Self-healing of geosynthetic clay liners (GCLs) after extreme drying periods

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ABSTRACT: For decades Geosynthetic Clay Liners (GCLs) have been installed as a sealing element in civil engineering applications. They have proven to be economic solutions and show major advantages compared to mineral sealing systems such as compacted clay liners (CCL). An essential point in technical consideration of GCLs in comparison with mineral sealing systems is the GCL self-healing capability. Various tests in the last years show that thick CCLs desiccate during extreme drying periods even under 1 m cover soil and lose their sealing function. During a four-year testing program several excavations on landfill caps and test fields in Germany have been carried out. Samples have been taken and the permeability behaviour even under rigid site conditions have been examined. The paper will present data on the self-healing capacity of different GCLs under impact of low confining stress. The self-healing behaviour of the tested GCLs is statistically analyzed and described with a mathematic self-healing function even under harsh desiccation conditions. It will be shown that GCLs – even after long-term installation in landfill capping systems – withstand extreme drying periods and that the sealing function of the whole system will not be significantly influenced.

1 INTRODUCTION

In the second half of the nineties results from the „test plots Georgswerder“ showed a slight increase of permeability, questioning the suitability of GCLs in a very low confining stress (≈ 5 kPa) application. Although the (self) healing capacity of Bentofix® geosynthetic clay liners was proven in numerous excavations already published in Reuter et al. (1996), the available results at that time did not allow an assessment which was reliable from the scientifical point of view. With this paper, a four year study of testing and documentation on ion exchange of this type of geosynthetic clay liners under laboratory and in-situ conditions, on the self healing capacity after dry stress impact, as well on the forecast of the long-term performance of GCLs TASi alternatives after ion exchange and dry stress impact is finalized.

In this paper only projects were included in which the standard needlepunched GCL of one brand structure is comprising of a top cover geotextile and bottom carrier geotextile with one layer of encapsulated sodium bentonite, with a mass per unit area of 3000 to 5000 g/m². All tests on the hydraulic conductivity were carried out with a confining stress of 15 to 20 kN/m² and thus correspond to a soil cover of approx. 0.8 to 1.0 m. The test results may hence be transferred to nearly all standard applications of capping systems.

2 INVESTIGATIONS ON THE ION EXCHANGE

Theoretical basic infomation on bentonite, its water absorption and the swell behaviour are summarized in Egloffstein (1997). Since calcium is the cation which occurs most often in the soil solution of natural cover soils, the ion exchange of sodium against calcium and thus a modification of the geochemical environment has to be expected if a geosynthetic clay liner is used in such a geochemical environment. This is a natural slow process which occurs in two to three years following latest experience. No damage of the bentonite in its crystal structure or any other kind of mineralogic modification is implied with this. There are only effects on the swell behaviour and the hydraulic conductivity.

This is no new unkown finding of the nineties, but was already found out and documented previously in numerous comprehensive investigations (Dobras et al. (1993)). If the effect of ion exchange processes on the sealing performance of sodium GCLs shall be examined, only excavation samples from landfill projects may be taken into account if it is ensured that these samples were not subjected to any other influences besides the ionic exchange. Since this can actually never be excluded, it is recommended to simulate the influence of ion exchange in laboratory testing. For this purpose, normally long-term tests on the hydraulic conductivity are conducted in which the test liquid is exchanged against a highly saturated calcium salt solution after a preliminary hydration phase. Within a few weeks, the result is a time concentrated ion convertion and a permeability or permittivity process over the time as shown in Figure 1.

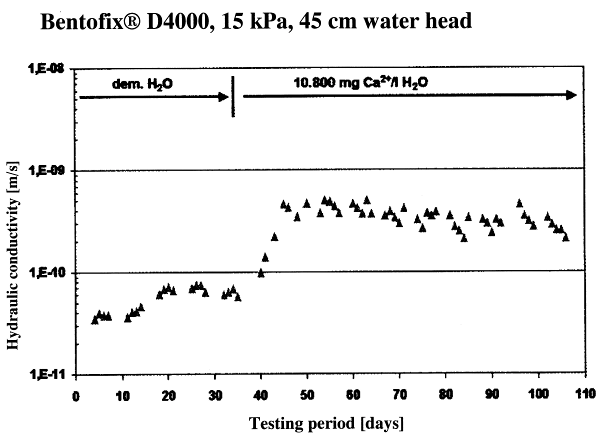

Figure 1. Naue Fasertechnik ion exchange testing.

Through the use of salt solutions, which - compared to natural soil solutions – have a 100 times higher concentration, worst-case-conditions are simulated. The results are according to ICP (1999), therefore Table 1 shows such test results on standard GCLs as installed in numerous landfill projects.

Table 1. Ion exchange factors MFPA Weimar.

Test conditions for the use of a test liquid with Ca = 10,800 mg/l	Permittivity factor based on Bentofix® QC data $\Psi = 5 \times 10^{-9}$ l/s
GCL D 4000	
confining stress 15 kN/m^2 i = 30	2,8
confining stress 50 kN/m^2 i = 150	4,4

The permittivity values after ion exchange shown in Table 1, which were retrieved by an independent material testing institute, confirm manufacturer's quality control test results. It may be assumed that the values for standard products are increased by a factor of 3 through ion exchange, compared to the production characteristics. Due to the previously explained time concentration method for ionic exchange, the use of a low confining stress (only 15 kN/m² - corresponds to appx 0.75 m soil cover) and a hydraulic gradient i = 30, these values are, compared to in-situ-conditions, clearly on the conservative side.

3 (SELF) HEALING AFTER ION EXCHANGE AND DESICCATION

During the procedure for obtaining the general certification for landfill caps in 1998, special Bentofix® geosynthetic clay liners were subjected to six weeks of dry stress / suction stress, lying appx 50 times over the permanent wilting point with pF = 5.6 to pF = 6. According to Baumgartl et al. (1998), the selected conditions referring to a depth of 1 m and for German climate conditions are lying on the conservative side so that desiccation safety is proved. However, in practice, the required sealing performance can often be achieved by using standard GCLs.

Prior to installation in such a case, an exact analysis of the desiccation behaviour of the sealing system under project specific conditions becomes necessary. In a first step it has to be proven that the specific GCL has an appropriate (self) healing capacity after ion exchange and under the planned conditions. Such a proof was conducted and published by Egloffstein et al. (1999). For this purpose, only those samples were taken from the excavations for which increased initial permittivities were recognized with a water content $w \leq 100$ % as well as ion exchange from sodium to calcium. 56 permeability tests from eight excavations on seven different landfill capping systems were selected for a statistical evaluation. The excavation samples cover GCL products with an age of up to five years after installation. All excavations were carried out between May and October, in the dry period of the hydrological year. The excavations were always accompanied by independent experts to assure the scientific backup. All tests were conducted by external laboratories and testing institutes, such as the laboratory of the testing institute for foundations and soil mechanics of the Technical University of Munich which conducted the permittivity tests.

After comprehensive statistical evaluation by the consulting company ICP, Karlsruhe, Germany, the time dependent process of re-hydration or the decrease of the permeability, as shown in Figure 2, was evaluated. The GCL self-healing function is based on statistical evaluations of 56 different permeability tests which are based on several years old ionic exchanged GCLs with a mass per unit area of 3000 to 5000 g/m² and a confining stress corresponding to appx 1.0 m soil cover.

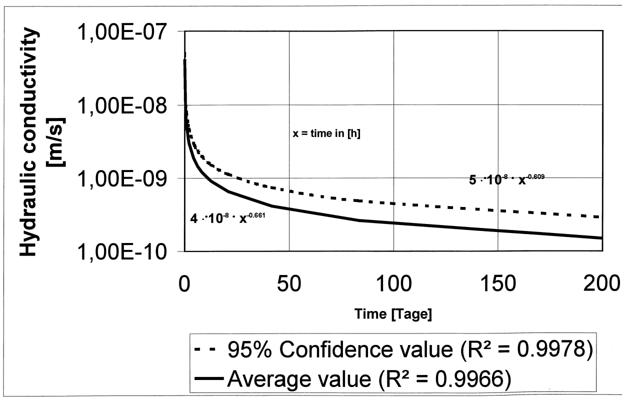

Figure 2. GCL (self) healing function after ion exchange.

The lower curve in Figure 2 shows the time development of all average permeability values. The quality of a statistical relationship between permeability and time is described by the regression coefficient, which – with R^2 = 0.9966 has a very high significance. Corresponding to the usual procedure used to assess construction products, the top curve completes the function which is limiting the 95 % area of confidence towards the disadvantageous side. The graphical presentation clearly shows: The increased initial permeability, which can be observed during the early re-hydration, is reduced within 24 hours after re-hydration to a value of k = 7 x 10^{-9} m/s (this value corresponds to the 95 % area of confidence towards the disadvantageous side on average 5 x 10^{-9} m/s). After 10 test days the permeability is only 2 x 10^{-9} m/s (also 95 % area of confidence) and appx one month after the beginning of the re-hydration, the relating value is only 9 x 10^{-10} m/s (95 % area of confidence, on average 5 x 10^{-10} m/s).

The fact that this positive GCL product behaviour is not a result of technical laboratory influences is shown by two other results:

1. Investigations on the (self) healing capacity of standard GCLs were documented by Maile (1996) under test plot conditions in a large-scale lysimeter of the University of Applied Sciences Essen: Simple re-hydration tests with an extreme water flow of more than 100 mm in a few minutes show a reduction of the initial permeability of k = 7 x 10^{-8} m/s to k = 2 x 10^{-10} m/s after four hydration steps. These permeability values confirm the above described (self) healing function.

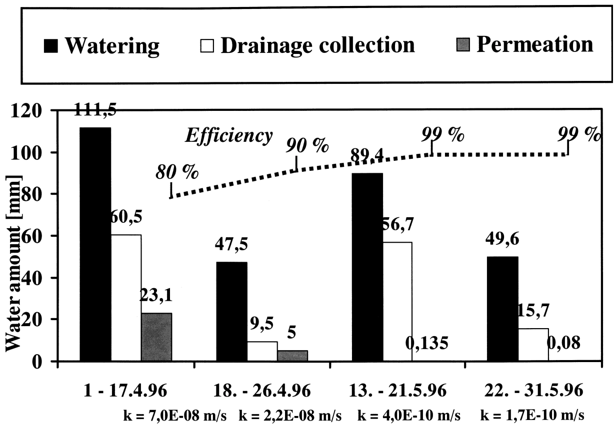

Figure 3. (Self) healing of the desiccated GCL BFG 5000 in the lysimeter test after four hydration events.

2. Furthermore, permeability tests in so-called fixed-wall-cells confirm the GCL self-healing capacity proven in the triaxial cells of the test institute of the Technical University Munich.

All above (self) healing properties were found out on standard GCL products which were subjected not only to an ion exchange but also to all usual project influences. These are, besides ion exchange and desiccation, influences from roots, frost/thaw, landfill gas and elongation strains from settlements of the landfill body, which, however, cannot be assessed separately concerning their impacts, due to missing measuring data on the landfill site.

4 FORECAST ON THE LONG-TERM EFFICIENCY

The proof of (self) healing is an essential step in the forecast on the long-term desiccation susceptible designs. The forecast on the long-term efficiency is the second step and is mainly based on an examination of the water balance in the planned sealing system. For an exact modelling of the water balance, the German Society for Geotechnics suggests in their recommendation E2-30 the use of the US American water balance model HELP, which has already been introduced in Germany, and gives recommendations for its application. Based on these recommendations, another HELP modification was performed, the computer processing of variable permeability values for any mineral sealing element. Due to program restrictions, only 22 variable k-values could be programmed as function over the time in this first available version. However, as described previously, the main part of the (self) healing function was registered.

Based on site specific climate data, water balance results have been determined for dry, medium or wet weather periods in this HELP efficiency model in order to compare the efficiency of any sealing systems to standard GCLs under extreme weather influences with the TASi (German Instructions for Municipal Waste) requirements.

As soon as dry periods in the interface drainage layer/sealing element exceed a critical time period (conservative depending on the weather period: 10 to 20 days) in the water balance results, a precipitous rise of the permeability is assumed in the Bentofix® efficiency model. The actual critical periods are influenced by the system structure, soil types and weather, as results from test plots and excavations showed. In case of a 1 m cover, intensive vegetation of the mixed grained recultivation layer, and hot, dry weather, the critical period is at least four weeks until changes of the structure occur in the investigated standard GCL.

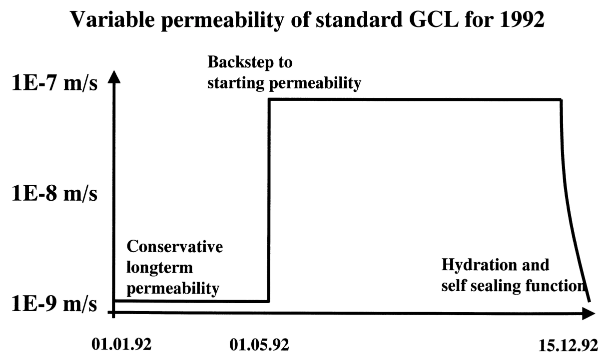

Figure 4. Variable permeabilities of GCL standard products according to Egloffstein (1999), model year 1992, location with little rainfall.

The variable permeability properties of the investigated standard GCL shown in Figure 4 follow the water balance which has been calculated for the selected project location and the basic sealing system (TASi alternative) as an example for the year 1992 with little rain. In the efficiency model the (self) healing function of the GCL is set from the time at which a new water inflow occurs in the interface drainage layer/sealing (beginning drainage flow, here: Dec. 15, 1992).

In the water balance calculation, the status of wetness at the interface drainage layer/sealing is continuously checked daily. Depending on the status, it is repeatedly leaped back to the increased initital permeability or the following day simulation, taking into account the decreasing permeability due to re-hydration. The complete simulation of any time period – normally at least one year – results in a statement on the efficiency of the sealing system in consideration of the factors ion exchange, desiccation and (self) healing which also have long-term effects.

Based on this conservative, scientifically secured model of forecast, location specific considerations for a comparison of system and profitability between this GCL and other sealing variants are made available.

5 APPLICATION IN LANDFILL ENGINEERING

Following the previously described model of efficiency, a system comparison between four different capping systems was carried out by Egloffstein (1999) (Figure 5). The system 1 contains compacted clay liner in the TASi structure for landfill class I and assumes – contrary to different experiences (Figure 6 Melchior 1993) – no negative desiccation effects.

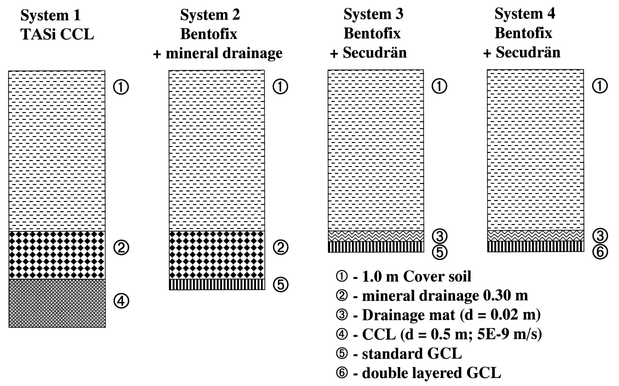

Figure 5. Structure of the layers of the four capping systems in comparison.

The systems 2 and 3 contain standard GCLs in combination with a mineral collection system according to TASi or a Secudrän® drainage mat resp. The forecasts on the residual percolation of both systems take into account the ion exchange and desiccation. The system 4 contains a GCL BZ/DZ 6000 in combination with a Secudrän® drainage mat; here only the ion exchange, not the desiccation was taken into account.

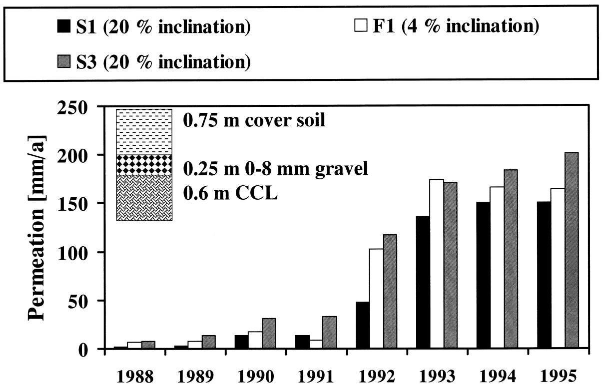

Figure 6. Percolation rates of different mineral cappings.

A well developed grass vegetation was assumed as recultivation, the recultivation soil was assumed as clayey to loamy sand, and a comparatively low slope inclination of 5 % was considered.

The results for the year 1992 are from the Berlin climate data from the Institute for Meteorology of the University Berlin and thus for a year with little rainfall on average in Germany (yearly rain 596 mm) (Figure 7).

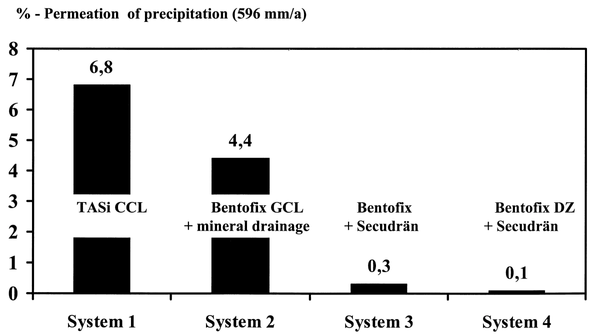

Figure 7.Residual percolation for the four capping systems (in percent of the rain).

The retrieved residual percolations would be significantly reduced assuming steeper slope inclinations. Nevertheless, it can be stated that all GCL systems, even the sealing systems with standard GCLs, fulfill the requirements of the Technical Instructions on Municipal Waste (TASi) landfill class I. These efficiency forecasts were based on results from excavated GCL products which had been subjected over many years to all impacts which are typical for capping systems in German climate conditions and construction procedures.

6 PLAUSIBILITY TESTS

As in all model investigations, the received results have to be scrutinised and compared to comparable measurings in practice. There is an appropriately structured and scientifically supervised capping system on a burden dust landfill in Luxembourg which is described in detail by Schnatmeyer (1998).

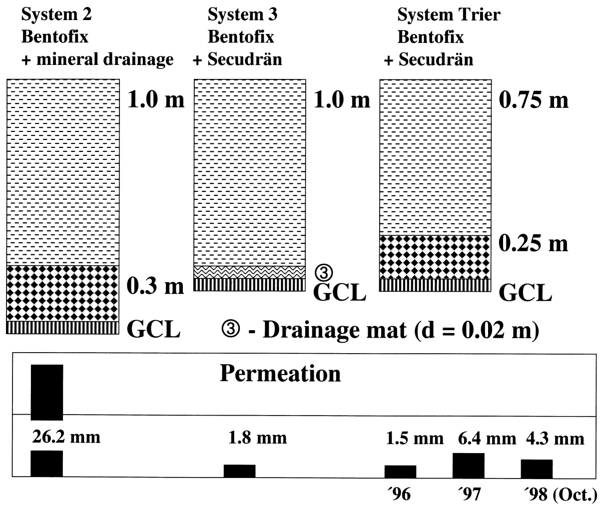

Figure 8. Comparison of forecast and measuring at a similar system structure.

Unfortunately, the owner has meanwhile stopped the investigations due to the finished support period and in connection with the revitalisation of the production location. However, a current excavation from 1999 has confirmed the complete ion exchange and the positive effects of an appropriately dimensioned recultivation layer on the water balance of the sealing system including the GCL. Also this sealing system was produced with a minimum gradient of 5 % and had no special attention or maintenance measures.

The measured results are between those which have been forecasted for the systems 2 and 3 (Figure 8). It has to be taken into account that the drainage performance of the mineral drainage layer on the Luxembourg landfill is significantly better than the minimum requirement of the TASi as it has been considered in system 2. The efficiency model contains the safety addition or reduction resp. which have been mentioned earlier. The measured results cannot continue the high efficiencies of the system 3 which may be explained by the fact that the recultivation layer in Luxembourg – despite a comparable soil type - is significantly thinner and the drainage mat in system 3 has a substantially larger discharge capacity than the Luxembourg gravel drainage. Hence these field measurings over several years fit completely without contradiction into the efficiency forecasts for standard products.

7 CONCLUSION

The investigations which have been shown confirm the high efficiency of capping systems with needle-punched GCLs, and are also a standard for the assessment of the performance of other GCLs as well as of other compacted clay liners (CCL). It must be recognized that CCLs undergo similar changes, resulting to higher permeabilities, usually with no (self) sealing effects, due to changes in the water content.

8 SUMMARY

Needle-punched geosynthetic clay liners have successfully been used in thousands of projects and have successfully been installed in numerous landfill cap systems. Numerous laboratory studies in in-situ performance tests have shown that natural sodium bentonite is an excellent hydraulic barrier with self-healing characteristics.

With achieved data from various laboratory testings and excavations a long-term efficiency of needle-punched geosynthetic clay liners has been demonstrated. With the modification of the „Hydraulic Evaluation of Landfill Performance“ (HELP) it is possible to model on-site conditions and prove or/and achieve the efficiency of various sealing systems (GCLs and clay liners) under verified conditions.

Data from realistic capping designs have shown that needle- punched GCLs show an excellent performance with high efficiency rates overall summarizing that needle-punched GCLs are an acceptable alternative to the compacted clay liner normally specified in regulations for landfill capping systems.

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REFERENCES

Baumgartl, T. et al. 1998. Wasserspannungsverläufe in Böden unter unterschiedlicher Nutzung als Entscheidungsgrundlage für die Prognose Rißgefährdung mineralischer Dichtschichten. *Zeitschrift für Kulturtechnik und Landesentwicklung.* September 1998

Bidlingmaier, W., Maile, A. 1996. Untersuchungen zur Wirksamkeit der Bentonitmatte Bentofix® BFG 5000 als Dichtungs-komponente in Oberflächenabdichtungssystemen von Landschaftskörpern und Deponien. Unveröffentlichtes Gutachten einschließlich einer Ergänzung.

Dobras, T.N., Elzea, J. M. 1993. In-Situ Soda Ash Treatment for Contaminated Geosynthetic Clay Liners. *Geosynthetic ´93, Vol. 3, Industrial Fabrics Association International.* St. Paul, USA, pp. 1145-1160.

Egloffstein, T. 1997. Bentonit als Dichtungselement in geosynthetischen Tondichtungsbahnen. *Naue Fasertechnik – Workshop „Innovative Lösungen mit Geokunststoffen im Erd- und Deponiebau",* Lübbecke, Germany

Egloffstein, T., Markwardt, N. 1999. Modellierung des Durchlässigkeitsverhaltens von Bentonitmatten unter Berücksichtigung von Austrocknung und Wiedervernässung mit dem HELP-Modell. *Egloffstein/Burkhardt/Czurda (Hrsg.) Oberflächendichtung von Deponien und Altlasten*.

Ingenieurgesellschaft Prof. Czurda und Partner GmbH 1999. Auswirkungen des Ionenaustausches auf die Wasserdurchlässigkeit von Bentofix®-Tondichtungsbahnen. Fachtechnische Stellungnahme (unveröffentlicht.

Materialforschungs- und Prüfanstalt an der Bauhaus-Universität Weimar. 2000. Durchlässigkeitsprüfungen an Bentofix® D 4000 unter Verwendung spezieller Prüflösung. Prüfbericht Nr. B 50/171-00 (unveröffentlicht).

Materialforschungs- und Prüfanstalt an der Bauhaus-Universität Weimar, vorläufige mündliche Mitteilung, Prüfbericht in Vorbereitung

Melchior, S. 1993. Wasserhaushalt und Wirksamkeit mehrschichtiger Abdecksysteme für Deponien und Altlasten. *Hamburger bodenkundliche Arbeiten, Verein zur Förderung der Bodenkunde in Hamburg., Band 2. Eigenverlag.*

Reuter, E., Kruse, B. 1996. Prüfung der Wirksamkeit geotextiler Tondichtungen durch Aufgrabungen. *Heft 45 der Schriftenreihe Angewandte Geologie Karlsruhe. Universität Karlsruhe*. Germany

Schnatmeyer, C. 1998 Alternative Oberflächenabdichtungssysteme für Halden und Altstandorte am Beispiel einer Gichtstaubdeponie. *Trierer Geologische Arbeiten, Band 1. Selbstverlag der Universität Trier,* Germany