Water Permeation through Geomembranes: Mechanism and Measurement

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ABSTRACT: Water diffusion and water permeation tests conducted on geomembranes (by volumetric and radioactive tracer methods) give an understanding of the water transport mechanism through non porous media. This paper also presents the main results obtained on HDPE, PVC and bituminous membranes, which show quite different behaviours.

1 INTRODUCTION

Geomembranes are expected to be a real barrier between a liquid (or solids generating liquids) and the subsoil. They can then be submitted to a liquid static pressure. It is the case in all liquid reservoirs; in waste disposal facilities, this pressure occurs only when the drainage fails. Characterizing water transfer in the presence of an hydraulic pressure difference is then necessary.

A description of the water transport mechanism through non porous media such as geomembranes is necessary to characterize the water permeation through geomembranes by the appropriated quantity. This is the objective of section 2.

Results of water permeation tests using volumetric and radioactive tracer methods and conducted on the main geomembranes now used in France (High Density Polyethylene (HDPE), Polyvinylchloride (PVC), bituminous membranes are presented in section 3.

2.MECHANISM AND MEASUREMENT METHODS

2.1 Mechanism

Water in contact with a geomembrane (considered as a non-porous medium) always dissolves inside the membrane. In case of a balance of driving forces, at the steady state, the number of water molecules entering the membrane is the same as that leaving. This phenomenom is the self-diffusion as seen in figure 1, with the "self-diffusion flow" Q_D. If the membrane is submitted to driving forces such as a hydraulic pressure difference $(p_1 - p_2)$ a "driven flow" Q_V is added to the self-diffusion one (figure 2).

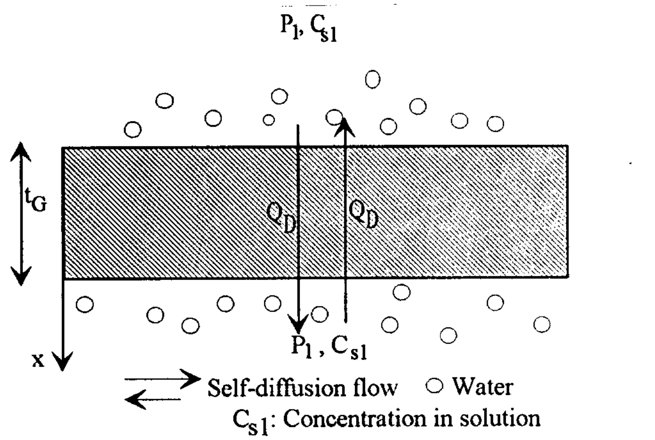

Figure 1: Water transfer in case of a balance of driving forces.

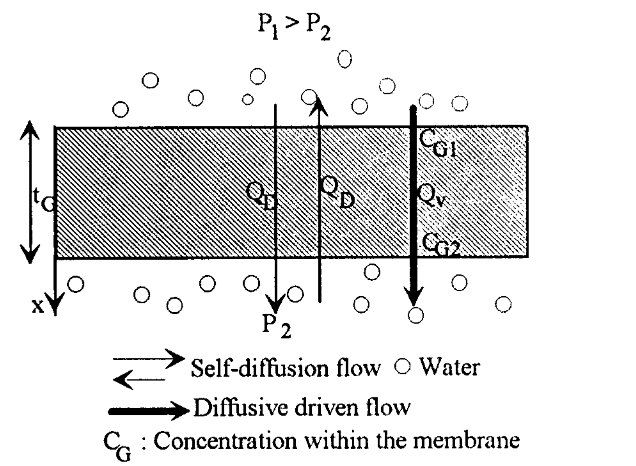

Figure 2: Water transfer when the membrane is submitted to a hydraulic pressure difference.

This driven flow is still a diffusion flow as the pressure difference generates a concentration difference within the membrane (Paul, 1975; Lee, 1975; Van der Waal, 1990). This mechanism is quite different from the one observed in porous media. Therefore, it cannot be described by the

Darcy's Law but by the Fick's Law, characterizing the diffusive flow Q :

$$Q = -D\frac{\partial C_G}{\partial x} \qquad (1)$$

Where D is the diffusion coefficient and C_G the concentration within the membrane;
Since it is impossible to measure the concentration inside the geomembrane, it is then impossible to determine D directly. Furthermore, D often depends on C_G which can change. In this paper, all the results are then given under the form of flows Qv which can always be measured and which is the most useful quantity to be known for characterizing the water leakage through membranes.

2.2 Measurement methods (Eloy-Giorni, 1993)

2.2.1 Volumetric method

This test was conducted and developped at the IRIGM (Pelte, 1993). The measurement principle of the hydraulic permeameter consists in measuring the quantity of liquid passing through the geomembrane when each side of the membrane is submitted to a different pressure. The measure gives the volume variation ΔV of the downstream and upstream chambers of the permeameter cell during the time Δt. The diffusive driven flow Q_v is obtained by the equation (2).

$$Q_v = \frac{1}{A}\frac{\Delta V}{\Delta t} \qquad (2)$$

A is the sample area.

2.2.2 Radioactive tracer method

This method uses a device developped at the CEA-CENG. A known quantity of tracer molecules is introduced in the upstream chamber of the diffusion-permeation cell. Tritiated water is a good water tracer and is detected in the downstream chamber by the β-emissions of the Tritium.

Whithout a hydraulic pressure difference, the self-diffusion flow Q_D (see figure 1) can be determined with the help of the curve m(t) which has an asymptote and where m is the water mass crossing the membrane (Crank, 1968).

If the hydraulic pressure difference is applied to the upstream chamber filled with tritiated water ("parallel flow" permeation test), the parallel flow Q_c is measured (figure 2):

$$Q_c = Q_v + Q_D \qquad (3)$$

To determine the diffusive driven flow, a counter flow Q_{cc} has to be measured: this flow is created by the opposition of the hydraulic pressure difference (Q_v from downstream chamber to the upstream chamber) and the radioactivity difference of tritiated water (Q_{cc} from upstream chamber to downstream chamber) (Eloy-Giorni, 1994):

$$Q_{cc} = Q_D - Q_v \qquad (4)$$

Combining (3) and (4), Q_v can be calculated:

$$Q_v = \frac{Q_c - Q_{cc}}{2} \qquad (5)$$

3.RESULTS

3.1 High-Density Polyethylene (HDPE)

The results of the volumetric and radioactive tracer tests are given in figure 3.

The diffusive driven flow obtained by the volumetric test is less than 1E-7 $m^3/(m^2.day)$ which is the accuracy limit of the apparatus used (Pelte, 1993). Those results cannot be considered as it can be seen on figure 3: Q_v is higher than Q_c and Q_{cc} which is impossible (see equation 3 and 4). The parallel flow is constant when the pressure difference varies between 0 and 2000 kPa and equal to the self-diffusion flow. Taking into account the measurement errors, the counter flow has the same value as the parallel flow. It can then be deducted that driven flow is non-significant and that hydraulic pressure difference does not appear to create a driven flow across a hydrophobic medium like HDPE.

3.2. Poly(vinyl chloride) (PVC)

The results of the hydraulic permeation tests are given on figure 4.

The parallel flow is nearly constant when the pressure difference is higher than 800 kPa. This may be due to a modification of molecular structure in the medium under the mechanical stress. The driven flow measured for P = 500 kPa, by the volumetric method (Q_v = 5.5E-8 $m^3/(m^2.day)$), is smaller than the parallel flow (Qc = 1.6E-8 $m^3/(m^2.day)$), which is in agreement with the theory.

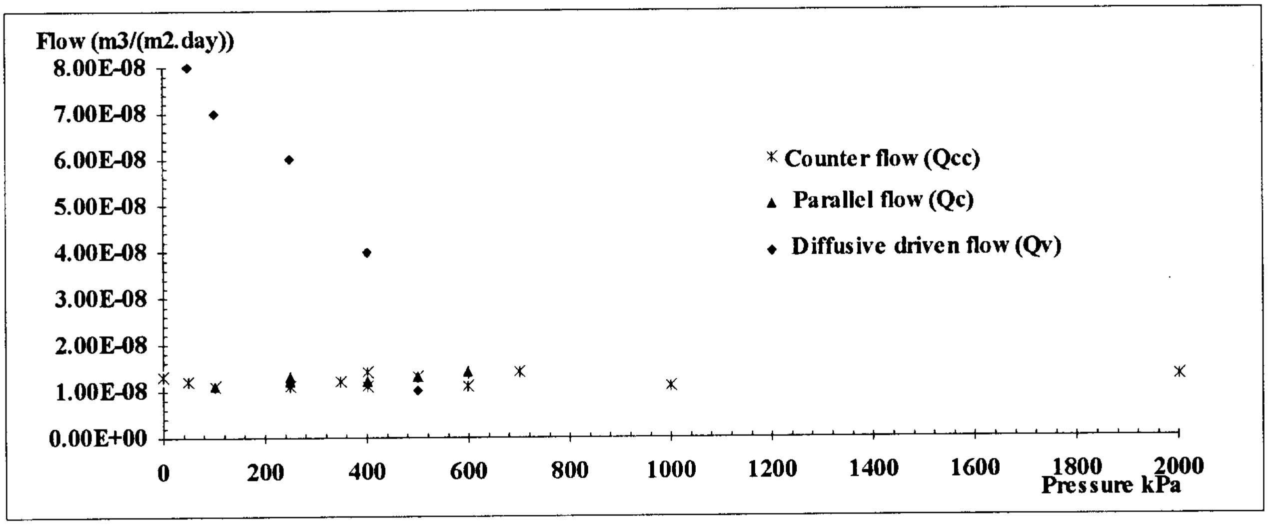

Figure 3: Comparison between the parallel flow Q_c, the counter flow Q_{cc} and the driven flow Q_v of water across a HDPE membrane (1.7mm) versus pressure difference at 23°C.

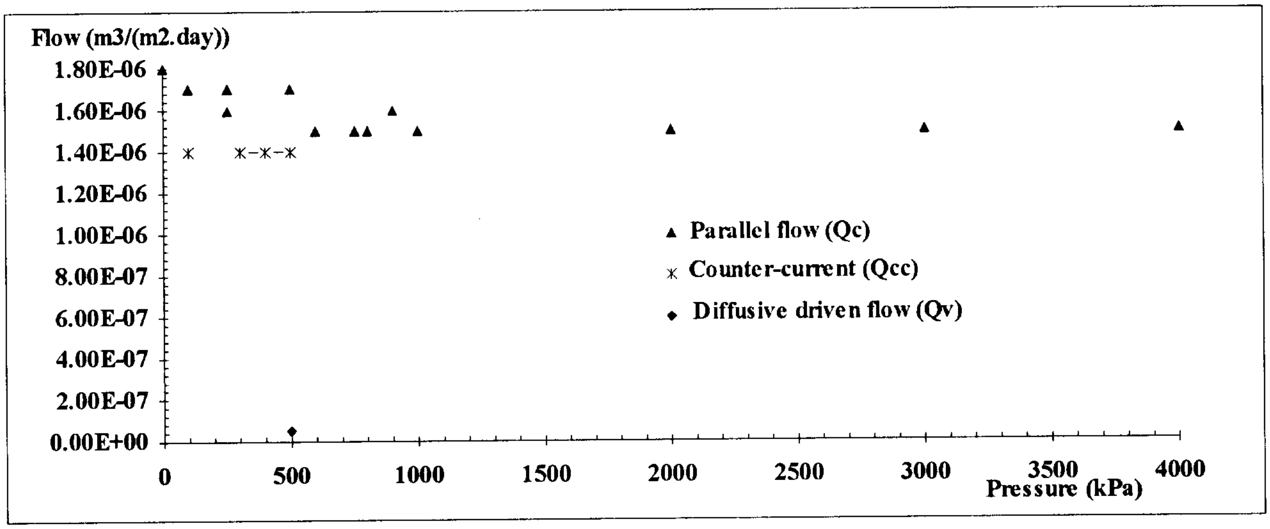

Figure 4: Parallel flow (Q_c), counter flow (Q_{cc}) and driven flow (Q_v) of water accross a PVC membrane (1.6 mm) versus pressure difference (23°C).

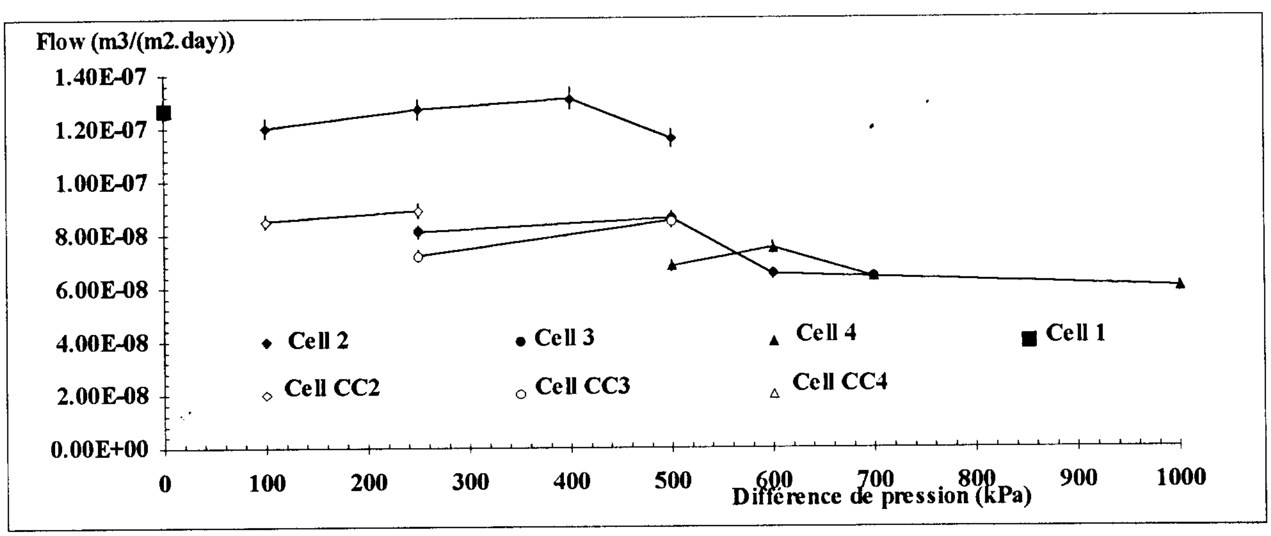

Figure 5: Corrected parallel flow (Q_c), corrected counter flow (Q_{cc}) and driven flow (Q_v) of water across a bituminous membrane (5 mm) versus pressure difference (23°C).

It can also be observed that the measurement of parallel flow and counter flow lead to the following value calculated from equation 5:

$Q_v = 7E\text{-}8\ m^3/(m^2.day)$

which very similar to the previous value obtained by the volumetric method.

3.3 Bituminous geomembrane

Eloy-Giorni (1994) showed that the self-diffusion flow measured with radioactive tracer method increases with time. Values of hydraulic permeation were therefore corrected to take into account this phenomenom. The corrected results of the permeation tests with this method are presented in figure 5.

Four cells were used: the first one was the reference one and corresponded to the self-diffusion conditions. The three others were submitted to a hydraulic pressure difference. The first pressure was different for each cell (increasing from cell 2 to cell 4). For a given cell, the first pressure gives the order of magnitude of the flow which does not vary significatively if the pressure increases. This first compression seems to strain the membrane. This compression effect continues weakly during the test and is attenuated if the pressure difference increases. Cells CC2 and CC3 give counter flows with the same first pressure as respectively cells 2 and 3. A driven flow can then be calculated (equation 5) by comparing the results of cells 2 and CC2: Qv = 1.8E-8 m3/(m2.day) for 100 kPa and Qv = 2.1E-8 m3/(m2.day) for 250 kPa.

The results obtained on cells 3 and CC3 where the first pressure was higher show that there is no driven flow. These observations confirm the hypothesis of a molecular rearrangement. This rearrangement is greater when the pressure difference is rapidly applied than when it is gradually applied. The mechanical compression of this type of membranes increases their watertighness. It is not the case for PVC and HDPE geomembranes which are far less compressible than bituminous membranes.

4. CONCLUSION

This study shows that a water flow can be observed through geomembranes submitted to a hydraulic pressure difference except for HDPE where it can be considered as negligted. For other materials tested such as PVC and bituminous membranes, this water flow was measured by volumetric and radioactive tracer methods. Results were in agreement in the case of PVC. The water flow through bituminous membranes depends on the value of the first hydraulic difference: for high values, the membrane is highly strained and the driven flow cannot be detected.

In all cases, it was observed that:

1. water permeation through geomembranes due to a hydraulic pressure has to be characterized by the measurement of the water flow (coefficient K deduced from Darcy's Law must not be used)
2. direct driven measurements which can be conducted in any laboratory, cannot be used in the case of too small water flows because of the accuracy limit of the apparatus. For example, bituminous membranes submitted to rather high pressure differences have to be tested by a radioactive tracer method.

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