Experimental study of the gas permeability of GCLs: influences of the type of material and the water content

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ABSTRACT: This paper examines geosynthetic clay liners tightness against biogas flow in cover systems of municipal solid waste landfills. It shows the influence of the main parameters of the bentonites (natural or activated calcium bentonite, natural sodium bentonite) tested under different degrees of saturation on the permeability to gas of GCLs. The influence of the bonding process of the GCL was also studied. The results obtained showed important variations of the permeability to gas due to moisture content. The type of bentonite as well as the bonding process of the GCLs studied showed an important influence on the gravimetric moisture content required to the GCL to attain certain value of intrinsic permeability.

1 INTRODUCTION

The release of biogas produced by municipal solid wastes into the atmosphere must be minimized. Therefore, the permeability to gas of all components of the cover system, particularly of geosynthetic clay liners (GCLs – when used), must be determined as a function of the main parameters characterizing these materials. According to Egloffstein (2002), the low permeability of bentonites, which is the main component of GCLs, comes mainly from three aspects: (i) the larger the thickness of the diffuse doubled layer around the clay particle, the lower the permeability; (ii) the hydration water and the adsorption water are bound by adhesion in the montmorillonite crystal and only a fraction of the pore water follows the Darcy's law and (iii) the microstructure of the bentonite, which depends on the nature of the bentonite.

Natural sodium bentonites or activated calcium bentonites presents a more advantageous fine-dispersed micro-structure compared to natural calcium bentonites. Sodium bentonites have a considerably higher swelling capacity because their expansion is also due to osmotic swelling, which causes the de-lamination of the silicate crystals, increasing the distance between them. Despite the greater distance between the silicate crystals, they have a lower permeable space volume with longer flow paths around individual clay particles, yielding to lower permeability values compared to natural calcium bentonites, which present a more aggregated structure.

Experiments conducted by different authors showed the influence of the moisture content on the GCLs permeability to gas (Bouazza & Vangpaisal 2003, Bouazza et al. 2006, Didier et al. 2000, Shan & Yao 2000 and Vangpaisal & Bouazza 2004, for instance). Some studies show the influence of the type of the bentonite (granular or powdered) on the permeability to gas (Didier et al. 2000 and Vangpaisal & Bouazza 2004) but without considering all the different natures of bentonite used in GCLs, such as natural or activated calcium bentonites and natural sodium bentonites. Because the nature of the bentonites can influence its permeability to water (Guyonnet et al. 2009) this study aims at verifying the influence of the nature of bentonite on the permeability to gas under different unsaturated conditions.

To achieve this objective, the dependence of the mechanism of gas transport to the degree of saturation must be considered: advection when the pores are large enough so as Darcy's law may be applied, or diffusion under highly saturated conditions, following Fick's law. Such different mechanisms require the use of different coefficients to characterize the permeability of GCLs to gas (the coefficient of permeability, independent of the gas nature in case of advection and the coefficient of diffusion depending on the gas nature in case of diffusion). The comparison among different materials under different conditions of moisture content requires the use of an unique parameter, which may be the gas flow, when it can be measured. However, in case of highly saturated specimens, the gas flow may be very difficult to be measured in a steady state experiment under a constant gas pressure difference. Therefore, a transient state experiment can be used, where the response of the specimen to a differential gas pressure is studied. This paper shows the repercussions on GCL tightness to gas flow depending on its bentonite type and moisture content.

2 MATERIALS AND METHODS

As stated above, the measurement of the gas flow through the specimen tested may be a good characterization for the gas permeability of the specimen in all conditions of moisture content if the tests conditions are well specified. In ISO/CD10773 (ISO 2007) test the gas flow rate is measured when steady state conditions are reached, corresponding to a constant specific differential gas pressure of 15 kPa between both sides of the specimen. In the case of specimens close to saturation this method requires long test durations. Bouazza & Vangpaisal 2003 refer to 3 to 9 hours test durations, for instance. The increase of the gas pressure difference may reduce the test duration (Didier et al. 2000) but it can also modify the moisture content of the specimen (Bouazza & Vangpaisal 2003). Therefore, a solution is to carry out the test under transient flow conditions, with lower differential gas pressures. Such a method does not require the steady state flow condition to be reached and reduces the test duration considerably. It is often used to test rocks, soils, (Haskett et al. 1988, Carles et al. 2007, Barral et al. 2009), concrete (Figg 1973, Claisse et al. 2003), asphalt (Li et al. 2004) and more recently GCLs (Pitanga et al. 2009).

2.1 *The falling pressure test*

The falling pressure test is carried out by means of the equipment presented in Figure 1 and described in Pitanga et al. (2009). It consists of a permeameter cell composed basically by three cylindrical units made of aluminum: bottom, intermediate and upper units. In the base unit a porous layer with known voids volume is accommodated. The bottom unit has an inlet port for gas supply. The intermediate unit is placed on the bottom unit and the GCL specimen overlays the porous layer. The upper unit fixes the specimen edges and 5 bolts around the cell attach the three units. Bentonite is used to seal the contacts between the cell and the GCL specimen and an o-ring between the walls of the intermediate and top units reinforce the sealing. Inside the upper unit, overlying the GCL specimen, there is a sand layer which is placed in order to distribute uniformly the vertical pressure of 20 kPa, simulating approximately a 1 m thick cover soil layer. A nonwoven geotextile (with mass per unit area equal to 300 g/m^2) is placed between the GCL specimen and the sand layer to avoid the impregnation of the GCL by sand particles.

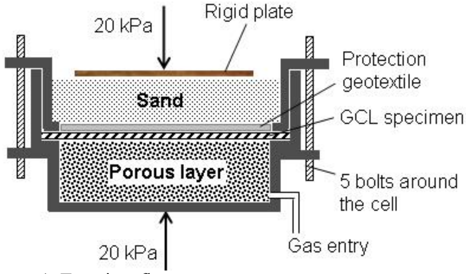

Figure 1. Transient flow permeameter.

The falling pressure test consists in measuring the pressure reduction in the voids of the porous layer underlying the GCL due to gas flow through the GCL, the nonwoven geotextile and the sand layer in the permeameter (Figure 1). Pressurised nitrogen (N_2) (viscosity of 1.76 x 10^{-5} Pa.s, density of 1.15 kg/m^3 at 20°C) is supplied to the porous layer until a target initial pressure is reached. The permeameter is then isolated and the nitrogen pressure reduction inside the porous layer is recorded until the pressure inside the porous layer is equal to the atmospheric pressure. This enables the determination of the GCL permeability to gas without the need of measuring the gas flow rate by means of Equations 1 and 2 (Barral et al. 2009).

$$P_c(t) = P_{atm} + \left(P_c(0) - P_{atm}\right) \cdot \exp\left(-\frac{t}{\tau}\right) \qquad (1)$$

Where $P_c(t)$ is the absolute pressure inside the porous layer voids; P_{atm} is the atmospheric pressure, t is the time and τ is the time constant, which can be related to the intrinsic permeability coefficient, k, in case of specimens with moderate values of degree of saturation, by:

$$\tau = \frac{V \cdot \eta \cdot Z}{A \cdot k \cdot P_{atm}} \qquad (2)$$

Where: V is the volume of the voids in the porous layer; η is the gas dynamic viscosity; Z is the GCL thickness; A is the specimen area; k is the GCL intrinsic permeability coefficient; and P_{atm} is the atmospheric pressure.

2.2 *Materials tested*

Four different GCLs were tested. Three of them came from the same manufacturer with the main difference among them being the nature of the constitutive bentonite: natural calcium (specimen code: 1-Ca), activated calcium (1-Ca.ACT) and natural sodium (1-Na). These products were composed by a bentonite core encapsulated between two layers of polypropylene woven geotextiles with a mass per unit area equal to 110 g/m^2. These GCLs were stitch-bonded with parallel stitch-bonding rows 40 mm apart. Another GCL composed by natural sodium bentonite (2-Na) coming from a different manufacturer was also tested. In this case the bentonite was encapsulated between two different geotextiles: a polypropylene nonwoven geotextile (300 g/m^2 mass per unit area) and a polypropylene woven geotextile (200 g/m^2 mass per unit area). The attachment of the layers of this GCL was achieved by needle-punching. Table 1 presents the main features of the GCLs studied.

Each GCL specimen was tested with different moisture contents, aiming at studying the influence of the moisture content on the permeability to gas of the GCLs studied. The specimen preparation consisted of the immersion of a 550 x 550 mm sample under zero confinement pressure in a water tank. The immersion time of each specimen was different, resulting in different final moisture contents. After immersion, the sample was kept in a sealed plastic bag for seven days, following the recommendations from the French standard XP P 84-707 (AFNOR 2002) aiming at obtaining a homogeneous moisture distribution along the specimen surface. A free swelling process was chosen, because it corresponds to the most unfavourable condition in field, when there is a time lapse between GCL and soil cover installations.

Measurements of the specimen thickness were made prior to immersion and after the swelling process under 0 and 20 kPa of confining pressure. The initial gravimetric moisture content was determined prior to the test in four specimens located outside the circular area effectively test. The gravimetric moisture content was again determined at the end of each test, by cutting other four specimens located in the center of the GCL area tested in order to verify the loss of moist during the test. It was observed an average reduction of 6% in the gravimetric moisture contents of the specimens tested.

3 RESULTS OBTAINED

3.1 *Moisture content*

The variation of the intrinsic permeability of the GCLs tested with the gravimetric moisture content is presented in Figure 2. As expected, a reduction of the intrinsic permeability with the moisture content can be noticed for all GCLs studied. More than two orders of magnitude difference in the permeability can be verified for a relatively narrow range of values of moisture content.

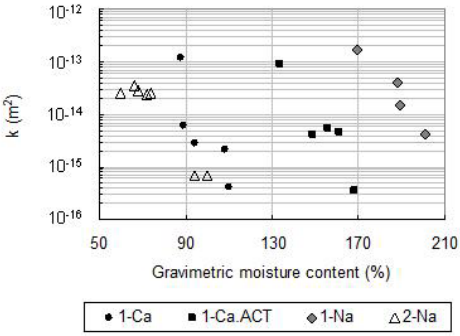

Figure 2. Permeability to gas versus moisture content.

One can also observe in Figure 2 that each GCLs studied required different levels of hydration to reach the same range of permeability (2x10^{-13} to 3x10^{-16} m^2). For the GCLs coming from the first manufacturer, one can observe that the natural calcium bentonite (GCL 1-Ca) required lower moisture contents to attain the same permeability than the GCL composed by activated calcium bentonite (1-Ca.ACT). The GCL composed by natural sodium bentonite (1-Na) required greater moisture contents, compared to the other GCLs coming from the same manufacturer to reach the same range of intrinsic permeabilities. An intrinsic permeability of 10^{-13} m^2, for example, is obtained with moisture contents of approximately 90%, 130% and 170% for the GCLs 1-Ca, 1-Ca.ACT and 1-Na, respectively.

In the case of the GCL from the second manufacturer, 2-Na, the moisture content required to attain the same range of intrinsic permeability was lower than those the other materials (GCLs from the first manufacturer). The moisture contents of GCLs 1-Na and 2-Na to attain the same intrinsic permeability values were very different, despite both GCLs being composed by bentonites of the same nature. It should be pointed out that the manufacturing processes of these GCLs are different, which can explain such difference as will be discussed in the next section.

3.2 *Influence of bonding process*

The tests performed on two GCLs with sodium bentonite, but with different bonding processes (stitch bonding in 1-Na and needle punching in 2-Na) allowed observing the influence of these processes on their performance as a gas barrier. Comparing the results of tests performed with these two GCLs one can verify a significant difference on the moisture content required to attain a certain value of permeability. The needle-punched GCL required a moisture content of approximately 70% to attain an intrinsic permeability of 2x10^{-14} m^2, while the stitch-bonded GCL required a moisture content of approximately 190% to attain the same permeability

Table 1. Main features of the GCLs tested

		1-Ca	1-Ca.ACT	1-Na	2-Na
GCL	Tickness (mm)	11.7	6.5	7.0	7.0
	Mass per unit area (g/m^2)	10590	5460	5410	5100
	Hydraulic Conductivity following NF P 84-705 (AFNOR 2008) under 50 kPa (m/s)	6.9x10^{-10}	4.4x10^{-11}	3.2x10^{-11}	2.0x10^{-11}
Bentonite	Type	Natural Calcium	Activated Calcium	Natural Sodium	Natural Sodium
	Mass per unit area (g/m^2)	10300	5200	5130	4600
	w_{nat} (%)	9.5	10.5	14.8	10

value. This result suggests that the bonding process may restrict more or less intensely the expansion of the bentonite encapsulated between the geotextiles, influencing the structure of the GCL. This probably leads to different demands of hydration to attain the same permeability, even in GCLs composed by the same type of bentonite.

4 CONCLUSIONS

This study was dedicated to the characterisation of the permeability to gas of GCLs under unsaturated conditions and confirmed the reduction of the GCLs permeability to gas with the increase of its moisture content. It was verified that the gravimetric moisture content which guarantees a low permeability in one type of GCL may be insufficient to attain such low permeability in another type of GCL. Both the nature of the bentonite and the bonding process of the GCL seem to influence the demand of hydration to attain a certain value of permeability to gas. Such results show that the nature of the bentonite, as well as the GCL manufacturing process, are intimately related to the GCL permeability to gas.

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REFERENCES

AFNOR, 2002, NF XP P 84-707. Perméabilité au gaz des géosynthétiques bentonitiques partiellement saturés. French Association for Normalization, Paris.

AFNOR, 2008, NF P 84-705 Détermination à l'oedoperméamètre des caractéristiques de gonflement – Flux et perméabilité des géosynthétiques bentonitiques (GSB). French Association for Normalization, Paris

Barral, C., Oxarango, L. and Pierson, P., 2009, Characterizing the gas permeability of natural and synthetic materials. Transport in Porous Media. Submission DOI 10.1007/s11242-009-9398-x (in press).

Bouazza, A. and Vangpaisal, T., 2003, An apparatus to measure gas permeability of geosynthetic clay liners. Geotextiles and Geomembranes, 21(2): 85-101.

Bouazza, A., Vangpaisal, T. and Jefferis, S., 2006, Effect of Wet-Dry Cycles and Cation Exchange on Gas Permeability of Geosynthetic Clay Liners. Journal of Geotechnical Engineering, 132(8): 1011-1018.

Carles, P., Egermann, P., Lenormand, R. and Lombard, J.M., 2007, Low permeability measurements using steady-state and transient methods. Proceedings of the International Symposium of the Society of Core Analysts, Calgary, 12p.

Claisse, P.A., Ganjian, E. and Adham, T.A., 2003, A Vacuum-Air Permeability Test for in situ Assessment of Cover Concrete. Cement and Concrete Research, 33(1): 47-53.

Didier, G., Bouazza, A. and Cazaux, D., 2000, Gas permeability of geosynthetic clay liners. Geotextiles and Geomembranes, 18(2-4): 235-250.

Egloffstein, T.A., 2002, Bentonite as sealing material in geosynthetic clay liners – influence of the electrolytic concentration, the ion exchange and ion exchange with simultaneous partial desiccation on permeability. Clay Liners Barriers, Zanzinguer, Koerner & Gartung (eds) 2002. Swets & Zeitlinger, Lisse.

Figg, J.W, 1973, Methods of measuring the air and water permeability of concrete. Magasine of Concrete Research, 25(85): 213-219.

Guyonnet, D., Cazaux, D., Touze-Foltz, N., Didier, G., Couradin, A., Norotte, V. and Bour, O., 2007, French approach to equivalence in landfill geological barriers. Proceedings of the Eleventh International Waste Management and Landfill Symposium- Sardinia 2007, S. Margherita di Pula, Cagliari, Italy, 11 p.

Haskett, S.E., Narahara, G.M. and Holditch, S.A., 1988, A method for simultaneous determination of permeability and porosity in low-permeability cores. Proceedings of Annual Technical Conference and Exhibition of the Society Petroleum Engineers (SPE), New Orleans, 8p.

ISO, 2007, ISO CD 10773. Geosynthetic Clay Barriers: Determination of gas flow through a GCL or GCB (Geosynthetic Clay Liner or Geosynthetic Clay barrier) (under development)

Li, H., Jiao, J.J. and Luk, M., 2004, A falling-pressure method for measuring air permeability of asphalt in laboratory. Journal of Hydrology, 286(1-4): 69-77.

Pitanga H.N., Pierson P. and Vilar O.M., 2009, Measurement of gas permeability in geosynthetic clay liners in transient flow mode. Submitted to Geosynthetics International (under review).

Shan, H.Y. and Yao, J.T., 2000, Measurement of air permeability of GCLs. Geotextiles and Geomembranes, 18(2-4): 251-261.

Vangpaisal, T. and Bouazza, A., 2004, Gas permeability of partially hydrated geosynthetic clay liners. Journal of Geotechnical and Geoenvironmental Engineering, 130(1): 93–102.