The Effects of Polycom on the Permeability of Compacted Clay Landfill Liners

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Abstract
As a part of modern landfill design, a liner is constructed of low permeability, compacted clay which must follow strict construction requirements given by the South Australia Environmental Protection Agency (SAEPA). This protects the ground and groundwater from the potential infiltration of leachate and is one of the major costs associated with landfill. In order to decrease this cost, research was conducted into possible additives to the compacted clay liner (CCL) which would decrease its permeability and therefore allow a reduction in the thickness of the clay layer.
The soil trialled was taken from a local landfill site and is classified as Hindmarsh clay. A series of testing methods were used to achieve the research objectives, consisting of the following:

- Flexible Wall permeability testing (conducted at the University of Adelaide Geotechnical laboratories)
- Flexible Wall permeability testing (conducted by Golder & Associates)
- A self-designed long term test, which allowed for the use of local leachate as the permeating fluid

It was determined through these methods that Polycom is an effective additive as it achieved permeability reductions at 32% recorded by Golder & Associates and 14.5% recorded at University of Adelaide. Furthermore, it was not negatively affected by leachate. It is recommended Polycom be tested further so that it can be used commercially. It was also found that the permeability of Hindmarsh clay alone is significantly lower than that required by the SAEPA, which strongly supports the argument for decreasing the thickness of the CCL.

1. INTRODUCTION

Safe disposal of solid waste is a global issue. Landfill liners are constructed to protect the surrounding environment from the effects of leachate. Leachate is a combination of harmful chemicals, released into a solution, which has entered a landfill site from external sources (generally rain), during waste decomposition (Arasan & Yetimoglu, 2008). Early liners consisted of a 1 to 5 foot thick, low permeability, clay soil liner (Sharma & Lewis, 1994). Modern landfills barriers consist of a compacted clay liner (CCL), which is constructed from low permeability clay. This protects the surrounding environment from the potential infiltration of leachate.

In Australia, the majority of non-recycled waste is deposited in landfill sites. This accounts for 48% of total waste generated, which increased by 12% from 2001 to 2007 (ABS, 2010) and continues to do so. Due to this, the efficient use of available space is an extremely important matter. It is vital that we utilise modern methods to ensure that fewer landfill sites are required whilst still protecting safety of the environment and surrounding communities.

The South Australian Environmental Protection Authority (SAEPA) has set strict guidelines for the construction of landfill sites to ensure that barriers are in place, protecting groundwater from leachate contamination. These specify that a CCL be a minimum of one metre thick, with a permeability of no more than 1×10^{-9} ms^{-1} (SAEPA, 2007).

Clay continues to be the best possible, readily available material today and the most significant factors affecting CCL performance are permeability and thickness (Daniel, 1987). In order to reduce the thickness of a CCL without impeding its barrier performance, the permeability of the clay used must be reduced. If this can be achieved, it will allow a larger volume of waste to be deposited in each landfill site; significantly increasing waste disposal efficiency and reduced construction costs.

A great deal of research has been undertaken to improve the permeability of CCLs by amending clay with the introduction of various additives, such as fly ash and silica fume (Kalkan, 2009; Kalkan and Akbalut, 2004; Shankar and Phanikumar, 2012; Sun et al., 2012).

The objectives of this paper are to assess the ability of Polycom to reduce the permeability of the Clay, and to investigate the effect leachate has upon the permeability of the amended clay.

Polycom is a polymer that has traditionally been used to stabilize soils for road construction. The polymer is believed to increase the strength, flexibility and water resistance of soils. However, the polymer's effect on soil permeability has never been tested.

2. METHODOLOGY

2.1 Materials

2.1.1Clay

The clay used for this research was Hindmarsh Clay, which is currently used in construction of CCLs in South Australia.

2.1.2Leachate

The leachate used in long-term testing was supplied by Transpacific. It was taken from their Inkerman landfill site.

2.1.3Polycom

Polycom is a commercially available polymer traditionally used to stabilise soils for road construction. Samples were donated by NGP Roads through Polycom representative Charlie Misale who suggested that 3 kilograms of Polycom is sufficient to stabilise 50 cubic metres of clay. It was noted that any additional Polycom would have no increased positive effect on reducing permeability (Pers. Comm.). During compaction it was determined that the recommended volume of polymer was too small to keep consistency throughout the sample. For this reason 2% was used.

2.2 Flexible Wall Test

Flexible wall testing was undertaken as detailed in AS 1289.6.7.3-1999. However, due to a lack of equipment in the Adelaide University laboratories preventing following this standard exactly, there were some differences in the method. The issues with the apparatus were; the inability to produce an effluent pressure on the sample as well as the inability to measure the permeability of a sample with diameter greater than 38 mm. This meant that the results, while accurate, needed to be verified with the proper equipment to follow AS 1289.6.7.3-1999 properly. The additional testing was undertaken by Golder and Associates.

Samples were pre-prepared by combining, mixing and compacting in the University Laboratories before being sent to Golder and Associates to maintain consistency. The samples sent to Golder and Associates differed only in diameter, which was 50mm to meet the requirements of AS 1289.6.7.3-1999.

2.3 Long Term Tests

When following the Australian standards to measure permeability, leachate could not be used as a permeating fluid as it would have to flow through expensive testing equipment and may contaminate it for future use. To overcome this issue a long-term permeability test was designed. This test allowed the investigation of the effects of leachate on the permeability of clay and clay amended with Polycom.

It was important to measure the permeability over time because the changes expected may require prolonged exposure to leachate, greater than four to five days (considered short-term). As such the long-term permeability test was designed to measure the permeability over the period of three weeks to determine if a change in chemical composition of clay due to permeating fluid (in this case leachate) other than water, would cause the soil's permeability to increase. This study is useful when designing CCLs as leachate is a known permeate that can have an effect on the composition of clay.

2.3.1 Hydraulic Head

The SAEPA guidelines (2007) for landfill give the maximum allowable hydraulic head in a landfill site to be 300 mm. This is therefore the head that was used and kept constant for the duration of the test. By using the maximum allowable head the test gives the worst-case scenario for permeability in a South Australian landfill. To keep the head constant at approximately 300 mm the tests were topped up when the level went down by more than 10 mm. This was deemed to be an insignificant drop and therefore have negligible effect on the results. The tests were checked a minimum of once every three days and topped up depending on the rate at which the level had decreased.

2.3.2 Edge Effect for Long Term Tests

Edge effect is the effect of permeating fluid running down the side of a sample between the soil and the edge of the mould, instead of only through the soil. Since the soil being used in this research is extremely impermeable already, the errors creating from this were deemed to be too great and a method to reduce them was developed.

It was clear that a smooth edge was going to cause a bigger problem than a rough edge. Options, such as sand papering the inside of the sample mould were considered before it was determined that the best surface for the clay sample to be compacted against was clay. This would reduce the chance of fissure(s) forming, adversely affecting the results. Super glue was determined to be the most effective adhesive to hold the clay to the wall of the mould.

The method formulated, after a series of tests, was to apply the glue in sections to the inside of the mould and after dip the mould into a pile of dry soil. The soil had to be dry so to actively adhere to the walls of the mould. Another issue with wet soil was that when it did stick to the mould, the grain size was too high due to clumping, protruding too far into the mould. The surface was visually inspected to ensure that the interior was completely covered to a height that would be greater than the thickness of the sample and that there were no gaps or imperfections. Once a satisfactory level of cover had been achieved the mould was left to dry for 24 hours before the mould was used.

2.3.3 Collection

After the leachate had seeped through the soil it travelled through a plastic plate with drilled seepage holes. This plate held the soil in place so that it did not fall into the catchment beakers, keeping the sample intact. The permeating fluid; once travelled through the clay layer dripped through a funnel and into a beaker. The beaker was weighed weekly to determine the permeability of each sample by converting weight of permeating fluid into volume and determining flow based on the time between weighing. This made it possible to determine whether the rate of permeability changes over an extended period of time. Figure 1 shows the design of a single testing unit.

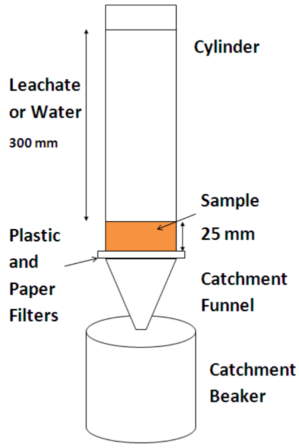

Figure 1 – Long Term Test Design

2.3.4 Clay Preparation

Clay preparation was one of the most important aspects of testing. It is imperative that all test samples have the same clay properties, such as moisture content and grain size, to ensure accurate and unbiased results.

2.3.4.1 Compaction

There are many methods of compacting a sample for use in a tri-axial machine. Research by Sridharan and Silapullaiah (2005) describes a mini compaction apparatus, however this apparatus was not available and therefore a similar solution was developed before testing could begin. The solution involved apparatus that compacted the sample from both sides at once, using a falling hammer. For testing in the tri-axial apparatus a ratio of 2:1 (height to diameter) is acceptable. The height of each sample was 76 mm. The weight of each sample was 172.8 grams, which corresponds to the optimum compaction of a sample this size as determined during compaction testing.

The long-term test sample's height and diameter were 25 mm and 100 mm respectively. To ensure the same compaction as the flexible wall tests, the number of layers and blows using the falling hammer was scaled in proportion to the dimensions of the two tests. One layer with nine blows was found to provide the optimum compaction for this test.

2.3.4.2 Pre-Hydration

The method used for flexible wall testing is that of backpressure saturation. The method used for these tests followed the Australia Standards: AS 1289.6.7.3-1999. The pre-hydration method chosen for this testing was a gravity fed system, simply allowing distilled water to sit on top of and permeate the soil for 24 hours. As the thickness of these samples is relatively thin (25 mm) this time was deemed to be appropriate.

2.3.4.3 Addition of Polycom to Clay Sample

The preferred method of adding an additive to a clay sample is to first measure out the required amount of clay, additive and water in separate containers. The additive and clay are then mixed using an egg beater until the mixture is uniform. The distilled water can then be added slowly, to achieve the optimum moisture content, until the mixture becomes uniform. The optimum moisture content for this clay type was found following AS 1289.5.1.1 to be 16.3%.

Due to the relatively low thickness of the long-term test samples, to achieve uniform compaction the soil had to be separated into small pieces before being placed in the mould. Without this step the samples did not evenly distribute around the mould, causing fissures and uneven thickness, as well as poor compaction.

3. RESULTS

3.1 Golder and Associates' Flexible Wall Tests

The tests required a total of approximately 4 days each to complete. Unlike the tri-axial machines in Adelaide University's geotechnical lab which are limited to 2 pressure controllers, these tri-axial machines had 3. This allowed for separate pressures to be set at the cell, influent and effluent (or wall, top and base of the specimen). Pressures used were 400, 350 and 300 kilopascals for cell, influent and effluent; respectively.

Table 2 – Results, received from Golder Associates

Sample	Permeability (ms^{-1})
$Clay_{(Polycom)}$	**1.70×10^{-11}**
Clay	2.50×10^{-11}

The results shown in table 2 suggest that Polycom possesses the ability reduce the permeability of Hindmarsh clay samples. This additive was able to reduce permeability from 2.5 to 1.7 ($\times10^{-11}$ ms^{-1}); an approximate reduction of 32%.

3.1.1 Clay Sample

The initial permeability of the Hindmarsh clay samples (2.5×10^{-11} ms^{-1}) is much lower than the clays used in the research papers assessed, such as 1.75×10^{-9} ms^{-1} by Kalkan (2009) and 9.7×10^{-9} ms^{-1} by Shankar and Phanikumar (2012). Their research sought to decrease permeability in clay to the level required by their respective environmental protection authority's safe levels; whereas this research sought to decrease permeability indefinitely. The clay samples assessed by Kalkan (2009) and Shankar and Phanikumar (2012) each had LL, PL and PI moisture content percentages of 75, 35 and 37; and 80, 28 and 52, respectively. This was considerably higher than the Hindmarsh clay's LL, PL and PI of moisture content percentages 51, 19.6 and 31.6. This may have been due to the clay-sized particle content of Hindmarsh clay being considerably lower, average of 10%, than those detailed by Kalkan (2009) and Shankar and Phanikumar (2012) of 69% and 32%, respectively; and, in turn, be attributed as the reason for a significantly lower permeability.

By examining Figure 2 below it can be seen that the clay on its own does provide permeability readings distributed as should be expected from this test. Though a concerning aspect of the graph is the 'kick' at the end.

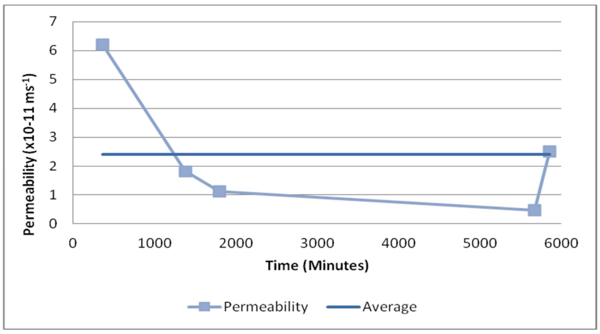

Figure 2 – Golder permeability of Clay sample.

This increase in permeability demonstrates inconsistency in the test data, particularly the non-asymptotic nature of the graph. It would have been beneficial to leave the sample in the apparatus for a longer period of time, observing the permeability over the next few days. This would have allowed us to see if any further variance occurred in the data and, more importantly, if the permeability continued to increase by a significant factor.

3.1.2 Clay (Polycom)

As Polycom has never been tested for its ability to reduce the permeability of clay, instead being primarily used as a soil stabiliser, there are no outside sources with which to compare these results to. It can be seen (Table 2) that this additive, was able to reduce the permeability of our Hindmarsh clay sample by approximately 32%; to 1.70 x 10^{-11} ms^{-1}. It may be concluded that Polycom, in this testing environment, has the ability to reduce the permeability of very low permeability clays and may significantly reduce permeability in much higher permeability clays such as those tested by Kalkan (2009) and Shankar and Phanikumar (2012).

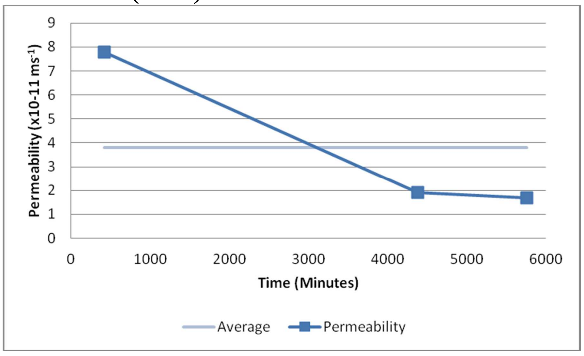

Figure 3 –Golder permeability of Clay (Polycom).

Looking at Figure 3 it could be observed that the Polycom sample may still be trending down after its final reading. Therefore it is possible that the permeability could have been lower than that recorded. Further testing was necessary to determine whether Polycom could withstand the degrading effects of leachate and time. Though the results produced here were promising.

3.2 Adelaide University Flexible Wall Tests

Flexible wall tests were undertaken in the University of Adelaide's laboratory to determine the permeability of the clay and the amended clay samples. AS 1289.6.7.3-1999 was followed as well as possible; however there were restrictions due to the equipment available. Samples were tested in the laboratories to observe a number of features of the soil as well as to compare to the results found by Golder and Associates. The samples were left in the tri-axial apparatus for a longer duration than would be expected during permeability testing detailed by AS 1289.6.7.3-1999 (nine days). This was to compare the effects of pressure on the samples over a longer time period than is usually tested as well as to observe any changes in permeability over this extended time frame.

3.2.1 Clay Sample

The clay sample was left in for nine days, four days being easily enough time to determine the permeability, so that the effects of a high pressure on the soil could be observed over a longer period of time than would otherwise be tested. The trend line of the graph of volume vs. time had a residual squared value of 0.9992, which is extremely high and leads to believe that the sample was not affected by the pressure.

The graph has a slope of 0.003, which gives a permeability of 3.0815 x 10^{-9} ms^{-1} as shown in Figure 5. This value does not take into account the high pressure that was applied to the sample, which skews the permeability calculation to make the soil seem less permeable. Taking into account the influent pressure of 385 kPa and the effluent pressure, which was atmospheric pressure, the hydraulic gradient becomes 29.07 m. The permeability of this sample is therefore 8.06 x 10^{-12} ms^{-1}. It is important to note that the volume values given for each sample are arbitrary. Where the change in volume is important, the actual volume values do not influence the permeability of a sample.

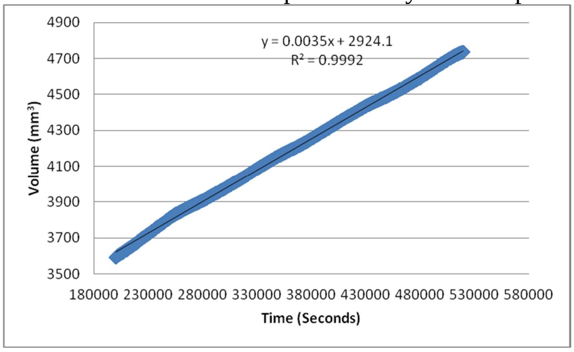

Figure 5 –Clay Sample, Volume vs. Time

The value found is an average of the permeability over the nine days. As the test ran for so long the influence that the initial readings have on the overall value is diminished considerably and has a negligible influence on the overall results. The permeability of the amended sample was also determined in this way. Figure 6 shows the daily permeability readings of the clay sample.

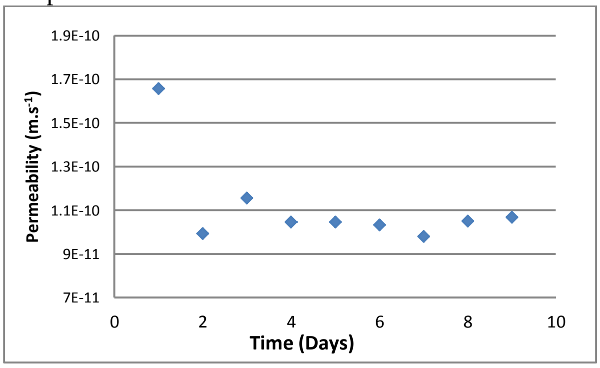

Figure 6 – Clay sample, daily permeability readings

3.2.2 Clay (Polycom)

The Permeability of the sample amended with Polycom is lower, than the permeability of the clay sample, which is consistent with the values of permeability calculated by Golder and Associates. The permeability as determined in the laboratory is 6.89 x 10^{-12} ms^{-1}, which is excellent. This is an improvement of 14.5%.

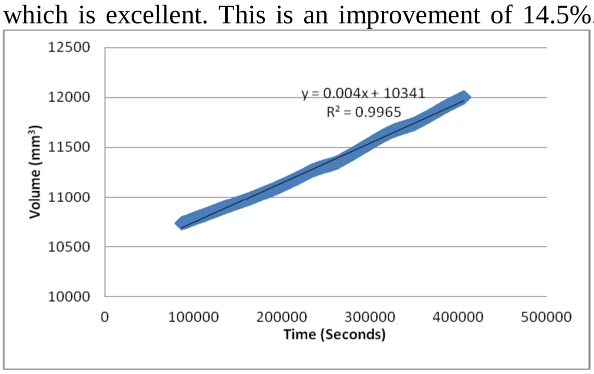

Figure 7 – Polycom Sample, Volume vs. Time

The worrying aspect of Figure 7 is that the sample seems less consistent than the clay sample, which is unexpected, having a residual squared value of 0.9965. Figure 8 shows the daily permeability readings of the Polycom sample. The variation of these values is slightly larger than the clay sample; being 5.80 x 10^{-11} as opposed to the clay sample having variation of 5.42 x 10^{-11}. However, this difference in variation is extremely small and does not take into account that the daily permeabilities for the sample amended with Polycom are trending down. This suggests that the permeability of the sample was still improving when the test was stopped. The marginally lesser variance in the clay sample is far outweighed by this.

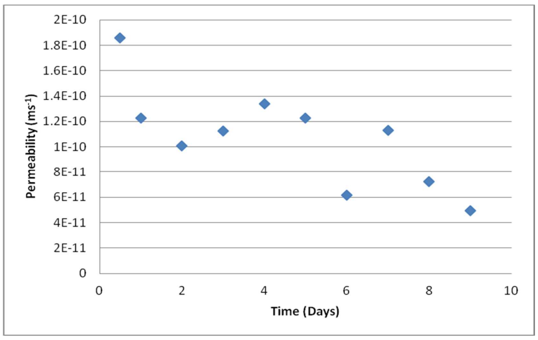

Figure 8 – Polycom, daily permeability readings

3.2.3 Flexible Wall Conclusion

Based on the permeability values from both the flexible wall testing undertaken by the group and Golder and Associates, Polycom is expected to improve the permeability of a clay for use in a CCL. While the consistency of the clay sample as tested by the group was found to be slightly more consistent it was concluded that this was overshadowed by the downward trend of the amended samples' daily permeability readings.

3.3 Long-term tests

3.3.1 Clay Sample

Figure 9 shows that the clay sample consistently produced a higher permeability when permeated by leachate compared to water, and after three weeks the permeability has increased by a factor of 10. It should be noted that the clay did not fail, as the permeability is still well below 1 x 10^{-9} ms^{-1}, which is the maximum permeability as required by the SAEPA.

Contrary to our results, Guyonnet, et al. (2005) indicated that leachate can have positive effects on permeability by allowing cation exchange and forming a 'gel phase'. Kolstad et al. (2004) also found that leachate should not have a detrimental effect on clay however they do mention that 'strong' leachates would have the power to greatly increase the permeability of clay. Therefore it is possible that the leachate's composition is what has caused the negative effects. It is also possible that the Hindmarsh clay's composition is particularly reactive. As the leachate and Hindmarsh Clay used for this testing has been taken from a landfill site which uses the same clay, it can be concluded that the effects of leachate on the CCLs at this landfill site would be similar. Though, this could also be due to the differences in soil properties as discussed in Section 3.1.1.

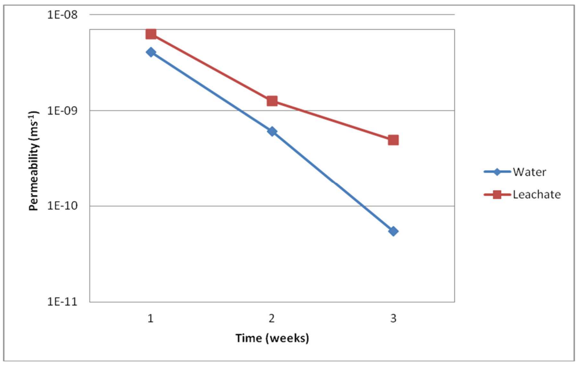

Figure 9 – Permeability of clay sample, water and leachate permeation over three weeks.

3.3.1 Clay (Polycom)

After being permeated by both water and leachate for three weeks the Polycom sample was able to achieve a very low permeability of 1.4 x 10^{-12} ms^{-1} in both circumstances as shown in Figure 10. As little information is known about Polycom this is significant as it can be established that Polycom does not fail when in contact with leachate after three weeks and it is likely that its addition reduces the permeability significantly under these conditions.

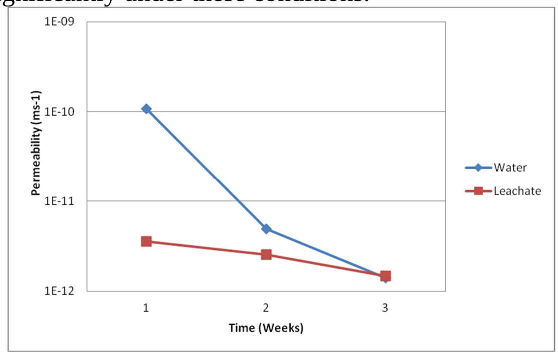

Figure 10 – Permeability of the Polycom sample, water and leachate permeation over three weeks.

3.3.2 Long-Term Test Conclusion

These results indicate that the sample amended with Polycom was not been negatively affected by leachate, whereas the clay sample was. This is a positive outcome as the effects of leachate on a CCL are of great importance and any additive chosen to amend the clay must be able to perform whilst under these conditions.

4. CONCLUSION

The samples amended with Polycom outperformed the clay samples consistently. The permeabilities found using the flexible wall testing method by both Golder and Associates and in the University of Adelaide's laboratories were considerably lower. The variance of data was extremely close, with the clay sample being slightly more consistent during the flexible wall testing performed. However, these variations are considered to be negligible as the amended samples performed considerably better in terms of permeability.

Polycom would allow the thickness of a CCL constructed with Hindmarsh Clay to be reduced to 0.017 m. It is important to note that this thickness is only hypothetical; in practice a CCL with a thickness such as this will not be successful in protecting the surrounding area, due to effects such as cracking in wetting/drying cycles, shear stress loading imposed on the liner itself and puncturing.

The long term permeability test allowed the effect of leachate on the amended clay's permeability to be observed and compared to results found using the same apparatus with distilled water. It was found that the clay sample was negatively affected by leachate and the amended sample achieved a lower permeability with leachate as the permeating fluid than the clay sample did with distilled water. It is recommended Polycom be tested further so that it may be used commercially.

After completing flexible wall testing and long-term testing (using leachate) it was found that Polycom gave the best results by all criteria. It achieved the greatest permeability reductions at 32% recorded by Golder and Associates and 14.5% recorded at the University of Adelaide. It was not negatively affected by leachate. Subject to further positive results, particularly in assessing the strength of a thinner liner, the potential exists for the SAEPA to consider reducing the required thickness of CCLs with the amendment of clay using Polycom.

5. REFERENCES

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