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# Quantification of flow rates through virgin and exposed geomembranes and multicomponent geosynthetic clay liners

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**ABSTRACT:** An experimental device was developed which gave rise to a European standard, EN 14150. This standard is used in CE marking to quantify the flow rates of virgin geomembranes during the manufacturing process. The principle of the test consists in applying a 100kPa water head difference between both sides of a flat geomembrane. Recently, this device was also used to quantify the flow rates of exposed geomembranes of high density polyethylene (HDPE), ethylene-diene terpolymer (EPDM), polyvinyl chloride (PVC) and bituminous geomembranes. The objective of the paper will be to show the results obtained for virgin geomembranes first and then to validate the use of the device from EN 14150 for testing geomembranes up to 30 years after installation to check if they are still ensuring the watertightness function. Most geomembranes used are still exhibiting flow rates close to the one of virgin geomembranes, so close to  $10^{-6} \text{ m}^3/\text{m}^2/\text{d}$ . An adaptation performed to quantify the flow rate through multicomponent GCLs is also presented.

## 1. INTRODUCTION

A geosynthetic barrier (GBR) is defined in EN ISO 10318 [1] as ‘a low-permeability geosynthetic material, used in geotechnical and civil engineering applications with the purpose of reducing or preventing the flow of fluid through the construction’. GBRs are classified into three categories according to the material that fulfils the barrier function: clay geosynthetic barrier (GBR-C) when the barrier function is fulfilled by clays; bituminous geosynthetic barrier (GBR-B) when the barrier function is fulfilled by bitumen and polymeric geosynthetic barrier (GBR-P) when the barrier function is fulfilled by a polymer. The International Geosynthetics Society (IGS) defines a geomembrane (GM) as ‘a planar, relatively impermeable, polymeric (synthetic or natural) sheet used in civil engineering applications’ [2]. The term ‘geomembrane’ is considered to be a synonym for GBR-P or GBR-B because the main function of both is waterproofing. Hereinafter, the term ‘geomembrane’ (GM) is used to refer to GBR-P and GBR-B. GMs are used around the world in civil engineering applications, notably for landfills, reservoirs, dams, canals, or tunnels, which are excellent examples of GMs used in waterproof liner systems. In order to quantify the watertightness of GMs, which is their unique function, an apparatus was first developed in France, which gave rise to a French, then a European standard, EN 14150 [3]. The principle of the test consists in applying a 100kPa water head difference between both sides of a flat geomembrane in a stainless steel cell. In the past years this device was also used to quantify the flow rates of exposed geomembranes of high density polyethylene (HDPE), ethylene-diene terpolymer (EPDM), polyvinyl chloride (PVC), bituminous geomembranes most of which had been exposed during at least 20 years in hydraulic applications. This device had also recently been adapted to quantify flow rates through multicomponent geosynthetic clay liners (GCLs) in which watertightness is ensured by the film or coating and not by the bentonite. The objective of this paper is first to give an insight in the background regarding the quantification of advective transfers through GMs. Data for virgin GMs are then given. In Section 2.3 a presentation of the measurement performed on various GMs of different natures sampled on site is given. The adaptations that are sometimes required based on the ageing of the geomembrane are discussed. Finally, a brief insight in the adaptation of the device for the measurement of advective flow rates through multicomponent GCLs is presented in Section 3.

## 2. QUANTIFICATION OF ADVECTIVE TRANSFERS THROUGH GEOMEMBRANES

### 2.1 Background

Geomembranes are non-porous media. It means that there is no void in the material, but only free spaces which size is in the range of solvent's molecule size. Transport in geomembranes does thus occur

at the molecular level [4]. However gases and liquids can migrate through the intact geomembranes by an activated diffusion process, different from the liquid convection process occurring through the pores of porous soils [5]. Different driving forces may cause diffusion: concentration, hydraulic or temperature gradients. It has also been shown that diffusion occurs even if there is no gradient: this phenomenon is called self-diffusion [6].

An apparatus was first developed in France [4, 6, 7, 8] in order to quantify flow rates through geomembranes linked with the application of a hydraulic gradient. This work led to a French standard and later to a European standard [3] for measuring the steady-state liquid flow through GMs. By using this method and the associated apparatus, the flow can be measured with confidence down to  $10^{-6} \text{ m}^3 \text{ m}^{-2} \text{ d}^{-1}$ .

EN 14150 stipulates that the two-part cell used for these measurements (see Fig. 1) be made of stainless steel because it must resist oxidation during long-term immersion. Hydraulic pressure may be applied over each part of the cell cavity, and a porous disc placed in the downstream cavity prevents the GM from deforming.

The cell was designed to clamp and hold specimen without allowing any leaks at the interface between specimen and cell. The cell has no tightening system: clamping between flat surfaces is usually sufficient (if not, a sealant is added). The minimum diameter of the measuring chamber is 0.2 m, and the cell is equipped with an inlet and outlet to allow liquid to pass through the cell. Finally, each section contains a flushing valve.

The volume variation in each chamber of the cell is measured by using a pressure-volume controller. This device applies a constant pressure to the specimen while measuring the volume. It consists of a cylinder through which a piston slides. A computer controlled motor drives the piston to apply the desired pressure, which is measured by a pressure sensor. Displacement of the piston corresponds to changing the volume of the liquid.

Validity of the measurement is examined by comparing upstream and downstream flow rate values. Theoretically, these values should be equal, but, in practice this is rarely the case for geomembranes. For flow rates values greater than or equal to  $10^{-6} \text{ m}^3/\text{m}^2/\text{d}$ , upstream and downstream flow rates are considered as equal if the difference between them is less than 10 % of the measured flow rate on the upstream side. In particular circumstances where testing according to the described test method indicates that values obtained for a geomembrane lies below the threshold of sensitivity of the test method then the value of liquid flow will be declared as being less than  $10^{-6} \text{ m}^3/\text{m}^2/\text{d}$ .



Figure 1. View of the stainless steel cell and pressure volume controllers of type B device for flow rate measurement in geomembranes

## 2.2 Flow rate values for virgin geomembranes

Most values of flow rates obtained for virgin geomembranes are below the threshold ( $10^{-6} \text{ m}^3/\text{m}^2/\text{d}$ ) as can be noticed on Fig. 2. In France the definition of a geomembrane given by the standard NF P84-500 [9] states that the value of flow rate measured according to EN 14150 shall be lower than  $10^{-5} \text{ m}^3/\text{m}^2/\text{d}$ .

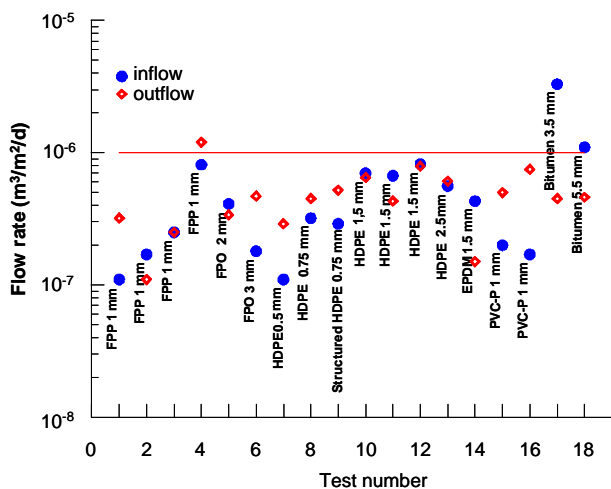


Figure 2. Synthesis of flow rate measurements through geomembranes according to EN 14150 with Type B device (from [10]) (FPP: flexible polypropylene, EPDM: ethylene-propylene-diene terpolymer, HDPE: high density polyethylene, PVC-P: plastified polyvinyl chloride, FPO: flexible polyolefine).

## 2.3 Flow rate values for geomembranes after on site exposure

The test device described by EN 14150 has also been used to quantify the evolution of the hydraulic properties of geomembranes used in hydraulic applications, some years after installation.

Table 1 is a synthesis of data previously published or currently under publication on the flow rates through geomembranes after exposure. Touze-Foltz et al. [11] did report the case of six oxidized bituminous geomembranes (cases 1 to 6). GMs 1 to 4 were left exposed, while GM 5 was located underwater continuously and GM 6 was covered and under water. A recent study [12] (site 7) presents the results obtained in a pond 15 years after installation of an elastomeric bituminous geomembranes and an oxidized bituminous geomembrane. Both geomembranes were left exposed. Touze-Foltz

and Farcas [13] did improved the knowledge on elastomeric bituminous GMs performance with time by publishing data for GMs sampled between 6 and 30 years after installation. Data collected correspond to sites 7, 8 and 9. Noval et al. [14] did also recently study the evolution along time over 21 years of an EPDM geomembrane installed in a pond, in the Canary Islands. Further studies are currently ongoing jointly in CEDEX (Spain), IFSTTAR (France) and Irstea (France) as regards the evolution of the properties, including the hydraulic properties of HDPE and PVC-P geomembranes with time, based on samplings performed in ponds. An indication of the flow rate values for those GMs is given in this paper (sites 11 and 12).

Table 1 Brief description of the GMs tested

Site	Type of site	Nature of GM	Age (years)	Thickness (mm)	Protection
1	Pond	Oxidized bituminous GM	21	4	No
2	Dam		19	4	No
3	Pond		-	4	No
4	Pond		-		No
5	Dam	Elastomeric bituminous GM	26	4.8	Water
6	Dam		30	4.8	Yes
7	Pond		15		No
7	Pond	Elastomeric bituminous GM	10		No
7	Pond		15		No
7	Pond		20		No
9	Pond		30		No
10	Pond	EPDM	21	1.5	No
11	Pond	PVC	26	1.4	No
12	Pond	HDPE	22	1.5	No

Significant differences exist between oxidized and elastomeric bituminous GMs when they are left exposed. Oxidized bituminous GMs can in this case exhibit micro-cracks at their surface [11]. The same observation was made by Touze-Foltz et al. [12] that the bitumen is scarce and the reinforcement is visible on the exposed GM surface. The surface of the elastomeric bituminous geomembrane is different. Some alligating can be noticed. However it is only surfacial and the reinforcement layer is not reached. Consequently, the hydraulic behaviour of the oxidized bituminous GMs when they are left exposed is significantly different from the hydraulic behaviour of a virgin GM. Table 2 gives a synthesis of results obtained for oxidized bituminous GM. In those measurements, a difference in hydraulic head equal to 100 kPa could not always be applied. The measuring device thus had to be adapted and the pressure volume controllers abandoned. Mariotte bottles were used instead to quantify flow rates through the GMs with limited hydraulic heads. In the case presented in Table 2, the level of protection is similar to the one that would be brought by a 1m thick clay layer [11], with flow rates measured in the range  $2.9 \times 10^{-5}$  to  $1.5 \times 10^{-3} \text{ m}^3/\text{m}^2/\text{d}$  for a hydraulic head equal to 0.5m. The recommendation that the oxidized bituminous geomembranes should not be left exposed after installation was given in [11] and [12].

Table 3 gives an insight in the flow rate values obtained for the one oxidized bituminous GM which was covered, elastomeric bituminous GMs, EPD, PVC and HDPE GMs.

The one oxidized bituminous geomembrane which was covered presented 30 years after its installation a value of flow rate identical to the one of virgin bituminous geomembranes, so that no hydraulic evolution was detected. Elastomeric bituminous GMs from site 7, with exposition durations ranging between 10 and 20 years exhibited flow rate values that can slightly exceed  $10^{-6} \text{ m}^3/\text{m}^2/\text{d}$ .

The flow rate for the elastomeric bituminous GM from site 8, 30 years after installation is very close to the threshold value, indicating that there is no significant impact of the exposure during 30 years of this elastomeric bituminous GMs on the flow rate, contrarily to what

was observed for oxidized bituminous GMs. It is thus of the primary importance to clearly distinguish between both natures of bituminous GMs, and to design their use appropriately.

In the case of the EPDM, PVC and HDPE GMs after about 20 years of exposure, the flow rate obtained is still below the threshold, so comparable to values obtained for virgin GMs.

Table 2. Flow rates obtained at steady-state for the various oxidized bituminous geomembranes samples from sites 1 to 5 and site 7 ( $\times 10^{-6} \text{ m}^3/\text{m}^2/\text{d}$ )

Site	Hydraulic head difference (m)					
	0.1	0.2	0.5	1.0	1.5	2.0
1	11	110	140	1100		1700
2	210	300	1400	2700		3500
3	500	1100	1500	2200		2000
4			29		90	
5			1	2.7	4.6	
7						45

Table 3. Flow rates obtained at steady-state for the geomembranes for which the test could be performed with a 100 kPa difference in hydraulic head

Site	GM	Age (years)	Flow rate ( $\text{m}^3/\text{m}^2/\text{d}$ )
6	Oxidized bituminous GM covered and under water	30	$<10^{-6}$
7	Elastomeric bituminous GM	10	$<10^{-6}$
7		15	$1.9 \times 10^{-6}$
7		20	$<10^{-6}$
9		30	$1.12 \times 10^{-6}$
10	EPDM	21	$<10^{-6}$
11	PVC	26	$<10^{-6}$
12	HDPE	22	$<10^{-67}$

Table 4 Characteristics of the Multicomponent GCLs

Multi component GCL	Type of bentonite	Cover GTX	Carrier GTX	Thickness under 10 kPa (mm)	Measured dry mass per unit area specimen ( $\text{kg}/\text{m}^2$ )	total per in Bonding type	Film coating Thickness (mm)	or Film or coating measured total dry mass per unit area ( $\text{kg}/\text{m}^2$ )
M1	Sodium Powder	Woven	Non-woven	5.2	4.58	Coated	0.4<ef<0.7	0.25<mf<0.4
M2	Sodium Granular	Non-woven	Woven	6.6	5.28	Adhered	~ 0.25	~ 0.2
M3	Sodium Granular	Slit film woven	Non-woven	5.8	4.41	Adhered	~ 0.25	~ 0.2

Results obtained show that flow rates in multicomponent GCLs are one order of magnitude larger than the ones usually measured for virgin geomembranes, i.e.  $10^{-5} \text{ m}^3/\text{m}^2/\text{d}$ .

The flow rate in multicomponent GCLs with an adhesive bounded film thicker than 0.2 mm or coating with a density larger than  $200 \text{ g}/\text{m}^2$  is thus closer to the flow rate in geomembranes than to the flow rate in GCLs which tends to show that the flow rate is controlled by the coating or attached film rather than by the bentonite in those products [18]. They thus cannot be considered as clay geosynthetic barriers. They cannot either be presented as geomembranes as the flow rate going through is larger than the flow rate through geomembranes according to NF P84-500 (i.e.  $10^{-5} \text{ m}^3/\text{m}^2/\text{d}$ ). There is thus a lack of the right wording and definition in the terminology standard on Geosynthetics, EN ISO 10318, as regards multicomponent GCLs.

### 3 FURTHER DEVELOPMENTS: QUANTIFICATION OF ADVECTIVE FLOW RATES IN MULTICOMPONENT GCLs

Multicomponent GCLs have recently been introduced to the market to perform sealing in landfills, dams, dikes, ponds etc... As they are combining a GCL to a coating or film, their hydraulic properties are falling between geomembranes (GM) and GCLs and devices have been developed very recently for their characterisation as regards transfers.

Touze-Foltz et al. [16] and Barral and Touze-Foltz [17] developed a procedure, combining measuring devices from EN 14150 for flow rate measurement through GM and a rigid wall permeameter from NF P84-705 [15], aiming at measuring the flow rates through GCLs, in order to measure flow rates through multicomponent GCLs (see Fig. 3). Indeed, the regular measurement device used in NF P 84-705 for GCLs does not allow to measure the small flow rates going through multicomponent GCLs. It was thus required to use the measuring device which is used to precisely measure flow rates in GMs combined with the rigid wall permeameter used to quantify flow rate in GCLs.

Barral et al. [18] did extend their study to the case of three GCLs and five different multicomponent GCLs from several manufacturers. Two multicomponent GCLs were coated with a mass per unit area of coating less than  $100 \text{ g}/\text{m}^2$  and larger than  $200 \text{ g}/\text{m}^2$  respectively. Three multicomponent GCLs were laminated with a film which presented different thicknesses and different bonding modes, corresponding to multicomponent GCLs M1 to M3 presented in Table 4.

### 3. CONCLUSION

The aim of this paper was to briefly describe the experimental device of the European standard EN 14150 which was developed in order to quantify advective flow rates through geomembranes. The principle consists in applying a difference in hydraulic pressure of 100 kPa between both sides of a GM specimen clamped between two chambers that prevent the deformation of the specimen. Values of virgin geomembranes after the manufacturing process are usually below the threshold of measurement of the method, i.e.  $10^{-6} \text{ m}^3/\text{m}^2/\text{d}$ . Specimens of geomembranes sampled in ponds or dams were submitted to the test. In some cases and adaptation of the hydraulic head was required, and it had to be lowered from the values given in the standard, i.e. 10 m to a few tenths of centimeters. This was the case of oxidized bituminous geomembranes that were left exposed. For an oxidized bituminous GM that was covered during 30 years in



a dam, elastomeric bituminous GMs, EPDM, PVC and HDPE GMs, the flow rate measured under a 100 kPa difference was still less than the threshold values corresponding to the measurement ability of the equipment, or slightly above (up to  $1.9 \times 10^{-6} \text{ m}^3/\text{m}^2/\text{d}$  for the elastomeric bituminous GMs). The fact that those results were obtained in most cases on a single GM (for the EPDM, PVC, HDPE) drives the author to recommend to avoid any generalization of those results.

A further recent development that has not yet been implemented in the standard has consisted in combining the measuring device from EN 14150 to a rigid wall permeameter in order to quantify flow rates through multicomponent GCLs. Flow rates obtained in the case presented here for multicomponent GCLs with an adhesive bounded film thicker than 0.2 mm or coating with a density larger than 200 g/m<sup>2</sup> are close to  $10^{-5} \text{ m}^3/\text{m}^2/\text{d}$ . This result cannot be extended to multicomponent GCLs with lighter coatings [18].



Figure 3. Experimental device for measurement of flow rates through multicomponent GCLs

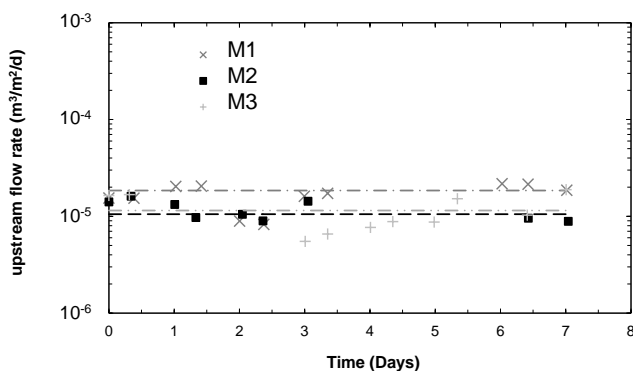


Figure 4. Experimental results obtained for multicomponents M1, M2 and M3 under a 50kPa hydraulic head difference and average values (lines) obtained on the last seven days of measurement (steady-state).

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