Desiccation tests on geosynthetic clay liners

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ABSTRACT: The problem of desiccation with geosynthetic clay liners (GCL) used as cap seals for landfills has been the subject of some controversy. Examinations in a test field have shown that under the conditions of that particular site cracks in a cap seal once developed, did not close, even after several re-wetting cycles. Special regulations for installation have therefore been drawn up in Germany for GCLs subject to construction supervision, to prevent desiccation of the GCLs as much as possible. The effectiveness of these measures has not yet been systematically proven. As a first step towards the quantitative assessment of protective measures against desiccation, this paper presents a laboratory test with the help of which the risk of GCLs desiccating may be assessed. The composition of the test takes into account the major factors affecting the desiccation process: temperature, temperature gradient and soil properties.

1 INTRODUCTION AND BACKGROUND

The main task of cap seals on landfills is to protect the body of the landfill from external influences (precipitation, erosion) and to prevent any landfill gas from escaping. For this purpose, more and more use is being made of geosynthetic clay liners (GCLs) as the sealing element in cap seals.

Sufficient long-term efficiency of mineral and geosynthetic clay liners in landfill cap seals has not yet been proven for all real boundary conditions. Since the examinations at the test field of the Hamburg-Georgswerder landfill (Germany), the long-term efficiency of GCL seals has been the subject of on-going discussion. The findings from Georgswerder show considerable deterioration in the sealing qualities of the GCLs installed there under the local system boundary conditions after only one summer (Melchior, 1998). The causes recognised for this have been the desiccation of the seal with accompanying cracking and the ion exchange of sodium ions for calcium ions in the interlayers of the montmorillonite.

Comprehensive examinations are needed to check the extent to which any deterioration of this kind in the functioning of the GCL occurs at other areas of installation, or if it can be prevented by suitable choice of materials for the layers above and below. As monitoring the performance of a GCL after installation in a cap seal is difficult and corrections to the functional boundary conditions may only be achieved at considerable cost, it is necessary to assess the danger of desiccation under the appropriate boundary conditions at the design and construction stage.

1.1 *Cracking in cohesive sealing layers*

There are a number of examinations and theories on the subject of desiccation cracks in mineral sealing layers due to a reduction of the water content. For example, Morris et al. (1992) and Heibrock (1996) drew up boundary condition diagrams which took into account the tensile strength and shear strength of the soil and with which the problem of cracking may be examined. Brauns et al. (2000) give a soil mechanical description of the phenomenon of desiccation. The basic parameters in all these considerations have been the suction potential of the pore water, the soil characteristics and the loading stresses. These last-named are of secondary significance in cap seals. Based on the equation derived from van Genuchten (1980) for suction potential as a function of the water content, Sivakumar Babu et al.(2000) have proposed a method for the prediction of onset of desiccation in GCLs, using the program developed by Döll (1996) and using the shear strength parameters in accordance with Fredlund and Rahardjo (1993).

1.2 *Ion exchange in bentonite*

Because of their higher valency and smaller size, Ca^{2+} ions are preferable to Na^{+} ions as intermediate layer ions in the montmorillonite minerals of the bentonite. According to Egloffstein (1997) even slight concentrations of Ca^{2+} in the soil water, which are present in practically every natural soil, are sufficient to convert an originally Na bentonite to a Ca bentonite in the course of only a few years. This conversion gives the bentonite a lower swelling potential and greater permeability.

The work of Melchior (1998) at the Hamburg-Georgswerder landfill showed that after an installation period of only two years under the conditions prevailing there, the conversion from Na to Ca bentonite was almost complete. The permittivity of the GCL was some four to five decimal powers greater than that of originally installed Na bentonite GCL. The LGA geotechnical institute’s own examinations of excavated GCLs from landfill cap seals confirm that the conversion from Na to Ca bentonite is completed within a few years under the widest range of conditions. Further, it was established that due to the ion exchange, the permittivity of the GCL was around one decimal power greater than that of the original Na bentonite, as long as there was no desiccation with cracks. When using Na bentonite, this increase in permittivity of around one decimal power is always to be reckoned with. When desiccation with cracks occurs, the cation exchange in the interlayers prevents the desired self-healing of the fissures. The ensuing leakages cannot be reclosed, causing the above-mentioned high permeability at Georgswerder.

1.3 *Transport processes*

The decisive factors in observing the processes of desiccation in cap seals are the transport of water and water vapor, as well as heat in unsaturated porous media. Because of differences in potential, water moves from areas with high potential to areas with low potential. The total potential is made up of the matrix, gravitational, osmotic, overburden and pressure potentials. Water vapor is transported as a result of differences in the water vapor pressure of the soil air. Heat is transported as a result of a temperature gradient by conduction at the solid and liquid phase and by convection at the liquid and gaseous phase of the soil.

The physical processes described above have a mutual influence on one another. For example, the matrix and the osmotic potential of the soil water and also the temperature has a direct influence on the water vapor pressure. Basic theories linking water, water vapor and heat transport have, for example, been put forward by Philip and de Vries (1957), proposing differential equations for the coupled transport of moisture and heat transport. Döll (1996) used this as a basis to develop a model for basal liners by which the coupled transport processes could be expressed numerically.

It is necessary to have controlled data on the desiccation of GCLs in order to adjust and check a numerical model. Only a laboratory test can produce this with justifiable cost and effort. The following presents a laboratory test of this type developed in the course of a research project.

2 LABORATORY TESTS

2.1 *Theoretical considerations*

The desiccation of the cap seals of landfills is influenced by site specific meteorological factors (precipitation, sunshine, temperatures, wind conditions), chemical factors (landfill gases, ion exchange), the physical factors of the soil (water conductivity, heat conductivity), morphological factors (the slope’s direction and angle of incidence) and biological factors (vegetation, digging animals). It is not possible to re-create these diverse influences in a laboratory test. In drawing up a test, much more attention must therefore be given to using clearly defined boundary conditions which allow comparison of the sealing systems examined, so that reproducible results are achieved for the relevant physical processes.

On the basis of this consideration and the theoretical background presented in Section 1, the following boundary conditions were drawn up as being decisive for the desiccation test:

- ion exchange in bentonite may be ignored.
- desiccation is determined by the change in the GCL's water content
- it must be possible to install different configurations of layers in cover systems.
- desiccation is induced by the effect of heat
- it must be possible to create a temperature gradient.
- lateral heat loss must be avoided, as far as possible.
- moisture may leave the system upwards and downwards.

2.2 *Test set-up*

Cylindrical plastic containers (dia. 0.5 m, height 0.8 m) are used to meet these requirements (Figure 1). These containers have a clamping ring for the GCL 12 cm above the lower opening. The installed layers are heated by a heating coil placed on the top layer. The heating coil is fully adjustable electronically to temperatures up to 100°C. The temperature may be measured at freely determinable points in the test set-up, using temperature sensors, and continuously recorded by computer. The whole test set-up is in a room set to a standard climate.

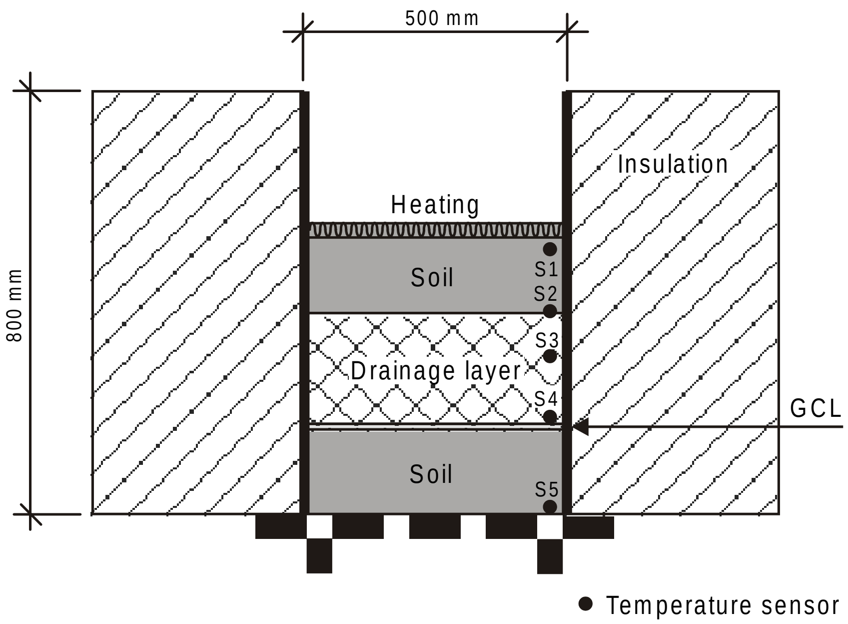

Figure 1. Test container

As the lateral insulation of the containers is of major importance in comparing different systems, particular attention was given to this aspect. The containers are insulated with a 40 cm thick wrapping of approx. 1 cm thick layers of closed-cell PE foam. The insulation efficiency was checked by computer simulation. This showed that there was hardly any lateral heat loss, even at high temperatures of up to 80°C. A trial run was also carried out to check the efficiency of the PE foam insulation. A layer of sand 55 cm thick was heated to 80°C from above. Figure 2 shows the variation of temperature over time at the different heights installed. Figure 3 shows the theoretical temperature variations (dotted line) compared with the readings obtained (solid lines).

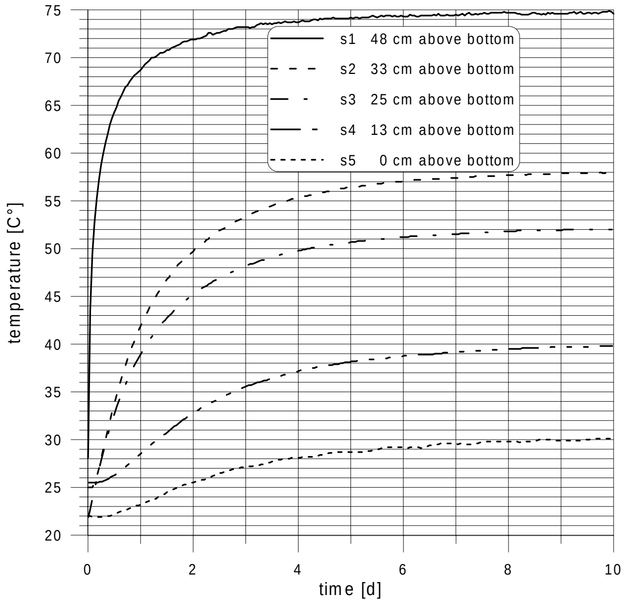

Figure 2. Heat insulation efficiency test
Variation of temperature over the period of time

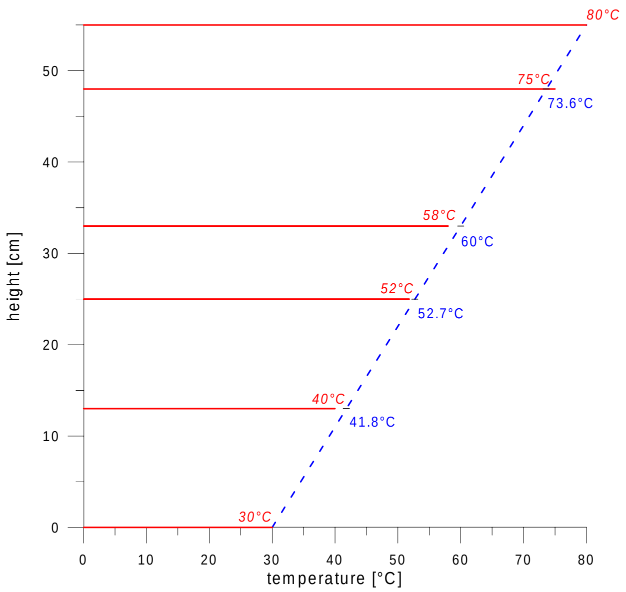

Figure 3. Heat insulation efficiency test
Comparison of measured and predicted temperatures

3 DESICCATION TESTS

GCL samples of a needled GCL with Na bentonite were used in carrying out the tests. A sample piece of this mat, sized 60 cm by 80 cm, was hydrated in deionised water for three days, under a normal stress of 15 kPa. It was subsequently stored for one week in plastic foil under the same standard load, so that a uniform water content was present over the whole surface of the sample. A sample piece, 50 cm in diameter, was cut from the hydrated sample and installed in the clamping ring of the test container, in order to avoid shrinking of the whole sample. The remaining material was used to determine the water content of the bentonite which was in the range of 200%. After completing the desiccation test, the water content of the removed GCL was determined, to determine the loss of water content of the bentonite.

3.1 *Test to compare single-layer with two-layer GCL*

3.1.1 *System set-up*

The following layer construction was installed in the test container (top to bottom):

- 12 cm sand
- 13 cm layer of drainage gravel, 8/16 mm grain diameter
- GCL (single-layer)
- geomembrane
- 12 cm sand

The geomembrane was stuck to the walls of the container to prevent any moisture movement downwards. Apart from the GCL, all the materials were installed in a dry state. The heating coil temperature was set to 80°C. A temperature of 39.5°C was measured at the level of the GCL. The durations of the tests were 10 and 20 days to determine the loss in water content over time. A second series of tests was carried out under identical test conditions, with two layers of GCL. The loss of water content of the upper and lower GCLs was measured.

3.1.2 *Results*

Figure 4 shows the GCL's loss in water content over time.

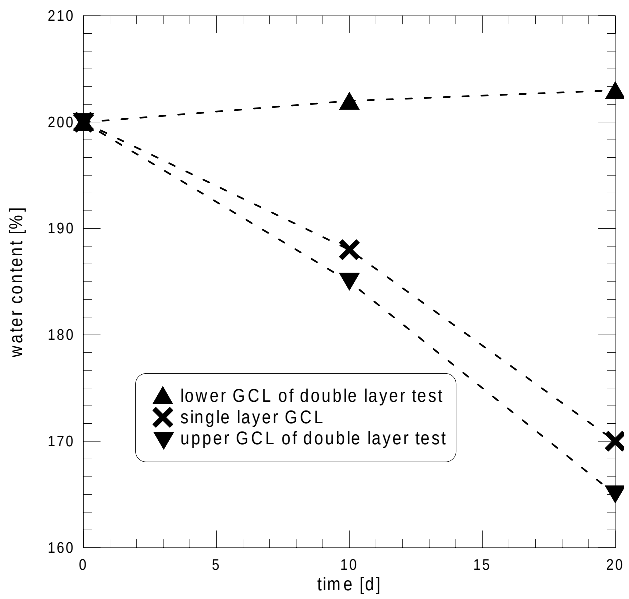

Figure 4. Water content of GCL during the test

It can be seen that the GCL installed in single-layer form and the upper GCL in the double-layer test show practically the same loss of water content, while the lower GCL, in contrast, did not show any change in water content after one or three weeks. The slight increase in water content is within the bounds of measurement accuracy.

3.2 *Test with different directions of moisture movement*

3.2.1 *System set-up*

To examine the direction of movement of moisture three series of measurements were carried out. The system setups are given below (top to bottom).

System 1	System 2	System 3
12 cm sand	12 cm sand	12 cm sand
GCL (single layer)	GCL (single layer)	geomembrane
12 cm sand	geomembrane	GCL (single layer)
	12 cm sand	12 cm sand

Unlike the test described in 3.1, the heating temperatures were varied. The systems were heated to 30°C and 70°C for a period of ten days. For each system, a comparative test was carried out without heating, at a room temperature of 20°C.

3.2.2 *Results*

The reduction in water content in the individual tests is shown in Figure 5.

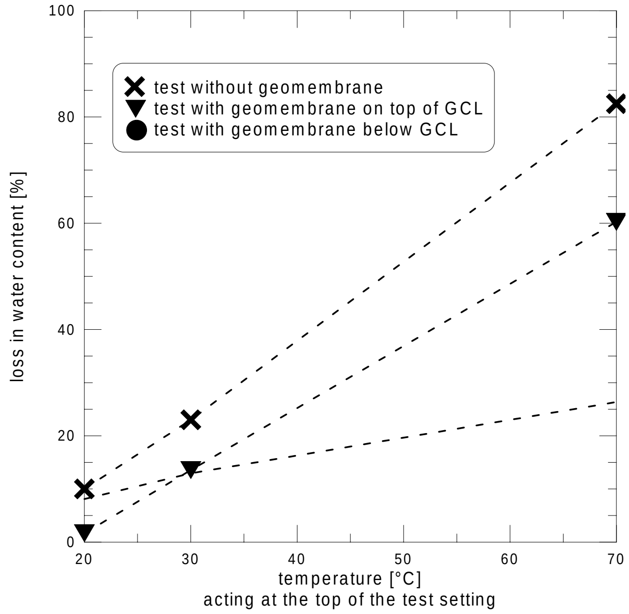

Figure 5: Reduction of GCL-water content within 10 days at various temperatures

It becomes apparent that in the absence of a temperature gradient (test at 20°C without heating) it was almost exclusively upward desiccation that was produced. The test with the geomembrane above the GCL shows a change in the water content of the bentonite after ten days, which is within the bounds of measurement accuracy, while the two other tests show an almost identical change in the water content of the bentonite here. However, with increasing temperature gradients the GCL desiccates downwards more strongly.

4 DISCUSSION AND FINAL COMMENTS

The test series presented in Section 3.1 wherein a single layer GCL-system is compared with a double layer GCL-system shows that under the applied boundary conditions in the double layer system the upper GCL apparently protects the lower GCL against desiccation, especially the geomembrane and the temperature play a decisive role here. An assessment with regard to a more general comparison of a single-layer system with a double-layer system with this test setup is not possible due to the prevention of moisture movement downwards. To what extent movement of water out of the lower GCL is really prevented is not clear. It is possible that a loss in water content of the lower GCL upwards is balanced by water movement from the upper GCL downwards.

This aspect is further examined in the test series described in Section 3.2 where an impervious geomembrane prevents migration downwards or upwards, to study moisture movements upwards and downwards individually. The results show that the temperature has a significant influence. At higher temperatures in all test set-ups the water content loss is generally more pronounced. At lower temperatures and the according lower temperature gradients the moisture movement to the top predominates the moisture movement downwards while at higher temperatures and temperature gradients the opposite is the case.

The test results demonstrate that laboratory tests on desiccation behaviour need to take care of upward and downward moisture movement. Due to the temperature dependence of the direction of moisture movement a special attention has to be paid to the test temperature, to make conclusions about the real conditions in landfill cap systems possible. This can be achieved by variation of the test temperatures of the same set-up. These test results of desiccation are very useful in the understanding of the role of moisture movement under the combined influence of water, water vapor and temperature. The results are reflected in loss of water content under the known boundary conditions. For a study of the coupled phenomenon of moisture movement under temperature gradients using numerical procedures it is necessary that simulations are calibrated against laboratory test results. The results of the present experimental study and of following tests are used for this calibration.

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