HYDRAULIC PERFORMANCE OF GEOSYNTHETIC CLAY LINERS (GCLS) COMPARED WITH COMPACTED CLAY LINERS (CCLS) IN LANDFILL LINING SYSTEMS

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ABSTRACT

Geosynthetic Clay Liner (GCL) is the most common term for a composite hydraulic barrier made of geosynthetics and high swelling bentonite clay as the sealing element. They are also known as Clay Geosynthetic Barriers (GBR-C). The widest spread type of GCL is needle-punched, where the sealing bentonite clay is sandwiched between two geosynthetic geotextiles. Other forms of GCLs may also additionally contain a coating or a lamination to either improve the strength of the composite or add other features to the GCL such as a root or a desiccation barrier and may even be used to improve the hydraulic barrier. As geosynthetic clay liners (GCLs) are frequently and often used to replace hard to build compacted clay liners (CCLs) it is useful to compare the hydraulic performance of each liner with respect to overall leakage to demonstrate the heightened performance that can be obtained with needlepunched GCLs. The hydraulic performance of liners is often evaluated by their total leakage and their breakthrough time. Total leakage is simply defined as the volume of leachate that passes through the liner over a given time period. Breakthrough time is defined as the length of time required for leachate to pass through the liner. This paper will compare GCLs and compacted clay liners (CCLs) with each other based on rational mathematical equations in regard to hydraulic performance. Further it will highlight the benefits of GCL products over traditional natural materials, when used for composite liner applications in landfills and discusses several common techniques used in their installation, emphasizing the role that equipment plays in ensuring a successful installation. At the end real field study results will also be presented, demonstrating the efficiency of the different systems.

Keywords: Geosynthetic clay liner, compacted clay, hydraulic conductivity, permeability, multicomponent

INTRODUCTION

Before the widespread use of composite liner systems, it was common for geomembranes or compacted clay liners to be relied upon as the sole hydraulic barrier for landfill base liners and closures. While this approach is still used in some cases, the CCL is often being replaced by a GCL component. With more than one choice for the clay component, the options need to be examined to determine what product will most suitably address the needs of the project. The following listing provides a general point/counterpoint comparison of a GCL when contrasted to a CCL.

Compacted Clay Liner Advantages

- Long history of (successful?) use.
- Regulatory approval is virtually assured.
- Thickness ensures that layer will not be breached by puncture.
- Thickness provides physical separation between waste and surface environment.
- Cost can be low if material is locally available.
- Greater capacity for attenuation.
- Familiar material to geologists and geotechnical engineers.

Compacted Clay Liner Disadvantages

- Susceptible to desiccation cracking.
- Must be protected from freezing.
- Very low resistance to cracking from differential settlement.
- Difficult to compact soil above compressible waste.
- Suitable quality borrow source not always locally available.
- Difficult to repair if damaged.
- Slow construction.
- Flow through possible macrostructures.

- Sensitive to construction.
- Concerns over interface shear strengths.

Geosynthetic Clay Liner Advantages

- Rapid installation.
- Very low hydraulic conductivity to water if properly installed.
- Low, predictable cost.
- Excellent freeze-thaw resistance.
- Can withstand large differential settlement.
- Excellent self-sealing characteristics.
- Manufactured highly quality controlled consistency.
- Low volume consumed by liner.
- Easy to repair.
- Not as sensitive to installation.

Geosynthetic Clay Liner Disadvantages

- Possible ion exchange
- Potential concerns over interface shear strengths.
- GCLs can be punctured during or after installation.
- Dry bentonite (e. g., at time of installation) is not impermeable to gas.

This illustrates the attributes of each type of clay liner material for a single liner design. It is unmistakable from even a basic comparison that the majority of significant benefits may be obtained with the GCL - and while not discussed in detail in this paper, typically at a lower cost than the CCL.

In composite liner systems where a clay liner is combined with a geomembrane the clay component of the composite liner must perform at the same minimum level as it would if used alone whether it is a GCL or a CCL. Therefore, the clay liner selection should be based on the best overall performing liner exhibiting the fewest deficiencies and the most positive attributes.

While the most significant and arguably one of very few shortcomings of the GCL is its potential for puncture, a GCLs susceptibility to puncture is not a product defect or directly related to its installation. GCL puncture is associated with design or operational procedures subsequent to the liner system installation and can be controlled and/or minimized through operational procedures.

PERMETION THROUGH LINER SYSTEMS

As geosynthetic clay liners (GCLs) are frequently used in lieu of compacted clay liners (CCLs), it is useful to compare the hydraulic performance of each liner with respect to overall leakage to demonstrate the heightened performance that can be obtained with GCLs.

Comparison Assumptions: Several fundamental assumptions are made in this analysis to allow for an equitable comparison.

1) It is first assumed that Darcy's Law is applicable to predict the leakage rates from both the CCL as well as the GCL. Extensive study by many researchers has corroborated this assumption under the condition that the liners are uniform in consistency and do not contain any preferential flow pathways such as cracks.

Darcian flow is a valid assumption for GCLs, as its high swelling sodium bentonite clay hydrates to form a uniform, dense, relatively “plastic” hydraulic barrier that resists cracking in its hydrated state.

Conversely, CCLs have been shown to contain a network of preferential flow pathways which are due to desiccation cracking, inconsistent mixing as well as poor bonding between individual lifts. The result is a randomly connected network of horizontal and vertical flow paths that may lead to field permeability values far higher than what would be mathematically predicted by Darcy's Law, and "breakthrough" of leakage much quicker than mathematically predicted. However, for purposes of this comparison, it is assumed that the CCL contains no such preferential flow paths and that its hydraulic characteristics are completely uniform, although research in Anderson et al. (1991) has shown that it is unlikely these conditions would ever be achieved in the field.

2) It is also assumed that the liners are both bottom liners in a landfill which contains a leachate collection system such that the maximum hydraulic head on the liner is 300mm and the confining stress is approximately 200kPa (approximately 15m of waste). While a GCL or a CCL would not be used as the sole hydraulic barrier in a landfill cell, the geomembrane component typically used over the clay component will not be considered in the performance calculations.

3) It is further assumed that the CCL is 500mm in thickness with a permeability of 1×10^{-9} m/s, and that the GCL is 10mm in thickness with a permeability of 3×10^{-11} m/s.

Performance Parameters: The hydraulic performance of liners is often evaluated by their total leakage and their breakthrough time. Total leakage is simply defined as the volume of leachate that passes through the liner over a given time period. Breakthrough time is defined as the length of time required for leachate to pass through the liner.

While Darcy's Law appears to be a valid leakage prediction tool, research has shown that mathematical predictions of the breakthrough time are often quite inaccurate. Due to the inconsistencies of the CCL as described above, CCL characteristics, which control flow can be difficult to quantify. Therefore, the CCL breakthrough time is conservatively estimated.

While this comparison calculates both total leakage as well as the theoretical breakthrough time, it's important to note that today's designers recognize that breakthrough time is irrelevant when the function of a liner is to maximize containment.

Leakage Comparison: The following Darcy's Law comparison presents estimated leakage rates from two hypothetical liner designs (a GCL with a thickness of 1cm compared with a compacted clay liner with a thickness of 500mm, both with a constant water head above of 300mm):

Leakage Through a Needle-Punched GCL

Darcy's Law states that leakage may be expressed as Q = k x i x A, where

Q = total liner leakage in m^3/ha/day

k = 1.5 x 10^{-11}m/s (@ 200kPa

i = Gradient = (hydraulic head + GCL thickness)/liner thickness

i = (300mm + 10mm)/10mm = 31

A = 1 ha = 10,000m^2

Q = 3 x 10^{-11}m/s x 49 x 10,000m^2 x (60s x 60min x 24hours = 0.46 m^3/ha/day

Leakage Through Compacted Clay Liner

Again, Q = k i A, where

Q = total liner leakage in m3/ha/day

k = 1 x 10^{-9}m/s

i = (hydraulic head + liner thickness)/liner thickness = (30 + 50)/50 = 1.6

A = 1ha = 10,000m^2

Q = 1 x 10^{-9}m/s x 1.6 x 10,000m^2 x (60s x 60min x 24hours) = 1.38 m^3/ha/day

This idealized analysis shows that, relative to CCLs, the lower permeability of needle-punched GCLs by far outweighs the effects of the higher hydraulic gradient and results in almost 66% less leakage, if comparing virgin installed material. This analysis can be repeated at various gradients to demonstrate that needle-punched GCLs will provide superior performance when examined at the gradients common in landfill cells.

However, it must be noted that CCLs will only perform as a liner if installed properly, especially considering the important criteria optimum density and moisture content. In areas with higher temperatures (semi-arid and arid) and/or areas with a lot of rain, it is nearly impossible to ensure an ideal installation condition to ensure a well functioning CCL after installation. Here needle-punched GCLs show one of their many benefits. More or less it is just an installation and cover process.

Breakthrough Time: Because the previous analysis has shown that the total leakage from needle-punched GCLs is less than through the CCL, a comparison of breakthrough times is in effect irrelevant. Based on this assumption, one can expected a breakthrough time of approx. 5 years with a 50cm thick compacted clay liner, based on Workman et al. (1989) in Fig. 1.

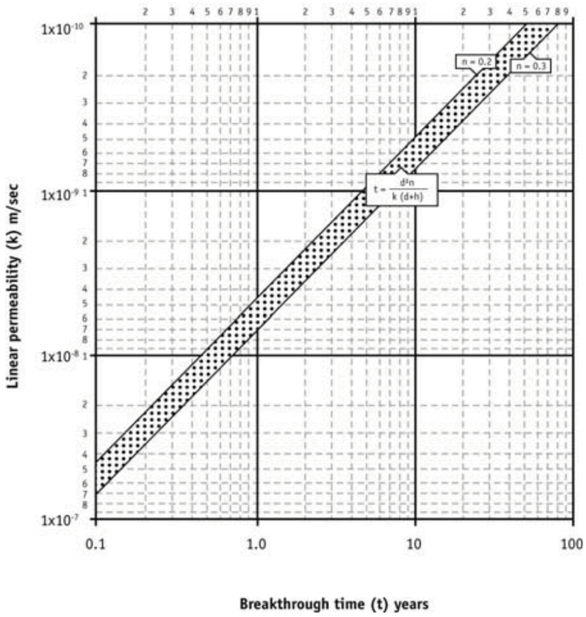

Fig. 1. Calculated breakthrough time for a 1m thick compacted clay liner and 300mm water head.

Rather than perform complex mathematical calculations which are difficult to verify, conservative assumptions have been used to investigate the influence of breakthrough time on total leakage. For this comparison, it is assumed that the breakthrough time for the GCL is instantaneous; in other words, leakage penetrates through the GCL, immediately. This, of course, is not the case but is the most conservative assumption that can be made. For the CCL, it is assumed that breakthrough occurs after 5 years. This is confirmed by research data, as can be seen in Fig. 1. This again is a very conservative estimate, and the actual breakthrough time is likely to be shorter (Goode et al., 1990).

Further, research data (Melchior et al. 2010) clearly shows that after approx. 5 years the permeation rate through the compacted clay liner (CCL) dramatically increases to rates which should be totally unacceptable for a liner system (Fig. 2).

Data from similar test trials with needle-punched GCLs on the other hand show that even after 12 years of testing the permeation rate of needle-punched GCLs with powder bentonite are constantly low (Fig. 3) and do not show a dramatically increase as can be seen with CCLs. The tested conditions for the lysimeters where similar to the research data from Fig. 2 (1 m cover soil) and the total cumulative leakage from each GCL liner is represented graphically in Fig. 3 as a function of time.

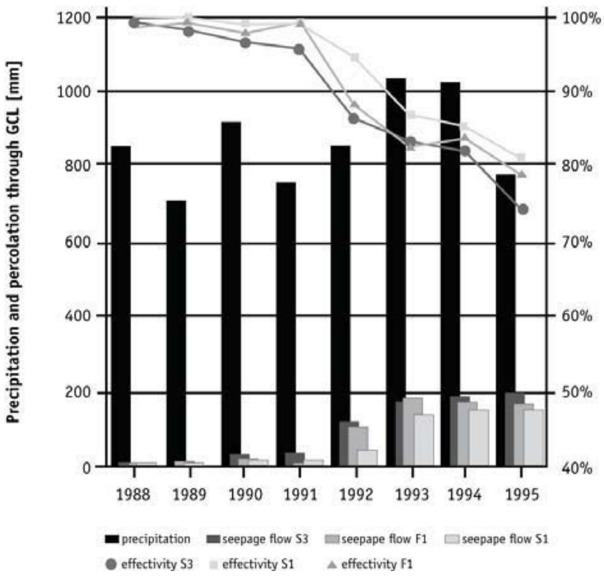

Fig. 2 Annual totals of precipitation of compacted clay liners from 1988 to1995 in mm/year (under 1 m cover soil)

Figure 3 summarizes the accumulated data over the 12 year period or precipitation, drainage run-off over the GCL, the estimated yearly permeation based on a regulatory recommendation of maximum 10mm/year, as well as the permeation performance of GCLs with granular and powder bentonite (Muller-Kirchenbauer et al., 2010).

It can clearly bee seen that GCLs with granular bentonite shows after approx. 6 years a higher permeation than the accumulated regulatory recommendation of maximum 10mm/year. The GCL with powdered bentonite does not exceed the accumulated 10mm/year value, even after 12 years. The difference is roughly a factor of 10 in favor to powdered bentonite.

From the standpoint of minimizing leakage, it is clear from this comparison that although the breakthrough time for the needlepunched GCL is shorter than that for a theoretically perfectly constructed CCL, the overall leakage is much less except at the very beginning of the life of the liner system.

A CCL would be the preferred liner only if the design life (including post-closure) of the facility were to be less than 5 years, based on the conservative initial breakthrough time assumed for the CCL. Studies have shown the initial breakthrough time to in fact be as low as several hours as flow was able to short circuit the compacted clay through a matrix of macropores (Rogowski, 1990).

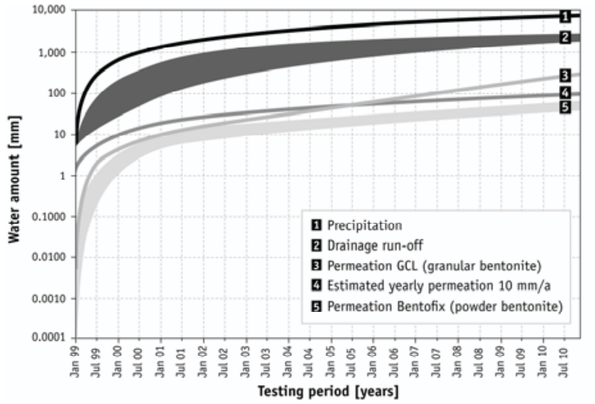

Fig. 3 Accumulated data from lysimeter test trials on GCL field performance indicating a better performance of powdered bentonite compared to granular bentonite

MULTICOMPONENT GCL

Most recently, multicomponent GCLs (Fig. 4) are introduced to the market. Either a thin plastic barrier is attached to one geotextile component of the GCL or a durable polyolefin polymer is firmly coated to the slit-film woven geotextile component of the GCL. This development enables GCLs to challenge particular site conditions where the use of GCLs has previously been limited.

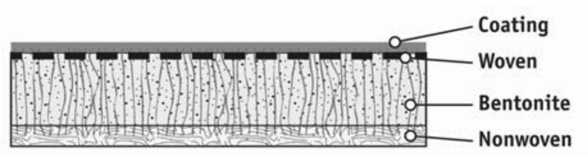

Fig. 4 Typical cross-section of a needle-punched multi-component GCL with a coating

The following definition proposals are currently being discussed in the ASTM D35 terminology task group and might be added in future in the ASTM terminology standard D4439.

multicomponent GCL, n - GCL with an attached film, coating, or membrane decreasing the hydraulic conductivity or protecting the clay core or both.

adhered geosynthetic clay liner (GCL), n - GCL product in which the clay component is bonded to a film or membrane by adhesion.

coated GCL, n - GCL product with at least one layer of a synthetic substance applied to the GCL as a fluid and allowed to solidify.

Needlepunched GCLs have a strong history as a stand-alone barrier, largely due to the high grade of powered sodium bentonite used in the GCL's construction. This sodium bentonite exhibits high swelling behavior, low water permeability, excellent water absorption and retention capacity, and a unique self-sealing/-healing effect. These exceptional capabilities of the bentonite remain, even with the use of a polymer coating on GCL.

This extra coating simply adds its advantages to the GCL which increases the GCL performance. The coating improves overall performance while further lowering the hydraulic conductivity of the GCL. With these advantages now combined, needlepunched GCLs outperform nearly any sealing system in regard to hydraulic conductivity during the service life of the coating and beyond.

The determination of the hydraulic conductivity is important for all sealing products and therefore also important for GCLs. The current test method ASTM D5887 was developed based on single component GCLs. Single component GCLs are considered to be GCLs where the primary and only sealing barrier is a bentonite based core. However, the development with GCLs continued and in the past more and more multi-component GCLs where and are developed for various purposes. Since these additional additions to the GCL are mostly polymer based and behave like a thin geomembrane, a range of test devices which were developed for single component GCLs may not be appropriate for multi-component GCLs, due to possible side wall leakage in the test cell. This is specific the case for ASTM D5887 – the determination of the index flux and calculation of the hydraulic conductivity.

Chapter 1.2 of ASTM D 5887 describes that "This test method is applicable to GCL products having geotextile backing(s). It may not be applicable to GCL products with geomembrane backing(s)" tests of multi-component Geosynthetic Clay Liners are currently carried out based on this standard (EHRENBERG et al., 2012). However, the results are questionable and modifications are currently being discussed to allow testing with multi-component GCLs.

A comparison based on Darcy´s Law is yet not possible but the added coating to multi-component GCLs will definitely improve the ratio of performance of multicomponent GCLs versus a compacted clay liner.

CONCLUSIONS

While this illustrates the relative performance of a GCL versus a CCL, it does not take into account the enhanced performance obtained when either of these liners is used as a component of a composite liner system. In composite liner systems, the calculated leakage is perceptively lower and much more a function of the performance of the geomembrane component. Regardless, even in a composite liner system, the GCL will still provide greater containment when compared to the CCL.

The data and information presented herein convincingly demonstrate that the hydraulic performance of Geosynthetic Clay Liner is superior to that of a 500mm thick CCL, even when extremely conservative assumptions regarding the uniformity of CCL are made for the comparison.

Multicomponent GCLs additionally can improve the performance of GCLs and will then increase the performance gap in favor of GCLs, when being compared to compacted clay liners.

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