Experimental investigation of the influence of the pre-hydration of GCLs on the leakage rates through composite liners

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ABSTRACT: Preliminary laboratory tests for studying the influence of the pre-hydration of GCLs on the leakage rates through composite liners due to holes in geomembrane were carried out. A stitch and a needle punched product were used. The influence of the normal stress and the type of cover geotextile of the GCL were also studied. The first results obtained show that the interface transmissivity depends on the initial water content of the specimens and on the normal stress applied. The type of cover geotextile (woven or non-woven) seamed to have a higher influence on leakage rate on the short term than on the long-term. Nevertheless, this topic is still under study.

1 INTRODUCTION

Landfills are generally designed to protect the environment against contaminants by using a composite liner consisting of a geomembrane laid on a compacted clay liner (CCL) or on a geosynthetic clay liner (GCL). Unfortunately, despite all precautions regarding the choice, transportation, handling, storage and installation of geomembranes, leaks are unavoidable on site.

The leakage through a composite liner when there is a hole in a geomembrane occurs as follows: (i) the liquid migrates through the geomembrane hole, (ii) it spreads laterally between the geomembrane and the underlying CCL or GCL, and (iii) it infiltrates. Thus in order to evaluate the leakage through composite liners, one has to know the hydraulic transmissivity of the interface between the geomembrane and the underlying material.

Although several experimental studies dealing with interface transmissivity were conducted, very little is known about the performance of composite liners when there is a pre-hydrated GCL under the geomembrane. It is usually recommended that GCLs be hydrated under a vertical stress after installation in order to reach a better performance. However, the hydration under a vertical stress after installation is not always possible in landfills. Therefore, there are uncertainties about the behaviour of prehydrated GCLs, which require further study. As a consequence we intended to quantify the interface transmissivity using hydrated and non-hydrated GCLs in order to be able to compare both situations. Two different products (stitch and needled punched bonded) were tested and tests are underway with other products.

2 EXPERIMENTAL DEVICE AND MATERIALS TESTED

The flow of water through the composite liners was measured using a circular Plexiglas cell shown in Figure 1, which has been specially designed for hydraulic transmissivity measurements. In the bottom part of this cell 4.5 cm of soil are compacted. The inner diameter of the cell is 0.2 m and corresponds to the GCL samples diameter. On top of this soil, one places the GCL sample and a geomembrane with a 3 mm diameter circular hole at its centre. Above the geomembrane a granular cover plate was placed for simulating the presence of a granular drainage layer. A normal stress can be applied on top of this experimental device.

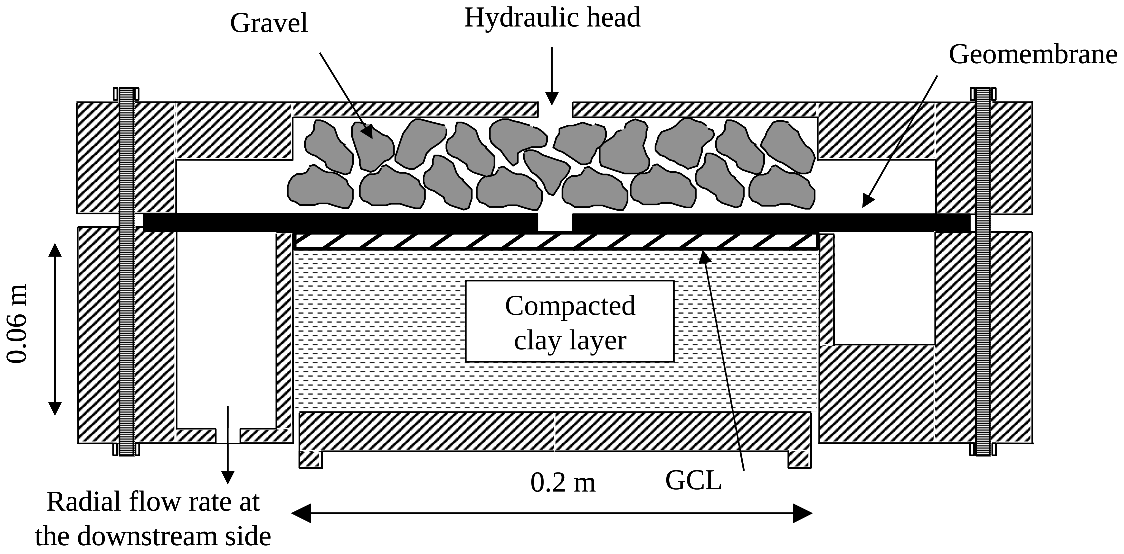

Figure 1. Schematic drawing of the interface transmissivity measurement cell

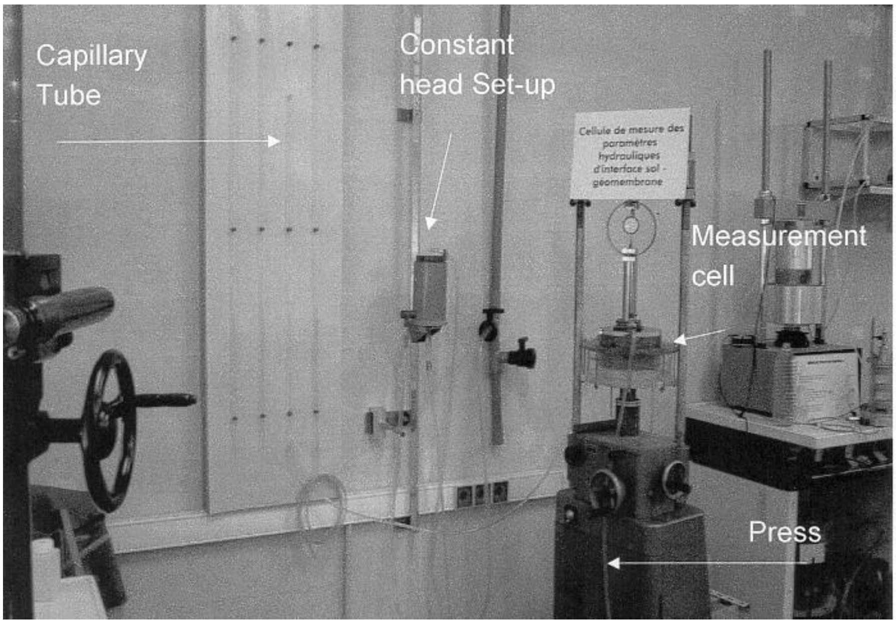

Figure 2. Photograph of the whole experimental device

Liquid flow measurements can be conducted in two different ways as described by Harpur et al. (1993): constant head tests are carried out when the radial flow rate at the downstream side of the interface is large enough to be measured by weighing. When very low or no flow rates can be measured in this way, a falling head test is conducted with a capillary glass tube having a 4 mm inner diameter and then the total flow rate is measured. The whole measurement device is shown in Figure 2.

Two different normal stresses were applied: 7 and 50 kPa. The first stress was chosen to allow a comparison with the results obtained by Harpur et al. (1993), and the second one to allow the sizing of experimental cells designed to study the long term interaction between leachate and GCLs of composite liners in the laboratory.

The hydraulic head applied on top of the composite liner was identical for all tests and equal to 0.3 m.

3 MATERIALS TESTED

3.1 *Soil*

A 4.5×10^{-2} m thick clay layer was compacted in the cell. This soil was previously used by Touze-Foltz (1999) for carrying out a large scale laboratory test experiment and for interface transmissivity measurements (Touze-Foltz 2002). The soil was compacted at 2% above the optimum water content of Proctor test. Its hydraulic conductivity was measured to be 10^{-10} m s $^{-1}$.

3.2 *GCL*

Two different GCLs were tested. They are described in Table 1. GCL 1 bis corresponds to GCL 1 tested upside-down

Table 1. Characteristics of GCLs according to the manufacturers

Specimens	GCL1	GCL2
Bentonite layer:		
Type of bentonite	Natural, granular Na^+	Natural, powdered Na^+
Mass per unit of area ($g.m^{-2}$)	5220 (roll)	4530 (roll)
Cover geotextile*:*	PP	PP
Mass per unit of area ($g.m^{-2}$)	110	60
Type	Woven	Woven
Carrier geotextile*:*	PP	PP
Mass per unit of area ($g.m^{-2}$)	220	60
Type	Non-woven, needle punched	Woven (covered by sand)
GCL:		
Type	Needle punched	Stitch
Dry thickness (mm)	6,48 (roll)	10
Hydraulic conductivity ($m.s^{-1}$)	10^{-11} at 50 kPa and 3×10^{-11} at 8 kPa (Comeaga, 1997)	3×10^{-11}

3.3 *Geomembrane*

A commercially available smooth high density polyethylene (HDPE) geomembrane 2 mm thick was used in this study.

4 TESTS CONDUCTED PRIOR TO PRE-HYDRATION

In order to ensure water-tightness, GCLs have to be hydrated after installation. According to the Comité Français des Géosynthétiques (1998) the pre-hydration must allow a minimum water content of at least 100%. The water necessary to reach this water content can be sprayed on the GCL or absorbed from the underlying soil.

Based on Soltani (1997) three different protocols were compared on GCL 1 in the laboratory to choose the best one that was then used to perform the pre-hydration of the GCLs.

The first one consisted in placing the GCL at its initial water content on the compacted clay in the cell under the stress that would be applied during the test and wait one week before starting the transmissivity measurement test. The GCL water content in this case was rather homogeneous through the sample what was checked thanks to destructive water content measurements on 3 × 3 cm^2 samples but only about 50 %.

The second one consisted in immersing the GCL in tap water during the time necessary for it to reach a water content of 100% and then placing it into a watertight bag under a normal stress of about 5 kPa. This method resulted in a non-homogeneous water content in the GCL specimen, with a maximum variation of 43 % in water content (3 × 3 cm^2 specimens).

The third method consisted in associating the pre-hydration in tap water and by the underlying soil. The GCL sample after pre-hydration was put in the test cell for a one week period before beginning the transmissivity measurement test under the stress applied during the test. This combination led to a water content approximately equal to 100 % through the GCL sample and a rather homogeneous water content with variations less than 13 % from one 3 × 3 cm^2 sample to another.

Based on these results the third method was used to pre-hydrate the specimens used for interface transmissivity tests.

5 RESULTS OBTAINED IN INTERFACE TRANSMISSIVITY TESTS

Table 2 is a synthesis of the tests carried out. Tests 1 to 4 were performed with GCL 1 and tests 5 and 6 with GCL 2. For both GCLs a test with a non pre-hydrated and a prehydrated specimen was conducted. On GCL 1 we also tested the influence of the normal stress applied on the prehydrated product, and of the nature of the type of cover geotextile (woven or non-woven). The results obtained were observed in terms of flow rates and wetted areas and interpreted in terms of interface transmissivity.

Table 2. Tests performed and results obtained at the end of the tests in terms of flow rate and final effective transmissivity

Test Number	GCL	Normal stress (kPa)	Initial water content (%)	Immersion time (min)	Water content after immersion (%)	Final flow rate (m^3s^{-1})	Final effective transmissivity (m^2s^{-1})
1	1	7	31.5	30	79.8	3.18×10^{-10}	7.05×10^{-10}
2	1	50	28.9	30	110.7	2.08×10^{-11}	4.54×10^{-11}
3	1	50	31.5	-	-	3.87×10^{-11}	8.50×10^{-11}
4	1bis	50	22.3	30	83.1	5.80×10^{-11}	1.28×10^{-10}
5	2	50	10.9	-	-	5.26×10^{-9}	1.16×10^{-8}
6	2	50	11.4	45	85.6	3.52×10^{-11}	7.74×10^{-11}

5.1 *Flow rate*

Figures 3 and 4 show the evolution of the flow rate with time for all tests. As Harpur et al. (1993) noticed, the flow rate is decreasing with time, even for the pre-hydrated GCLs. The flow rate obtained is larger for the lowest normal stress on the composite liner, and there is a one to two orders of magnitude difference between the results obtained in tests 2 and 4, where the GCL has the non-woven geotextile on top. There is also a difference between the tests carried out with and without pre-hydration: in the first case the flow rate values are lower and it seems that an equilibrium is reached earlier than when the GCL is not prehydrated. This conclusion is reinforced by the results obtained in tests 5 and 6 with GCL 2 (see Figure 4).

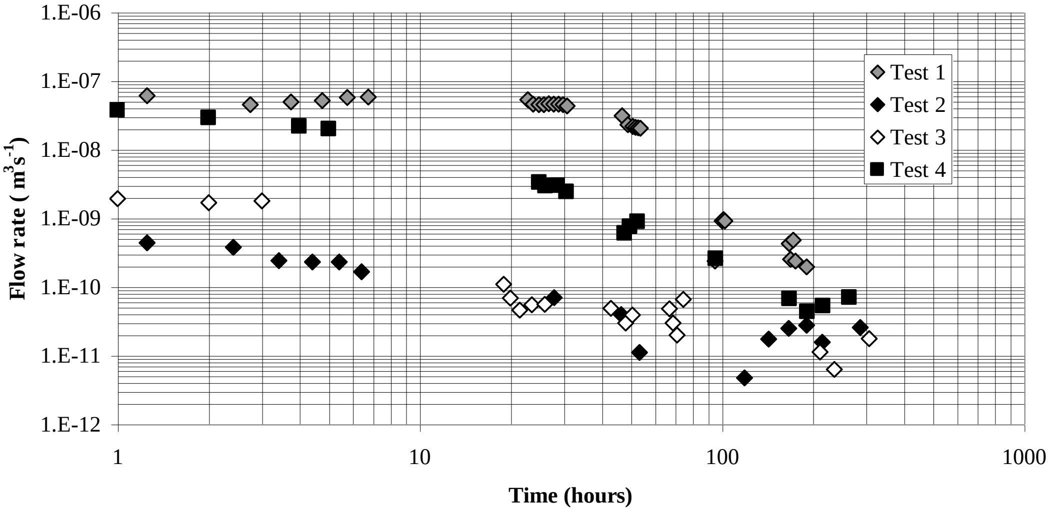

Figure 3. Comparison of the results obtained in tests 1 to 4 in terms of flow rates

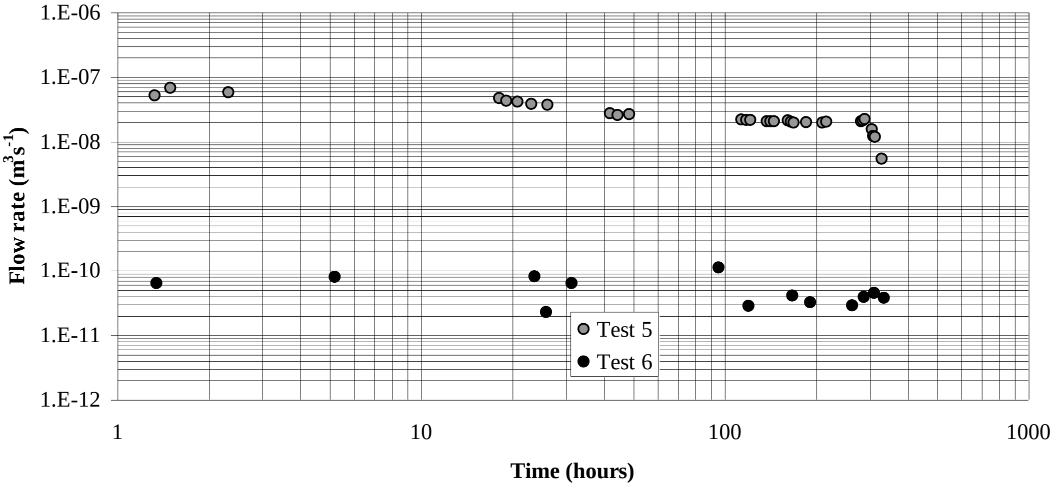

Figure 4 : Comparison of the results obtained in tests 5 and 6 in terms of flow rates

5.2 *Transmissivity*

The interface transmissivity can be estimated in two different ways. An apparent transmissivity was determined by Harpur et al. (1993) neglecting the flow within the bentonite and assuming that the flow at the interface is axi-symmetric. Thus the obtained value overestimates the real value of transmissivity, and the radius of the wetted area that corresponds to the GCL sample radius can as well be overestimated by the assumption that the wetted area corresponds to the whole specimen surface. For constant head tests Harpur et al. (1993) gave Equation 1 to calculate the transmissivity θ:

$$\theta = \frac{Q_r(R_c) \times \ln\left(\frac{R_c}{r_0}\right)}{2\pi h} \tag{1}$$

whereas Equation 2 has to be used for falling head tests

$$\theta = \frac{a \times \ln\left(\frac{R_c}{r_0}\right) \times \ln\left(\frac{h_0}{h_1}\right)}{2\pi t} \tag{2}$$

where $Q_r(R_c)$ = radial flow rate at the downstream side of the cell; R_c = specimen outer radius; r_0= hole radius; h = hydraulic head on top of the geomembrane hole; a = cross-sectional area of falling head capillary tube; h_0 = hydraulic on top of the geomembrane hole at the beginning of a falling head test; h_1 = hydraulic on top of the geomembrane hole at the end of a falling head test; t = falling head test duration.

A more accurate transmissivity value can be calculated, using the analytical solutions given by Touze-Foltz et al. (1999) assuming that the GCL, the underlying soil and the interface are fully saturated. The flow at the interface is again supposed to be axi-symmetric. For all tests we noticed until the end of the experiment the existence of a flow rate at the downstream side of the GCL specimen. As a consequence, the analytical formulation that has to be used corresponds to the existence of a flow rate at R_c with a hydraulic head equal to zero. The corresponding solution giving the total flow rate Q and the flow rate at the downstream side of the interface $Q_r(R_c)$ is given in Equations 3 and 4 (Touze-Foltz et al. 1999)

$$Q = \pi r_0^2 k_s i_s - 2\pi r_0 \theta \alpha \left[A_p I_1(\alpha r_0) - B_p K_1(\alpha r_0)\right] \tag{3}$$

$$Q_r(R_c) = -2\pi\theta\alpha R_c \left[A_p I_1(\alpha R_c) - B_p K_1(\alpha R_c)\right] \tag{4}$$

with

$$A_p = -\frac{h \times K_0(\alpha R_c) + C \times \left(K_0(\alpha R_c) - K_0(\alpha r_0)\right)}{K_0(\alpha r_0) I_0(\alpha R_c) - K_0(\alpha R_c) I_0(\alpha r_0)} \tag{5}$$

$$B_p = \frac{h \times I_0(\alpha R_c) + C \times \left(I_0(\alpha R_c) - I_0(\alpha r_0)\right)}{K_0(\alpha r_0) I_0(\alpha R_c) - K_0(\alpha R_c) I_0(\alpha r_0)} \tag{6}$$

α and C are given in the present case by Equations 7 and 8 (Rowe 1998):

$$\alpha = \sqrt{\frac{k_s}{(H_L + H_f)\theta}} \tag{7}$$

$$C = H_L + H_f \tag{8}$$

where I_0 and K_0 = modified Bessel functions of zero order , k_s = equivalent hydraulic conductivity for the GCL and compacted clay liner, H_L = GCL thickness; and H_f = clay liner (foundation layer) thickness.

Equations 3 to 8 can be used to evaluate the hydraulic transmissivity either for constant head tests or falling head tests once the flow rate has been calculated. For constant head tests $Q_r(R_c)$ is obtained by dividing the volume of effluent collected at the downstream side of the test by the collecting time. For falling head tests, the total flow rate Q is calculated by dividing the variation of volume in the capillary tube by the measurement time. In this study, no measurements were taken with a time interval higher than 30 minutes. The criterion used consisted of either measuring the time necessary for the water level to decrease of 5 mm into the capillary tube or measuring the water level decrease after the 30 minutes. This decrease was measured thanks to a cathetometer, ± 0.02 mm (see Figure 2).

The comparison between the apparent transmissivity and the transmissivity obtained using Equations 3 to 8 tends to show that for constant head tests, the transmissivity value is identical. This corresponds to a real validity of the hypothesis proposed regarding the low infiltration in the GCL at the beginning of the test. Nevertheless for falling head tests, the ratios of transmissivities obtained using Equations 2 and 3 is nearly constant and about 1.4. A change in the GCL hydraulic conductivity from 10^{-11} to 10^{-10} ms^{-1} results in a slight increase in this value.

By taking these differences into account, the transmissivity values given in Table 2 were calculated using Equation 3.

5.3 *Wetted areas*

For all tests, in which a radial flow rate could be measured, we noticed that the flow was not regularly coming out of the interface but that there were some preferential flow paths all along the GCL specimen during the tests.

At the end of the tests, when we removed the granular cover plate and geomembrane we noticed for test 1 conducted with the lowest normal stress that the whole surface of the geomembrane was wet, unless what happened for the tests in which the normal stress was larger. In this latter case, the geomembrane surface that was at the contact with the GCL was not uniformly wet. These results tend to show the non uniformity of the flow in the interface.

In test 5, for which the flow rate at the end of the test was large enough we injected a blue dye in order to visualise the flow patterns in the interface. The results obtained, which are presented in Figure 5, tend to show the non-uniformity of flow in the interface.

These results tend to show the limitations of the equations used to quantify the transmissivity of GCLs that are based on the assumption that the wetted area is circular.

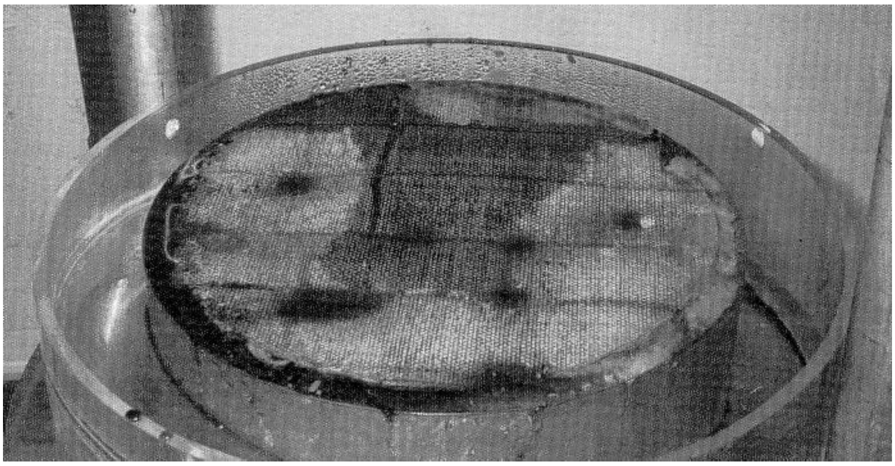

Figure 5. View of the aspect of the GCL surface at the end of test 5

6 DISCUSSION

6.1 *Comparison with the results obtained by Harpur et al. (1993)*

As Harpur et al. (1993) noticed, the flow rate is decreasing throughout the test, until a steady state or a nearly steady state is reached. But it seems however by taking a closer look at the results obtained in tests 1 and 5 that two weeks may not be enough to reach a steady-state and that it could be necessary to increase the test duration for low normal stresses or non pre-hydrated products.

The transmissivity value obtained at early times is rather close to a geotextile transmissivity value. But then the bentonite hydrates and swells and the quality of the contact with the geomembrane improves with time. Despite what was suggested by Harpur et al. we did not notice any bentonite intrusion in the geotextiles.

The transmissivity value obtained in test 1 is quite close to the one obtained by Harpur et al (1993) and seems to show that the transmissivity value is independent of the hole and specimen radii.

In overall terms the transmissivity values given by Harpur et al. are lower than the ones we have obtained: values given by these authors were in the range 3×10^{-12} to 2×10^{-10} m^2s^{-1} whereas the values given in this paper vary between 4.54×10^{-11} and 1.16×10^{-8} m^2s^{-1}. These differences could be related to the fact that the normal stress was uniformly applied in Harpur et al. tests whereas in our experimental device there is a limited number of contact points through which the normal stress is applied because there is a granular layer on top of the geomembrane. This difference could as well be related to the fact that we have not yet tested as many different products as Harpur et al. (1993). This point will be addressed in the follow-up of this study since we intend to test more GCLs.

6.2 *Influence of the type of the cover geotextile*

A comparison between results obtained in tests 2 and 4 tends to show that there is an influence exeretd by the way the GCL is installed and by the nature of the cover geotextile. When the GCL is installed with the non-woven geotextile on top, the flow rate is two orders of magnitude larger than when the GCL is installed with the woven geotextile on top, during the 100 first hours of test. But it seems that the order of magnitude of the flow rate obtained after two weeks is about the same. The issue is anyway to know the long term influence of the difference in transmissivity of the GCL during the first hours or days of wetting. A larger transmissivity value means a larger extension of the wetted area and thus, potentially, for on site conditions, a greater long term flow rate. The influence of this temporal evolution of transmissivity will be studied in the following thanks to finite element methods. A critical point for this is the knowledge of the retention curves for the bentonite as it is not saturated.

6.3 *Influence of the normal stress*

As shown by Harpur et al. (1993) we noticed that an increase in the normal stress applied on top of the composite liner resulted in a decrease of the flow rate obtained throughout the test. A longer test may lead to a common equilibrium transmissivity value, as we noticed for tests 2 to 4. This point will be addressed in the following studies.

6.4 *Influence of the pre-hydration*

A comparison between the results obtained in tests 2 and 3 and tests 5 and 6 suggests that the transmissivity obtained when the GCL is pre-hydrated is lower than when it is not pre-hydrated, especially at the beginning of the tests for GCL 1 and all test long for GCL 2. This tendency is much more significant for GCL 2 than for GCL 1. This may be due to the fact that GCL 2 was really dry before starting the test, as compared to GCL 1, which resulted in a higher flow rate and a longer time necessary to reach the steady-state with GCL 2. These test results seem to indicate that the test duration with non pre-hydrated GCL 2 should be longer in order to check if the same equilibrium value is reached as with the pre-hydrated GCL 2.

These results suggest that the pre-hydration of the GCL improves the quality of the contact between the GCL and the geomembrane, at least on the short term. These results reinforce the existing conclusion that GCLs have to be pre-hydrated before any hydraulic solicitation in order to ensure the best possible hydraulic behavior in terms of watertightness.

Once again the question is to know especially for GCL 1 what the result of the difference in the transmissivity during the early hours will be on a radial extension of the wetted area and thus on the resulting flow rates in the long term.

6.5 *Comparison with field contact conditions*

Very few data are available as regards transmissivity values for CCL – geomembrane interfaces and GCL – geomembrane interfaces. Very often flow rates through composite liners are estimated thanks to empirical equations developed by Giroud and Bonaparte (1989) where the non-uniformities of the composite liner interface are included in a contact quality factor. Various contact qualities have been defined by these authors. Rowe (1998) proposed an empirical relationship between the hydraulic conductivity of the soil liner (CCL or GCL) and the transmissivity based on these formula for the good and poor contact conditions. Figure 4 is a synthesis of these results and of the tests presented in this paper. The various results are presented in axes corresponding to the soil hydraulic conductivity and the calculated transmissivity respectively. Values of transmissivities proposed by Brown et al. (1987) for the perfect contact conditions were also added to this graph. It should be noticed that these empirical equations were based on experimental results obtained with loamy soils and thus they may not be representative of what could be obtained with GCLs.

As Harpur et al. (1993) did not mention the hydraulic conductivity of the GCLs tested their values could not be indicated in this figure.

All values are located below the good contact conditions, except the transmissivity value of test 5.

Transmissivity for test 1, with the lowest normal stress is located between the excellent and good field contact conditions, and it seems that the results obtained in test 2,3, 4 and 6 could be predicted thanks to the best field case (excellent field contact conditions) as defined by Giroud and Bonaparte (1989).

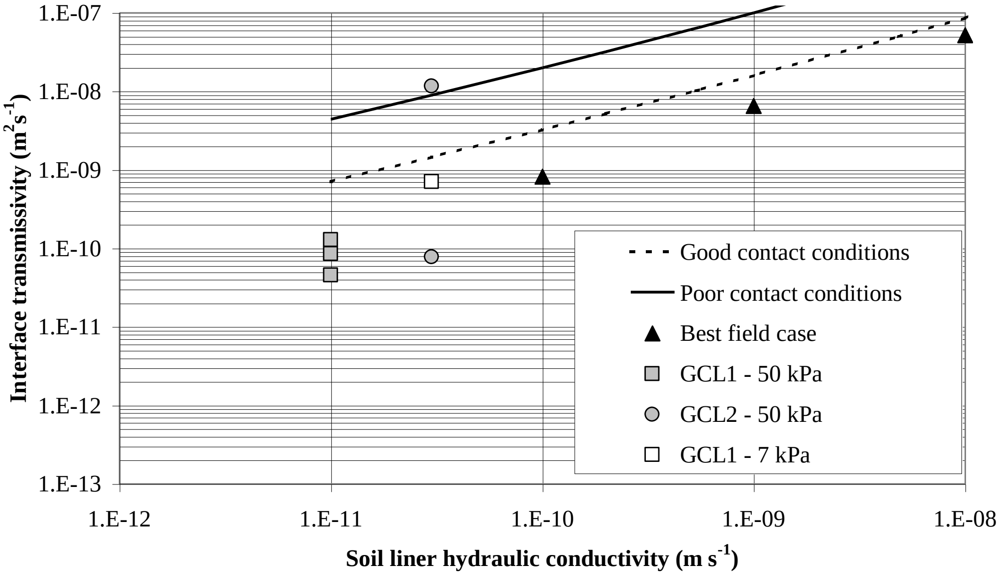

Figure 4: comparison of experimental results to poor, good and excellent field contact conditions

7 CONCLUSION

Laboratory tests for studying the influence of the pre-hydration of GCLs on the leakage rates through composite liners due to holes in geomembrane were carried out. Two different materials (stitch and needle punched) were used. On pre-hydrated GCL 1, the influence of the normal stress applied and the influence of the type of cover geotextile (woven, non-woven) were other issues addressed.

The preliminary tests, which were conducted to evaluate the best pre-hydration methodoly showed that prior to test and in order to obtain a water content as close as possible to 100 % and as homogeneous as possible through the sample it is necessary to immerse the sample in water and then place it in the test cell and wait one week until equilibrium is reached.

Transmissivity values obtained are a function of the normal stress applied, and of the initial water content of the GCL. Anyway, it seems that a common value of transmissivity at steady state could be obtained for a given normal stress, for samples with different initial water contents. A longer test duration could make it possible to check this preliminary conclusion.

The main issue is then to know the long-term influence of the time evolution of the transmissivity in the lateral extension of the wetted area and therefore in the total flow rate in the composite liner in the long term.

Values obtained at equilibrium for normal stresses of 50 kPa, for pre-hydrated products, are consistent with values given for the best field case.

The comparison between different methods of calculating the transmissivity suggests that for low flow rates it is better to use analytical solutions that take into account the infiltration into the GCL in order not to overestimate the transmissivity value.

Research into the interface transmissivity using hydrated and non-hydrated GCLs is currently ongoing. A larger number of GCLs will be used to study the influence of the confining stress, the type soil, and the hydraulic head above the geomembrane hole.

8 ACKNOWLEDGEMENTS

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