INFLUENCE OF GEOTEXTILES AT THE INTERFACE OF LANDFILL BOTTOM COMPOSITE LINERS

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ABSTRACT: An apparatus is described that allowed to estimate flow rates at the interface of compacted clay - geomembrane composite liners in the laboratory in presence of a geotextile. Thank to the results obtained in terms of flow rates some values of interface transmissivities could be deduced. Obtained values were compared to results obtained with ISO 12958 standard for single geotextiles. The results allow to study the influence of the normal stress applied on top of the composite liner, of the type of geotextile and topography of the soil liner surface. It can be deduced that on a flat compacted clay surface, the presence of a geotextile may increase advective transport in interface and thus through the composite liner, especially for thick non-woven needlepunched geotextiles. On an uneven surface, the implementation of a geotextile reduces the flow rate and thick geotextiles seem to act as resistant media. An increase in the mechanical load in the range 50 – 100 kPa does not modify these results and the compacted clay liner surface quality could be the most influent feature.

1 INTRODUCTION

The hydraulic transmissivity of the interface of a composite liner is a key parameter to predict rates of liquid flow when the geomembrane is damaged, thanks for example to analytical solutions (Touze-Foltz et al. 1999). One can find in the literature some experimental data for composite liners involving loamy soils (hydraulic conductivities in the range 10^{-8} to 10^{-6} ms^{-1}) (Fukuoka 1986, Brown et al. 1987, Liu 1998) or clayey soils (Touze-Foltz 2002) with or without a geotextile at the interface. Results obtained by the various authors do not allow to clearly understand the hydraulic influence of the geotextile. Furthermore, results obtained by Touze-Foltz (2002) are in apparent contradiction with results from Fukuoka (1986). But the soil hydraulic conductivity and surface topography, as well as the normal stress applied were very different in both studies. It then seems that more research is needed to correctly estimate the influence of the placement of a geotextile at the interface on the resulting flow rates (Touze-Foltz 2002). This point is all the more crucial as it is now recognized that it is common practice in France to use a geotextile at the interface of composite liners in landfills in order to make the seaming process easier or to prevent any damage to the geomembrane that could occur due to the existence of puncturing materials in the underlying clay liner, even if it is not specified by the current regulation for municipal solid waste landfills.

The main objective of this paper is to show experimental results obtained in a cell especially designed for interface transmissivity measurements with three different geotextiles. The results obtained allow to study the influence of the normal stress, geotextile type and soil surface topography on the transmissivity.

In the following we first describe the experimental device, the tested materials and the tests conducted. Then some of the results are presented. Different behaviours of the studied geotextiles were observed depending on the soil surface topography. Then, results obtained on a flat soil surface in the transmissivity cell are compared with results obtained thanks to ISO12958 standard and the influence of normal stress, geotextile type and soil topography are discussed.

2 EXPERIMENTAL DEVICE

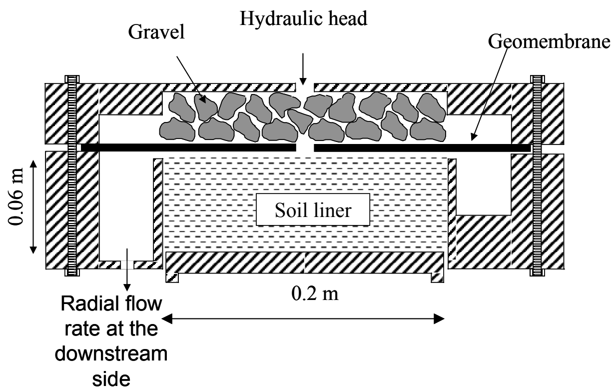

Figure 1 Schematic of the interface transmissivity measurement cell

The cell shown in Figure 1 has been specially designed for interface transmissivity measurements and was previously used by Touze-Foltz (2002) and Touze-Foltz et al. (2002) for transmissivity measurements at the interface of geomembrane-CCLs and geomembrane-GCLs composite liners respectively. In the bottom part of this cell six centimetres of soil are compacted. On top of it, one places a geotextile in the frame of the current study and a geomembrane with a circular hole 3 mm in diameter at its center. The geomembrane is covered with granular materials, simulating the presence of a granular drainage layer. A normal stress can be applied on top of this experimental device.

Constant head tests were carried out as the radial flow rate at the downstream side of the interface is large enough to be measured by weighing. The hydraulic head applied in all tests was 0.3 m. Distilled water was used in this experiment to prevent from any possible clogging of geotextiles that could occur with other fluids.

The normal stress was controlled by a dynamometric ring. Normal stresses equal to 50 and 100 kPa were applied.

3 MATERIALS

The different materials used in the experiment, namely the soil, the geotextiles and the geomembrane are presented in this section.

3.1 *Compacted Clay Liner*

The soil used for interface transmissivity tests is a dark clayey soil from the Armance geological formation (Eastern France), taken from the compacted clay liner of the Montreuil-sur-Barse Municipal Waste Landfill and previously used by Touze-Foltz (2002). The main clay minerals in this soil are illite, smectite and montmorillonite, providing a hydraulic conductivity as low as 2.10^{-10} $m.s^{-1}$. The large amount of clay particles also provides high plasticity to the material when the water content reaches the wet side of Proctor Optimum (about 20%).

3.2 *Geotextiles used at the interface*

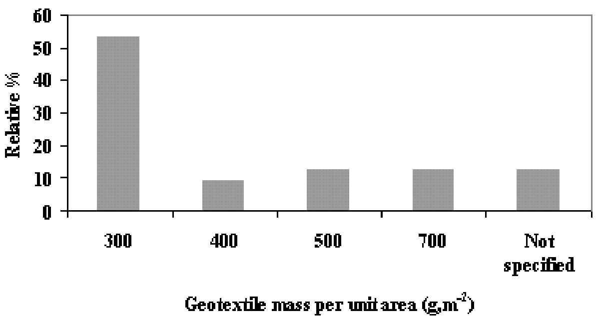

Figure 2 Relative proportion of geotextiles used at the interface as a function of mass per unit area

A first issue in studying the impact of a geotextile laying between the geomembrane and the compacted soil was to evaluate the frequency of such a practice and to identify the types of products used in landfill bottom liners. Geomembrane installers together with landfill owners were inquired in that purpose. They were also questioned on the reasons for this implementation. 33 answers were obtained among which 30 revealed that a geotextile was systematically set beneath the geomembrane. The type of products mentioned is shown in Figure 2 as an histogram giving the relative proportion of geotextile for given masses per unit area.

According to answers obtained, the geotextile implemented is assumed to (i) avoid the rutting of the CCL during installation of the geomembrane, (ii) improve quality of seams by ensuring that the geomembrane surface remains clean, and (iii) prevent damage of the geomembrane by hard puncturing elements from the surface of the CCL.

The inquiry also shown that only non-woven needlepunched geotextiles are used, with masses per unit area ranging from 300 to 700 $g.m^{-2}$. From these results, three geotextiles to be tested were selected: the first one, called GA in the following, is the most frequently cited (300 $g.m^{-2}$). GB is another non-woven needlepunched geotextile 330 $g.m^{-2}$ coming from a different manufacturer. GC is a thin non-woven thermal-bonded geotextile. Although this one had never been quoted, it seems of high interest in this study because of its small thickness and transmissivity. The features of the three geotextiles under study are summarised in Table 1.

Table 1 Features of the geotextiles under study

Geotextile	Type*	Mass per unit area ($g.m^{-2}$)	Thickness 2 kPa (mm)	Thickness 50 kPa (mm)	Thickness 100 kPa (mm)
GA	NW-N continuous PP fibers	300	2.8	1.56	1.39
GB	NW-N continuous PP fibers	330	3.5	2.36	1.90
GC	NW-Thermal-bonded PP fibers	130	0.4	0.4	0.4

* : NW: Non-woven, N: needlepunched, PP : polypropylene

Thickness measurements were made using EN ISO-9863 standard under 2, 50 and 100 kPa mechanical loads.

3.3 *Geomembrane*

A 2mm thick HDPE smooth geomembrane was used for transmissivity tests as it is the most commonly used in landfill bottom liners in France. A new piece of geomembrane is used for each test, as the granular part of the experimental device may distort it. Each geomembrane is trimmed to fit the transmissivity test apparatus and a 3 mm in diameter hole is perforated in the centre using a punch.

4 TEST INSTALLATION PROTOCOL

4.1 *Soil compaction and surface reproduction*

The soil is compacted manually with a Proctor piston (60 mm in diameter) in the transmissivity test cell in three layers approximately 20 mm thick and 1.5 kg each. During this compaction process the soil surface is in contact with a metal plate ensuring a soil surface as smooth and flat as possible with the clay used (Touze-Foltz 2002).

In order to study the influence of the soil surface topography, the soil surface was submitted to an uneven surface reproduction protocol for some tests. This reproduction protocol must ensure that a constant topography of the compacted clay surface is obtained for all experiments in order to assess the influence of the geotextile on flow.

Thus, a non-uniform surface of CCL was generated by compaction using a Proctor piston, showing circular patterns. Then, polyester plaster was poured in contact with this soil surface and removed after solidification. The topography appearance of this moulding is shown in Figure 3.

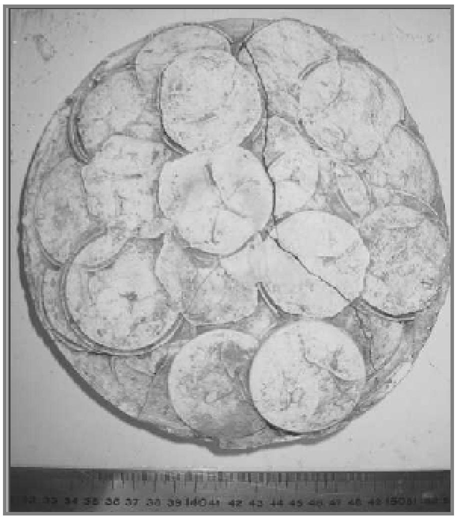

Figure 3 Photograph of the polyester plaster moulding used for surface topography reproduction

Maximum peak-to-valley distance is about 30 mm. The polyester moulding is used for each test in the same way: it is pressed close to the compacted clay in the transmissivity test cell with an applied load about 13 kN, during a few seconds. The moulding is always set in the same position into the cell, ensuring an identical geometrical configuration of the rough surface for all tests. Similarity of the reproduced topographies on clay surface was checked by comparing laser rugosimetry measurements of three reproductions from the same original moulding. Since a high water content (about 21%) is needed for a good quality of topographic reproduction, the compacted clay surface was levelled when applying a 50 or 100 kPa mechanical load during preliminary experiments. It was then decided to slightly dry the compacted soil after reproduction during 18 hours in a dry atmosphere at a temperature of 32°C before carrying out the hydraulic test. Using this protocol, only slight deformations of the soil surface topography were generated during the tests.

5 RESULTS

5.1 *Results on smooth CCL surface*

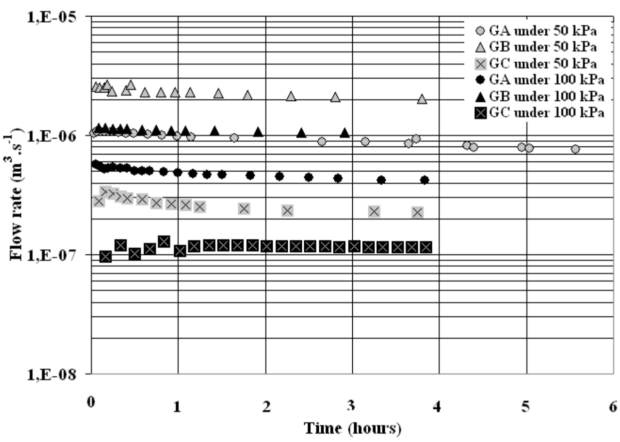

Figure 4 Flow rates for geotextiles GA, GB and GC under 50 and 100 kPa, smooth CCL surface

Hydraulic tests were performed on initially dry geotextiles. Under a 50 kPa normal stress, one can observe in Figure 4 that flow seems to reach steady state in about 4 hours.

Flow measured in interface filled by geotextile GB is the highest, with a value of 2×10^{-6} $m^3.s^{-1}$. Then, geotextile GA provides a flow rate of 8×10^{-7} $m^3.s^{-1}$ and geotextile GC yields to a flow about 2×10^{-7} $m^3.s^{-1}$. Non-woven needlepunched geotextiles GA and GB provide higher flow rates, almost one order of magnitude, than those of the thermal-locked geotextile. This observation is unsurprising since geotextiles GA and GB are thicker than geotextile GC. On a flat surface and for initially dry geotextiles, flow rate at the interface seems intimately related to the thickness of the product filling the interface.

Under a 100 kPa normal stress, flow rates for the three geotextiles are decreased compared to results obtained at 50 kPa by a factor slightly smaller than 2. The arrangement of curves for interfaces filled by geotextile GA, GB and GC, function of thickness, remains identical to those under the lowest normal stress.

The decrease in transmissivity (see part 6.2) due to the mechanical load increase is globally the same for the three products and thus appears to be insensitive to the thickness and manufacturing process of the geotextile.

Moreover, flow rates obtained at interface in presence of a geotextile point out that a thin thermal-locked geotextile provides smaller leakage than a non-woven needlepunched geotextile commonly used in landfills, under the geomembrane. This conclusion applies for specific conditions of experiments presented in this paper and should not be generalized without further investigations.

A comparison to results given by Touze-Foltz (2002) shows that in the case of smooth CCL surfaces the use of a geotextile in the interface will result in a dramatic increase of the flow rate as compared to a case without geotextile. Indeed this author measured flow rates in the range 6.3×10^{-12} to 4.5×10^{-11} m^3s^{-1} with the same clay and geomembrane and the same experimental device, no geotextile at the interface, and a normal stress on top of the composite liner equal to 3 kPa.

Results obtained on uneven CCL surface

Flow rate measurements were performed for geotextile GA, GB and GC under 50 and 100 kPa normal stresses on the uneven CCL surface. Results are presented in Figure 5.

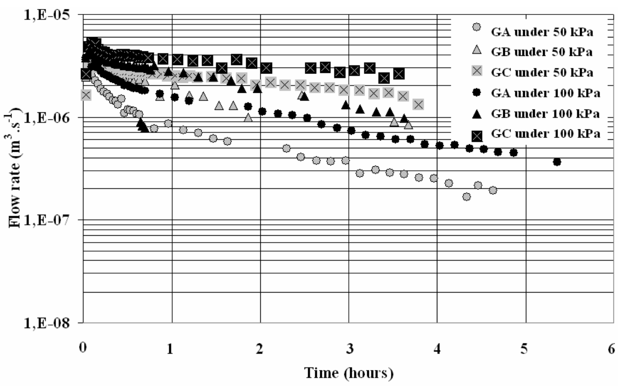

Figure 5 Flow rates for geotextiles GA, GB and GC under 50 and 100 kPa, uneven CCL surface

All geotextiles show a similar flow rate, about 4×10^{-6} $m^3.s^{-1}$ at the beginning of the test, for both normal stresses. The general decrease of the curves with time, despite the fact that the normal stress was held constant, is assumed to be related to poral space closure and compressive creep phenomenon under mechanical stress of geotextile fibres. One can notice that, contrary to results obtained on a smooth surface, the flow rate obtained with the thermal-bonded GC geotextile is not this different from cases with thicker GA or GB geotextiles.

The arrangement of the curves for the geotextiles is opposite to the case of flat surface: flow rate with GC is higher than flow rate with GB present at interface, itself higher than flow rate with GA. Increasing the normal stress applied from 50 to 100 kPa does not modify this configuration.

Flow rates are ranging from 2×10^{-7} to 2×10^{-6} $m^3.s^{-1}$ with the various interfaces with geotextile, whereas flow rates for empty interface (not plotted in Figure 5) are both about 1.5×10^{-5} $m^3.s^{-1}$ for 50 and 100 kPa. The negligible influence of mechanical stress on flow reduction in interface is attributable to the high irregularity of the CCL surface (see Figure 3) and will be discussed later on in this paper.

Second significant and unexpected result is the slight increase of flow rate for all the products tested when the normal stress is increased from 50 to 100 kPa. Geotextile GA seems to be the most sensitive to this phenomenon.

These facts clearly show that flow is not related only to geotextile type and thickness with the soil surface topography used in this experiment.

Finally, a comparison of hydraulic tests results with or without geotextile at the interface tends to show that all the products have a restrictive impact on flow.

5.2 *Interface transmissivity calculations*

As the soil liner hydraulic conductivity is low, and tests duration limited the infiltration and flow rate through the soil liner can be neglected. It is not thus necessary to use elaborated analytical solutions (Touze-Foltz et al. 1999) that take into account the infiltration in the soil liner. This point was numerically checked. Then the simple following equation was used (Fukuoka, 1986):

$$Q = \frac{2\pi\theta h}{\ln(R/r_0)} \qquad (1)$$

with θ the interface transmissivity, h the hydraulic head applied on top of the geomembrane, R the cell radius and r_0 the hole radius. Results obtained are presented in Table 2 for all tests.

Table 2 Interface transmissivity under 50 and 100 kPa for flat and uneven soil surfaces compared with values given from ISO 12958 standard test.

Smooth Surface

Geotextile	Transmissivity ISO12958 50 kPa ($m^2.s^{-1}$)	Transmissivity ISO12958 100 kPa ($m^2.s^{-1}$)	Transmissivity measures in cell 50 kPa ($m^2.s^{-1}$)	Transmissivity measures in cell 100 kPa ($m^2.s^{-1}$)	Transmissivity Ratio (ISO/Cell) 50 kPa ($m^2.s^{-1}$)	Transmissivity Ratio (ISO/Cell) 100 kPa ($m^2.s^{-1}$)
GA	1.7×10^{-6}	1.2×10^{-6}	1.58×10^{-6}	8.64×10^{-7}	1.07	1.39
GB	4.8×10^{-6}	1.7×10^{-6}	4.21×10^{-6}	2.19×10^{-6}	1.14	0.77
GC	-	-	4.66×10^{-7}	2.39×10^{-7}		

Uneven Surface

Geotextile	Transmissivity ISO12958 50 kPa ($m^2.s^{-1}$)	Transmissivity ISO12958 100 kPa ($m^2.s^{-1}$)	Transmissivity measures in cell 50 kPa ($m^2.s^{-1}$)	Transmissivity measures in cell 100 kPa ($m^2.s^{-1}$)	Transmissivity Ratio (ISO/Cell) 50 kPa ($m^2.s^{-1}$)	Transmissivity Ratio (ISO/Cell) 100 kPa ($m^2.s^{-1}$)
GA	1.7×10^{-6}	1.2×10^{-6}	4.01×10^{-7}	7.58×10^{-7}	4.24	1.58
GB	4.8×10^{-6}	1.7×10^{-6}	1.73×10^{-6}	2.02×10^{-6}	2.82	0.84
GC	-	-	3.30×10^{-6}	5.48×10^{-6}		

- : cannot be determined with ISO12958 Standard

6 DISCUSSION

6.1 *Comparison of test results to ISO 12958*

Table 2 allows a comparison of results obtained thanks to ISO 12958 and in the transmissivity cell for geotextiles GA and GB. This comparison is not possible for geotextile GC as the ISO standard does not allow to give a value for this geotextile (lower than 10^{-7} ms^{-1}). Values obtained on the flat soil surface are rather close to values given by ISO 12958 under 50 kPa. This result is no longer true for a normal stress equal to 100 kPa.

As regards the results obtained in the transmissivity cell with an uneven soil surface topography, the discrepancy with ISO 12958 is even larger under a normal stress equal to 50 kPa, and still significative, despite a decrease, for a 100 kPa normal stress.

As a consequence, it seems that transmissivities given by the ISO 12958 standard should not be used for prediction of flow rates in composite liners including a geotextile for the prediction of flow rates as this standard does not allow to take into account the influence of the soil surface topography.

6.2 *Influence of the normal stress applied*

In the case of smooth surface, increasing the normal stress applied on the composite liner in the transmissivity test cell by a factor of 2 induces a decrease in the transmissivity of the three geotextiles (see Table 2) by a factor close to 2, which is in good agreement with work of Palmeira and Gardoni (2002).

Since the CCL surface is flat, interface filled by the geotextile has an approximately constant thickness, thus the normal stress applied is spread over the whole area of the geotextile and the pressure is uniformly distributed.

The mechanical response of the geotextiles seems to differ as a function of the type of fiber bonding process. Nevertheless, geotextiles GA and GB, although made from similar process both with polypropylene fibers and having similar mass per unit area (see Table 1), exhibit different hydraulic reactions to stress. As shown in Table 2, for test on a flat surface, transmissivity of geotextile GB under 100 kPa is almost identical to the transmissivity of geotextile GA under 50 kPa.

The closure of the porosity was calculated, using thickness measurements under stress and the relation given by Koerner (1998):

$$n = 1 - \frac{m}{\rho . t} \qquad (2)$$

with n the porosity of the geotextile, m its mass per unit area in ($g.m^{-2}$), ρ the density of fibers (910 $kg.m^{-3}$) and t the geotextile thickness (m). Results are shown in Table 3.

Values show that the porosity of geotextile GA is totally reduced for normal stresses as low as 50 kPa, whereas the porosity of geotextile GB is still decreasing for a 100 kPa normal stress. Porosity of thermal-bonded GB is insensitive to mechanical stress since its fibres are already in contact from the manufacturing process. One can notice in Table 3 that geotextiles GA and GB have similar porosity under 2 kPa but their behaviour differ when the normal stress is increased. Porosity of GB under 100 kPa is close to porosity of GA under 50 kPa and this can explain the similar flow rates in Figure 4.

Table 3 Porosity reduction under stress

Geotextile	Porosity under 2 kPa	Porosity under 50 kPa	Porosity under 100 kPa
GA	0.882	0.788	0.763
GB	0.896	0.846	0.809
GC	0.643	-	-

- : cannot be determined.

In the case of the tested uneven surface, increasing the normal stress applied obviously does not yield to a reduction of flow and transmissivity, for both empty and geotextile-filled interfaces. Interface being of highly variable thickness, contact zones between geomembrane and CCL surface are only a fraction of the total interface area. When the mechanical load is increased, the surface of contact is not increased accordingly. If a geotextile is present in the interface, reduction of its thickness and thus its porosity can be expected in these contact zones, where the geotextile is pinched. But, since pinching zones are in minority, most geotextile zones above opened interface could remain at the same thickness value as those under no stress.

In conclusion, the effect of the normal stress on interface transmissivity is high with smooth surface of CCL and is low when the surface has an uneven topography such as the one used in this experimental study.

6.3 *Influence of the geotextile type and soil surface topography*

According to results obtained, the influence of the geotextile type may be important on smooth CCL surface and low on very irregular surface. This can be explained in the following way: in the case of smooth surface, flow rate is globally proportional to interface thickness and the thinner the geotextile, the smaller is the generated flow. Thus, very low flow obtained with the 0.4 mm thermal-bonded GC geotextile is logical. On the other hand, in case of uneven CCL surface with an interface of variable aperture, none of the geotextiles tested totally fill the gap between the geomembrane and the soil, flow takes place both in the geotextile plane and in voids and then the interface transmissivity is no more comparable to the one of the geotextile alone. The fibrous structure of the geotextiles plays a role of resistance to flow, and a thicker geotextile filling more space in interface will decrease the flow rate in higher proportion. In this specific case, a thin geotextile such as thermal-bonded GC provides a higher flow.

A very irregular topography with important roughness such as those used in the present work provides a highly variable thickness of the geotextile under normal stress, with compression and thus thickness reduction in pinching zones and uncompressed zones above locally opened interface, yielding to geotextile thickness similar to the case with no stress applied.

Nevertheless, the role of geotextile remains limited and differences between products are mitigated because, as

for natural rough fractures, flow is governed by highest aperture connected zones, in which only a fraction of the flow takes place in the geotextile plane. The compacted clay surface has been identified in this work as a key feature for leakage through the composite liner in case of damaged geomembrane and special care should be taken of CCL surface quality.
As regards the practice of using a geotextile in the interface, based on the soil surface topographies used in this study it seems that for a flat soil surface topography it is better not to use a geotextile in the interface whereas for an uneven soil surface topography, the geotextile can contribute in decreasing the obtained flow rates in the interface.

A whole range of configurations may exist in between the extreme geometrical configurations used in this study. Then it is not simple to draw useful conclusions for straightforward engineering application on the field from laboratory small-scale tests. One should keep in mind the experimental conditions of the results obtained, especially in terms of normal stress values in the experimental device, which are low as compared to those applied on a bottom liner under several tens of meters of compacted waste. The first author has observed, from many landfill visits, that CCL surfaces are formed by globally smooth zones and locally very uneven zones, with rutting due to heavy vehicles traffic. Leakage rates generated by defect occurring in the geomembrane above each of these distinct zones will be respectively more limited and slightly higher with a thermal-bonded geotextile than with a needlepunched one. The choice of the geotextile to implement should be a function of the surface topography condition and take into account the resistance to puncturing of products for geomembrane protection, in case of hard elements on the clay liner and, by this way, reduce the number of defects per hectare. Taking into account the great influence of the soil surface topography o the results it is recommended that the answer be given on a case by case basis and that the results obtained in this study are not extrapolated to any field condition.

7 CONCLUSION

The influence of the soil surface topography and geotextile type at the interface of composite liners on resulting flow rates was tested. Two very different soil surface topographies were used, a flat one and an uneven one.
Results obtained show the great influence of the combination of soil surface topography and geotextile type on the results obtained. On a smooth surface, the placement of a geotextile increases the flow rate compared to the case without geotextile, especially with thick needlepunched products. On the contrary, in the case of a very uneven surface, the flow in the interface is surprisingly reduced when it is partially filled by a geotextile, especially for geotextiles of important thickness. These results hold for specific experimental conditions in terms of normal load applied, system dimension and surface topographies and should not be used without further investigations. Furthermore, transmissivities given by ISO 12958 standard were proved not to be suitable for interface transmissivity estimation when the geotextile is used at the interface of a composite liner.
It results from this experimental study performed at the decimetric scale that the choice of the geotextile, if any, used at the interface of a composite liner has to be done on a case by case basis, taking account of the surface quality of the compacted clay liner.

8 ACKNOWLEDGEMENTS

The authors gratefully acknowledge Aurore Bessières, Robert Bouhenni and Roland Gallo from Cemagref who carried out part of the transmissivity tests, Bidim Geosynthetics, Landolt and Dupont de Nemours for supplying the geotextiles used in the described study. Finally the authors acknowledge Yves Duval from INRA de Laon who performed soil surface topography measurements.

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