minimum Requirements" for a hazardous waste lagoon, particularly regarding the design of the liner system.

4. LINER REQUIREMENTS

The “Minimum Requirements” prescribed liner design for a hazardous waste lagoon is presented in Figure 2.

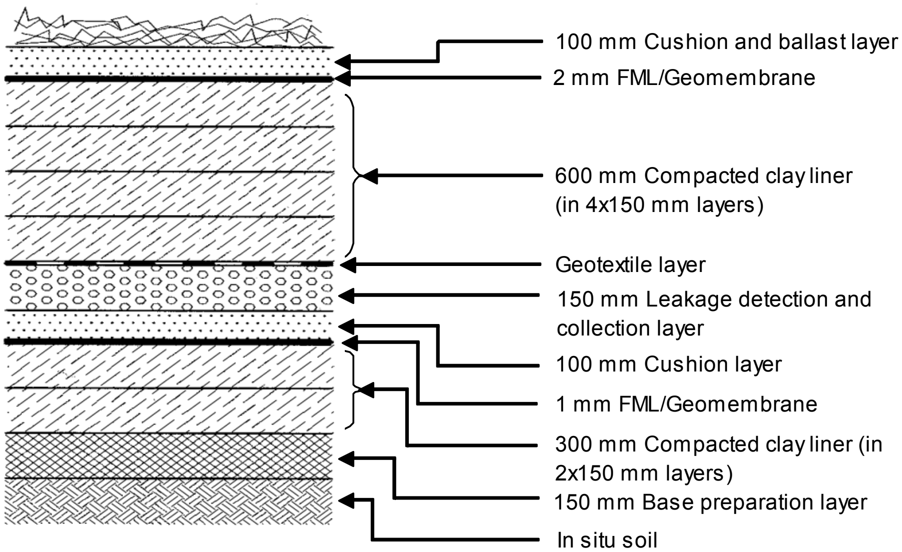

Figure 2. Minimum Requirements Liner System for Hazardous Waste Lagoons (DWAF 1998b)

As seen from the diagram, the emphasis is placed on a robust composite primary liner, followed by a leakage detection layer and a slightly less robust secondary liner. It is noted in the Minimum Requirements that, in the absence of suitable quality clay, the compacted clay component of the liner system may be replaced by a geomembrane, a geosynthetic clay liner (GCL), or a composite liner.

Unfortunately there was insufficient clay of acceptable quality in close proximity to the site, and it would have been prohibitively expensive to import clay from far away. The most suitable substitute for a natural compacted clay liner would normally be to use a GCL. A GCL consists of a sodium bentonite clay, sandwiched between two geotextiles. On average the GCL is approximately 5 mm thick and this very thin and very low permeability clay is assumed to provide permeability and attenuation equivalent to the four compacted clay layers (CCL) specified in the “Minimum Requirements”. The swelling property of the sodium bentonite when hydrated provides the GCL with its low hydraulic conductivity and self-healing properties. Sodium bentonite typically consists of 50-90% Na^+, 5-20% Ca^{2+}, 3-15% Mg^{2+} and 0.1-0.5% K^+ (Egloffstein 2001). Under ideal conditions, a good quality GCL would exhibit a saturated permeability of less than 10^{-11} m/sec.

However, the equivalency of a GCL with a CCL could be affected if the performance of the GCL is significantly reduced - for instance due to inorganic chemical attack. Literature (e.g. Benson and Edil 2004) shows that when a GCL comes into contact with solutions containing a significant concentration of divalent cations (such as Ca^{2+} and Mg^{2+}), the hydraulic conductivity of the GCL could increase significantly as a result of cation exchange of the monovalent Na^+ cations by the divalent Ca^{2+} and Mg^{2+} cations. The physical mechanism that causes these changes is a reduction of the thickness and related absorption capacity of the diffuse double layer of water molecules surrounding the clay minerals. This results in an effective decrease in the volume of the clay, since the water molecules are not attracted to the clay particles. The magnitude of the increase in hydraulic conductivity depends on a number of factors among which the following are the critical ones:

- Concentration of the divalent cations in the brine.
- Pre-hydration of the GCL.
- Confining pressure on the GCL.

Under ideal conditions, the GCL would normally provide a saturated hydraulic conductivity of less than 10^{-9} cm/s, however through Ca^{2+} cation exchange, there can be an increase in hydraulic conductivity of at least two orders of magnitude to $1x10^{-9}$ m/s. In the case of the brine, the Ca^{2+} concentration is almost 1 000 mg/ℓ, which could result in cation exchange and compromise the performance of the GCL in this situation. It is therefore advisable to assess the chemical compatibility and performance of a GCL prior to its use in a geocomposite barrier system.

5. GCL TESTING

A series of permeability tests were carried out on samples of GCL subjected to the brine as a permeant, using fixed wall permeameters, for the following conditions:

- Unhydrated GCL (14% moisture content) with brine permeant
- Partially hydrated GCL (100% moisture content) with brine permeant
- Fully hydrated GCL (219% moisture content) with brine permeant

For each of the above tests, a similar control test using water was also conducted.

The test results showed the following:

- The permeability of the GCL with water as permeant was found to be very similar to that quoted in the literature, between 10^{-10} and 10^{-11} m/s after 2 000 hours with a decreasing trend.
- The permeability of the GCL with brine as permeant varied between 6.5 x 10^{-10} and 1 x 10^{-9} m/s after 2 000 hours with a slightly increasing trend. The fully hydrated GCL yielded the lowest permeability values.
- In the brine tests, the permeability was very low initially, 1 x 10^{-10} m/s, however with time the permeability increased probably as a result of the Na^{+} cation exchange with Ca^{2+}.

Based on the permeability test results, it was decided that it would be inappropriate to replace the four compacted clay layers of the primary liner as specified in the “Minimum Requirements” with a GCL, as the GCL would not have access to moisture for hydration being sandwiched between two geomembranes. The first time the GCL would be subjected to moisture would be in the event of a leak where the moisture would be brine rather than water. It was however felt that the GCL could be used as a replacement for the two compacted clay layers in the secondary liner, as it would be placed a soil subgrade and would therefore draw moisture from the underlying soil for hydration.

6. ALTERNATIVE LINER SYSTEM

An alternative triple liner system consisting entirely of geosynthetic components was proposed for the lining of the brine evaporation pond (Figure 3). The concept of this liner system was to provide an additional geomembrane liner and a drainage layer instead of the 600 mm CCL. This aimed at providing an additional defence system whilst reducing the head on the composite liner system.

The unit cost of this alternative liner system was about 9% more expensive than that of the prescriptive liner system. The alternative liner system however provided about 32 300 m3 additional storage capacity, due to the much thinner nature of the alternative totally geosynthetic system compared to the thickness of the “Minimum Requirements” liner consisting of compacted clay layers, a granular leakage collection layer and cushion layer.

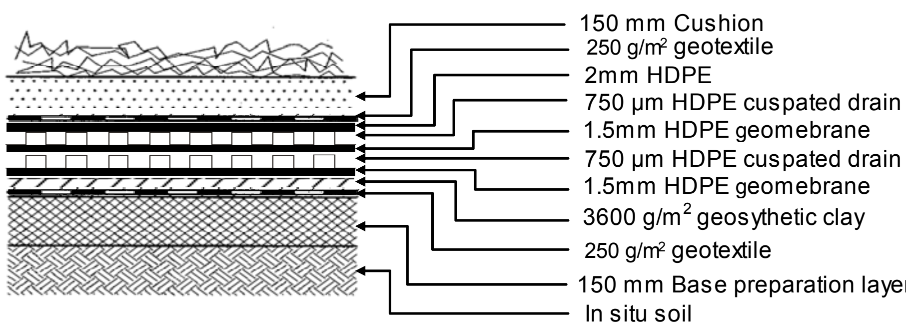

Figure 3. Alternative Geosynthetic Liner System for the Brine Evaporation Pond

The purpose of the 150 mm sand cushion layer is to prevent the primary HDPE geomembrane from floating in the event of a leak. The replacement liner for the “Minimum Requirements” primary liner consists of 2 mm and 1.5 mm HDPE geomebranes with a 750 µm cuspated HDPE drainage layer between the two geomembrane liners. This primary leakage collection layer has separate collection systems for the walls and floor, draining in separate pipelines to a common brine leakage collection sump outside the walls of the pond. The primary objective of separating the wall and floor was to allow easy maintainace in the event of leak.

The secondary leakage collection and conveyance system comprises a similar 750 µm cuspated HDPE drainage layer between the secondary and the tertiary HDPE liners, draining through a separate pipeline to the brine leakage collection sump. Figure 4 shows the three leakage system outlets during construction and Figure 5 shows the leakage system discharges into the monitoring sump.

The replacement liner for the “Minimum Requirements” secondary liner consists of a 1.5 mm HDPE geomembrane overlying a GCL. Beneath the GCL is a non-woven geotextile layer installed as part of a sub-surface drainage system for perched groundwater seepage. Because the GCL on the slopes does not have an applied confining pressure, the overlaps between adjacent GCL sheets was increased to minimise the risk of panel separation.

Figure 4. Leakage system outlets through the liner system

Figure 5. Leakage monitoring sump during construction

7. LINER PERFORMANCE MONITORING SYSTEM

At the leakage collection sump, the rate of leakage from each liner layer system can be measured and all brine leakage collected in the sump is pumped back into the brine pond for evaporation. The following action leakage rates (ALR) were set for the primary and secondary liner systems of the facility, above which immediate actions are required but below which no special actions are required:

- ALR for the primary 2 mm HDPE liner is set at 673 500 ℓ/month; and
- ALR for the secondary 1.5 mm HDPE liner is set at 118 600 ℓ/month.

The purpose of the primary leakage detection system is to remove water head from the secondary liner. If the ALR of the primary liner is exceeded the operator can take measures to investigate the possible reasons for the leakage and carryout actions that would reduce the rate to within the acceptable limit.
The secondary liner system is considered as the critical liner system of facility. Hence, if the ALR of the secondary liner is exceeded the Department of Water Affairs must be notified immediately and action plans should be set to control the leak.

8. CONCLUSIONS

In landfill or lagoon barrier systems where the leachate or contained liquid contains high concentrations of divalent or trivalent cations, caution must be exercised if a GCL is being considered as a replacement for the compacted clay component of the geocomposite barrier system. Appropriate testing should be carried out to confirm the chemical compatibility and permeability performance of the GCL when subjected to contact with such liquids. In the case of the Emalahleni brine pond, the conventional geomembrane / compacted clay liner system was successfully replaced with a totally geosynthetic triple geomembrane liner system. The first HDPE geomembrane is aimed at providing additional barrier system and the first leakage collection system reduces head from the underlying composite liner system in the event of leakage. The brine pond has been in operation since October 2007, and measured leakage rates are well below the set action leakage rates.

REFERENCES

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