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# Laboratory test method for determining gas permeation through double welded geomembrane seams

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ABSTRACT: Since nothing is absolutely impermeable, the knowledge of the permeability coefficients of geomembranes to gases or liquids is required to assess its effectiveness, especially in the seamed area. In order to determine the permeance of double welded high density polyethylene geomembrane seams to nitrogen and water vapour, laboratory tests have been carried out. Tests have been conducted using a permeation cell, designed to allow the immersion of each seamed specimen either in water or in air. The space between the two parallel welds was filled with nitrogen gas under a given pressure and the decrease of this pressure with time was monitored. The first results show that it is possible to characterise the seam by a permeance depending on the fluid and on the seam parameters. This suggests that the gas permeation test might be used to detect the quality of seams by quantitative measurement of the permeance.

## 1. INTRODUCTION

Due to their low permeability to gases and liquids, geomembranes are used in a wide range of engineering application as barriers to control fluid migration. The assessment of the effectiveness of a geomembrane during the design process requires the determination of the permeability coefficients. Several researchers have studied the permeability coefficients of the geomembranes to different fluids (Haxo *et al.*, 1984, 1990; Matrecon, 1988; Haxo, 1990; Eloy-Giorni *et al*, 1996; Pierson, 1996, and Hurtado Gimeno, 1999, Rowe *et al.*, 1996; Sangam *et al.*, 2001). However, little research has been done on predicting the permeability of geomembrane seams. These are vulnerable areas, due to the application of heat and pressure during the welding process, through which pollutants may migrate. The available test methods to assess the fluid-tightness of the seams in field can only be used to measure the continuity of seams and cannot be used to measure quantitatively its permeability. Therefore, a test method able to characterise quantitatively the permeability coefficients of seams could be very useful. Firstly, as a reference test in laboratory to control geomembrane seams in field. Secondly, for studying the influence of the welding parameters on the quality of seams.

This paper, first, describes a laboratory test method for determining gas (nitrogen) permeation through double welded geomembrane seams, then discusses the mechanism of permeation through the geomembranes, and finally, presents the preliminary test results for a 2,0 mm thick high density polyethylene (HDPE) geomembrane.

## 2. EXPERIMENTAL WORK

### *2.1 Materials*

The experimental work was carried out using 1.2 m long double welded specimens of a 2.0 mm thick HDPE geomembrane, sealed on both ends. The seams were made using the same equipment as the one used in field to join geomembrane panels by the double hot wedge method, leaving an air channel between them.

### *2.2 Apparatus*

Tests have been conducted at laboratory using a permeation cell (Figure1), designed to allow the immersion of each specimen in two different mediums: water and air. Briefly, it comprised two circular stainless steel plates and a glass pipe (inner diameter: 0.186 m; length: 1.5 m). The measuring devices and the nitrogen supply were connected to the top plate. For test carried out in air, the measuring devices comprised of: a pressure transducer for measuring the nitrogen pressure inside the specimen; a temperature sensor for measuring the air temperature; a pressure transducer to measure the atmospheric pressure; and a sensor for registering the relative humidity of the air. For the tests in water, two additional measuring devices have been attached to the top plate: a pressure transducer to assess the volume variations and a temperature sensor for registering the water temperature. The volume measurements were achieved by connecting the transducer to a capillary pipe. Transducer readings have been converted into height of water in the capillary pipe and then were multiplied by the area of the pipe to obtain the volume change at each time. All these devices have been also connected to a data system acquisition.

### *2.3. Procedure*

The specimens were inserted into the permeation cell and seams were pressurised (150 kPa) by introducing gas into the channel between the two parallel welds. During the test, gas was monitored with time. The permeation of the gas through the specimen was indicated by a decrease in pressure. The tests were carried out using nitrogen. This gas was chosen for testing rather than air (used in field to perform pressure tests on seams) in order to simplify the interpretation of test results. As regards pressure, the 150 kPa value was selected for having the closest possible pressure to the one used in field (200-300 kPa), but without exceeding the resolution of the measuring devices used.

The tests were performed under 27 ± 0.1°C, in a controlled temperature box, either immersing the specimen in deaired water, or in the air. The test in water was carried out not only for measuring the water vapour transmission rate but also for measuring the volume variations of the specimen with time, since the specimen's inner volume (channel) is required for

determining the quantity of nitrogen diffusing through the specimen. Deaired was used to minimise the variations of volume due to temperature variations.

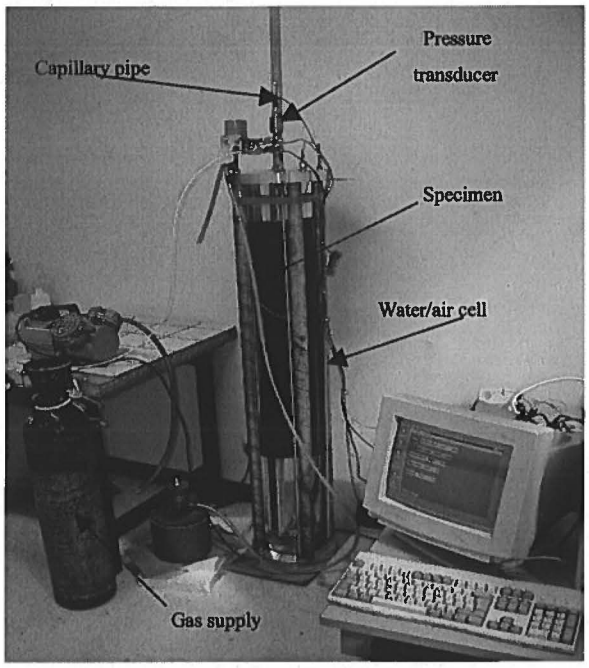


Figure 1. Photograph of the gas permeation test setup.

## 3. PERMEANCE DEFINITION AND CALCULATION

Since the specimens were immersed in two different fluids (air and water), in order to evaluate the permeability coefficients associated to each medium the following approach was used. In test carried out with the specimen immersed in air, the amount of nitrogen ($N_2$) passing through a unit of the parallel surfaces of the geomembrane per time unit (nitrogen transmission rate) was determined using the Equation 1, which is a derived form of the Fick law:

$$J_{N2} = \underline{P}_{N2}\frac{\Delta p}{t_{gm}} \quad (1)$$

where $J_{N2}$ is the nitrogen transmission rate in $mol.m^{-2}.s^{-1}$, $\Delta p/t_{gm}$ is the applied partial pressure gradient across the geomembrane of thickness $t_{gm}$ (the partial pressure must be considered when the medium is not a pure gas: it is the case of the air or of the water+nitrogen), $\underline{P}_{N2}$ is usually referred to in literature as the permeability coefficient. The SI unit for expressing $\underline{P}_{N2}$ is $mol.m^{-1}.s^{-1}.Pa^{-1}$. It should be noted that polymeric geomembranes are nonporous media, in which the transport of a permeating fluid (gas or liquid) occurs by diffusion on a molecular basis. This process involves three steps: (1) absorption or dissolution of the permeant at the upstream surface of the geomembrane; (2) diffusion of the permeant through the geomembrane due to a concentration gradient, and (3) desorption or evaporation of the permeant at the downstream surface of the geomembrane (Haxo et al., 1984; Haxo and Pierson, 1991). Thus, this coefficient of permeability has nothing to do with the coefficient of permeability used for porous media (Darcy's law).

Characterising the permeability of a geomembrane by the coefficient $\underline{P}_{N2}$ presents several disadvantages. First, it may be difficult to measure the geomembrane thickness ($t_{gm}$) properly; second, previous studies on this topic have shown that $\underline{P}_{N2}$ may depend on thickness (Haxo, 1990; Pierson and Duquennoi, 2000); and, finally, it is often confused with the permeability coefficient used for porous media. Therefore, it is advisable to prefer the permeance ($P_{N2}$) in $mol.m^{-2}.s^{-1}.Pa^{-1}$ for characterising the permeability of a specific specimen and calculated only from $J_{N2}$ and $\Delta p$ (Equation 2):

$$P_{N2} = \frac{\underline{P}_{N2}}{t_{gm}} = \frac{J_{N2}}{\Delta p} \quad (2)$$

As mentioned, to determine the nitrogen transmission rate it is necessary to know the area of the specimen. However, it can be observed that in the case of double welded seams, it is difficult to estimate the specimen area with a good accuracy. This difficulty may come from non-regular seams and, mainly, from an irregular specimen shape when it is filled with nitrogen. Furthermore, the nitrogen transmission rate through the specimen concerns also the seams. Thus, it is useful to express $J_{N2}$ in $mol.s^{-1}$ and calculate it during the time interval $\Delta t$ from Equation 3:

$$J_{N2} = \frac{n_{N2}(t+\Delta t) - n_{N2}(t)}{\Delta t} \quad (3)$$

where $n_{N2}(t)$ is the quantity of nitrogen, in mol, transmitted through the specimen in steady-state conditions at time t, calculated from the ideal gas law (Equation 4):

$$n_{N2}(t) = \frac{p(t).V(t)}{R.T(t)} \quad (4)$$

where p(t) is the nitrogen absolute pressure inside the specimen channel at time t (Pa); V(t) is the specimen's inner volume at time t ($m^3$); R is the universal gas constant, $8.3143x10^3$ ($m^3.Pa.mol^{-1}.K^{-1}$); and T(t) is the specimen absolute temperature at time t (K).

In order to compare results of different specimens, $J_{N2}$ can also be defined in terms of nitrogen flow rate per unit of seam length (L):

$$J_{N2} = \frac{n_{N2}(t+\Delta t) - n_{N2}(t)}{\Delta t.L} \quad (5)$$

with $J_{N2}$ in $mol.s^{-1}.m^{-1}$, leading to a permeance (from Equation 2) in $mol.s^{-1}.Pa^{-1}.m^{-1}$.

Concerning tests carried out with the specimen immersed in water, two simultaneous permeants must be considered. They correspond respectively to the migration of nitrogen from the inside to the outside of the specimen and the migration of water vapour from the outside to the inside the specimen (100% relative humidity at the outer surface in contact with water). In this case, it is possible to obtain $n_{N2}(t)$, step by step, from $n_{N2}(t-\delta t)$ after the calculation of the nitrogen transmission rate ($J'_{N2}$), which can be determined indirectly from the previous test (conducted with specimen immersed in air) as follows:

$$J'_{N2} = J_{N2}\frac{\Delta p'}{\Delta p} \quad (6)$$

where $\Delta p'$ is the partial pressure difference between inside and outside of the specimen in the test conducted in water (Pa) and $\Delta p$ is the partial pressure difference between inside and outside of the specimen in the test conducted in air (Pa).

After a certain time (t>0), the specimen channel contains moles of nitrogen and water vapor ($n_{N2+wv}$), which can be calculated, step by step, from ideal gas law and from the measured pressures, temperatures and volumes.

The mole quantity $n_{wv}(t)$ of water vapour in the specimen channel can be easily obtained from $n_{N2+wv}(t)$ and $n_{N2}(t)$ and the water vapour transmission rate ($J_{wv}$) can be then estimated from equation (7):

$$J_{wv} = \frac{n_{wv}(t+\Delta t) - nwv(t)}{\Delta t} \quad (7)$$

where $\Delta t$ is a time interval when steady-state conditions are achieved (s), leading to the permeance ($P_{wv}$) defined as $P_{N2}$ in Equation 2.

## 4. RESULTS AND DISCUSSION

The results obtained, in terms of absolute pressures (relative +atmospheric), during the permeation tests on a 2,0 mm thick HDPE geomembrane specimen are presented in Figure 2. The test lasted 938 hours (39 days).

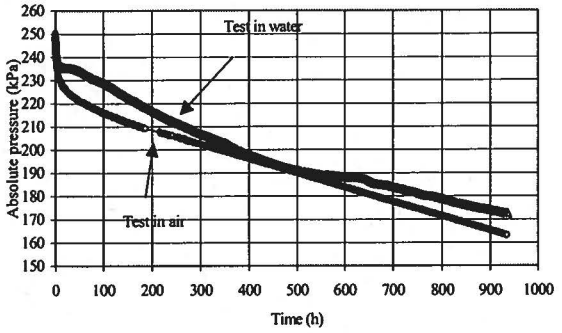


Figure 2. Comparison of the results obtained with test conducted in air and in water in terms of absolute pressure.

As can be observed from Figure 2, the curves present the same trend, the absolute pressure of nitrogen decreased with time on both tests. A comparison between the results obtain with test carried out in air and in water shows a slight difference in absolute pressure drop: 87kPa (35%) for the test in air, and 78kPa (31%) for the test in water.

The volume variations were recorded during the test carried out in water in order to evaluate the specimen's inner volume at each time. Results of this study indicate that the volume variations during test were negligible, considering the measurement errors, namely the water expansion/contraction due to the temperature fluctuation (± 0.1°C). Based on this observation, all subsequent calculations were done assuming a constant volume of the specimen.

### *4.1 Nitrogen transmission rate*

The amount of nitrogen passed through the specimen after the steady-state achievement is plotted versus time in Figure 3.

Based on this figure, the nitrogen transmission rate $J_{N2}$ was calculated:

$J_{N2} = 1.4 \times 10^{-10}$ mol.s$^{-1}$.

The nitrogen permeance ($P_{N2}$) was estimated by Equation 2, for a mean partial pressure difference of 95 kPa:

$P_{N2} = 1.5 \times 10^{-15}$ mol.s$^{-1}$.Pa$^{-1}$.

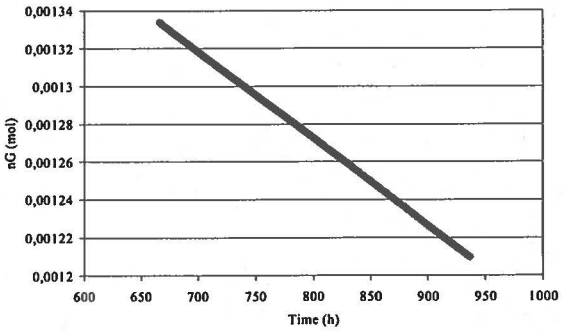


Figure 3. Nitrogen ($N_2$) permeated through the specimen after the steady-state achievement.

### *4.2 Water vapour transmission rate*

The amount of water vapour permeated through the specimen after the steady-state achievement is plotted versus time in Figure 4.

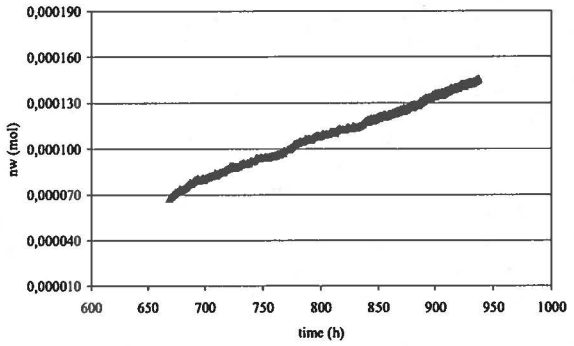


Figure 4. Water vapour (wv) permeated through the specimen after the steady-state achievement.

Based on this figure, the water vapour transmission rate $J_{wv}$ was calculated:

$J_{wv} = 8.3 \times 10^{-11}$ mol.s$^{-1}$.

Corresponding to a water vapour permeance ($P_{wv}$), estimated for a mean partial pressure difference of 89 kPa:

$P_{wv} = 9.4 \times 10^{-16}$ mol.s$^{-1}$.Pa$^{-1}$.

## 5. CONCLUSIONS

A test method to study the nitrogen permeation through double welded seams was developed. Two types of fluid-medium were used to carry out the tests: water and air. The test in air allows the determination of nitrogen permeation rate, whereas the test in water makes it possible to assess the water vapour transmission rate and the volume variations of the specimen.

The tests reported in this paper and other tests now in progress for different conditions suggest that the nitrogen permeation test might be used to detect the quality of seams by quantitative measurement of the permeance, but more results are required to confirm this preliminary conclusion.

Research into the nitrogen permeation through geomembrane seams is currently ongoing at the University of Grenoble. Factors being examined include the influence of the welding

parameters on seam nitrogen permeation rate, seaming method; namely the thermal-hot dual wedge and extrusion lap weld, and geomembrane thickness. The possible correlation between the welding parameters, the nitrogen permeation rate and mechanical strength of the seams will be studied, performing shear and peel strength tests after the nitrogen permeation tests. Finally, measurements using the same test principle on large-scale seams are also planned.

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