Quantification of oxidized bituminous geomembranes ageing through hydraulic testing

Touze-Foltz, N[1], Croissant, D.[1], Farcas, F.[2] & Royet, P[3].
[1]Hydrosystems and Bioprocesses Research Unit, Cemagref, Antony, France
[2] LCPC, Paris, France
[3]Hydraulics Engineering and Hydrology Research Unit, Cemagref, Aix-en-Provence, France

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ABSTRACT: This paper presents the result of a study aiming at quantifying the evolution in the flow rate of exposed and protected oxidized bituminous geomembranes with an adaptation of the European standard EN 14150. Samples were taken from dams and ponds between 2000 and 2006. The age of the geomembranes could reach 30 years. The flow rate through exposed oxidized bituminous geomembranes has dramatically increased as compared to virgin geomembranes, by a factor larger than 3500 in some cases. In case of the geomembrane located under water, only a one order magnitude increase in the flow rate was noticed. For the protected geomembrane, no increase was noticed. In all those cases but one, cracks were located at the surface of the geomembrane. It thus seems that cracks themselves are not a sufficient indication of the level of ageing of the geomembrane and that hydraulic tests are a useful tool to evaluate the ageing of bituminous geomembranes. From the results presented in this paper it is not recommended to use exposed oxidized bituminous geomembranes if one wants to ensure that the initial level of watertightness be maintained on the long term.

1 INTRODUCTION

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 molecules' size. Due to that, transport in the geomembranes occurs at the molecular level (Lambert & Touze-Foltz 2000). A test was designed in France in the 1990s that has become a European standard, EN 14150 (AFNOR 2006). The objective of this standard is to quantify the flow of water crossing geomembranes under pressure. A recent synthesis of data obtained by two independent European laboratories was recently published and interlaboratory trials are still ongoing (Touze-Foltz & Zanzinger 2009). From this latest study it appears that in most cases for virgin geomembrane the flow of water is lower than 10^{-6}m^3/m^2/d. The question arises however of the evolution with time of this flow of water through the geomembrane. Recent studies have shown that ageing of geomembranes appears to reduce the diffusive migration of organic contaminants through HDPE geomembranes (Islam & Rowe 2008). It is thus expected that the flow of water should decrease for those materials. However this has not been checked till now and will be further investigated. Furthermore such a knowledge is not available for all kinds of geomembranes.

Bituminous geomembranes are used in a number of applications: dams (Breul & Eldrige 2009), canals, landfill covers (Potié et al. 1997, Peggs 2008) included for low and moderate activity radioactive waste (Ossena et al. 1997, Marchiol et al. 2006). In the case of bituminous geomembranes, cracks have been observed in certain cases, especially for oxidized bituminous geomembranes remaining exposed, and it is thus of primary importance in this case to quantify the potential impact of those cracks on the flow of water through the geomembrane. It is the scope of this paper to present the results obtained for samples of oxidized bituminous geomembranes coming from six different locations, exposed or protected, sampled on site, regarding the flow of water. First a brief description of the apparatus used in this study, which is consistent with EN 14150, will be given. An insight will also be given in the testing procedure that had to be adapted in some cases where the flow rates obtained were too large to be measured according to EN 14150. Then the various bituminous geomembranes tested will be presented together with some information on their location and age. Results obtained will be presented in Section 3 of this paper and discussed in Section 4.

2 MATERIALS AND METHODS

2.1 *Apparatus*

The apparatus is composed of a two-part cell, two pressure volume controllers aiming at applying the desired pressure on both faces of the geomembrane and quantifying volume variations, and a computer (see Figure 1).

The stainless steel-cell gripps the geomembrane specimen. A sealant can be added on top of the geomembrane at the edges to prevent form any flow outside the cell. In both parts of the cell, two 200mm inside diameter chambers allow applying a hydraulic gradient through the geomembrane.

At the downstream side of the geomembrane a porous stainless steel disc allowing liquid transfer prevents geomembrane deformation and failure since the upstream pressure is larger than the downstream one.

Both parts of the cell are equipped with outlets for air flushing at the beginning of the test (Lambert & Touze-Foltz 2000).

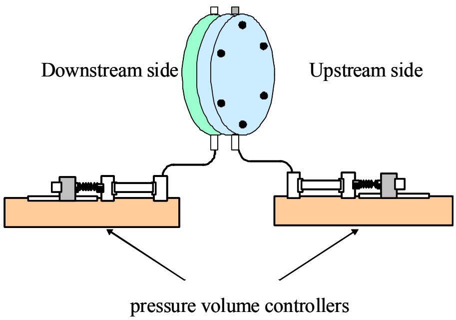


Figure 1. Testing device according to EN 14150 (computer not represented).

2.2 *Testing procedure*

According to EN 14150 after calibration phases aiming at quantifying the volume variations due to temperature variations in the test cell and in the pressure volume controllers, a constant differential water pressure is applied between both sides of the geomembrane. It equals 100°kPa with upstream and downstream pressures respectively equal to 150 and 50°kPa.

The result is expressed in terms of flow of water passing through the geomembrane.

For geomembranes coming from sites 1 to 5 tested in the present study, the surface of the geomembrane presented a number of macroscopic cracks (see Figure 2). In such cases a lower pressure difference was applied in the range 0.1 to 2°m. The pressure was simply applied by a constant level device at the upstream side of the geomembrane and the lowest face of the geomembrane was at the atmospheric pressure. The flow of water was in this case measured by weighing.

Figure 2. Aspect of the geomembrane surface from site 5 at the time of sampling

On the contrary, the geomembrane from site 6 which was covered did not exhibit any crack. It could be tested following the procedure described in EN 14150.

Figure 3. Aspect of the underlying face of the geomembrane from site 6 during sampling

2.3 *Geomembranes tested*

Bituminous geomembranes are essentially purpose-engineered multilayer composite liners consisting from the bottom up of a polyester film root barrier, a bitumen impregnated nonwoven polyester geotextile core, oxidized or elastomeric modified bitumen and a sanded surface layer for enhanced friction and ease of installation.

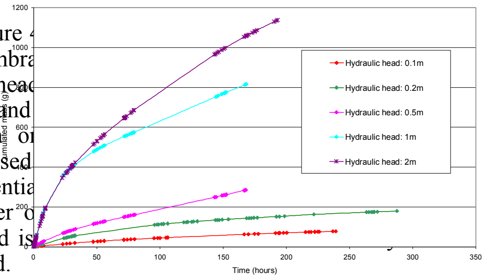
The oxidized bitumen is bitumen whose rheological properties have been substantially modified by reaction with air at elevated temperatures (AFNOR 2000). This oxidation results in the formation of highly polar and strongly interacting oxygen containing functional groups (Mouillet et al. 2008). The elastomeric modification is achieved with Styrene-butadiene-styrene (Peggs 2008). Table 1 gives a detail for each of the six sites where geomembranes were sampled between 2000 and 2006, of the nature of the site (dam, pond), age of the geomembrane at the time of sampling when available, its thickness, an indication regarding the exposition of the geomembrane or the presence of a protection. Only the geomembrane from site 6 was protected. The geomembrane from site 5 was not covered but located under water in a dam devoted to aquatic leisure, thus operated at constant full water level (except for inspections every ten years).

Table 1. Description of the features of the various oxidized geomembranes sampled

Site	Type of site	Thickness (mm)	Age (years)	Protection
1	Pond	4	21	No
2	Dam	4	19	No
3	Pond	4	-	No
4	Pond		-	No
5	Dam	4.8	26	Water
6	Dam	4.8	30	Yes

3 RESULTS

Figure 4 membra lic head 0.1 and with or creased potentia water o trend is head.



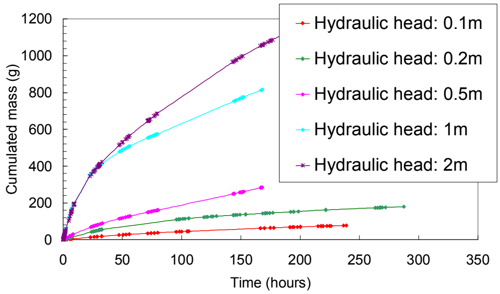


Figure 4. Example of experimental curves obtained (site 2)

Table 2. Flow rates obtained at steady-state for the various bituminous geomembranes samples from sites 1 to 5 ($\times10^{-6}m^3/m^2/d$)

	Hydraulic head (m)					
Site	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	

Values of flow rates obtained at steady-state are reported in Table 2 for those geomembranes. As a basis for comparison a virgin geomembrane of the same nature having a 3.5mm thickness was tested according to EN 14150. The flow rate value measured for this geomembrane was lower than $10^{-6}m^3/m^2/d$. The value of $10^{-6}m^3/m^2/d$ is considered as the limit of measurability with the equipment for EN 14150. Lower values of flow rates that may be obtained are not explicitly given in the results according to the standard.

In the case of the geomembrane from site 6, the test could be performed according to EN 14150 and the flow rate measured was lower than $10^{-6}m^3/m^2/d$.

It can be observed from Table 2 that in the case of the geomembrane from site 5, left exposed but located under the water, after 26 years in service, the level of watertightness of the bituminous geomembrane is rather close to the one obtained for virgin geomembranes that are in the range 10^{-7} to $10^{-6°}m^3/m^2/d$ as shown on Figure 5. One has to keep in mind however that the pressure difference applied across the geomembrane is not similar for data presented in Table 2 (a maximum of two meters) and in EN 14150 where the pressure difference across the geomembrane is equal to 10°m. On the contrary for the geomembranes that were left exposed, on sites 1 to 3, a large increase in the flow rate is observed in Table 2. This may not be a concern for small hydraulic heads on the geomembrane like is the case in landfill covers.

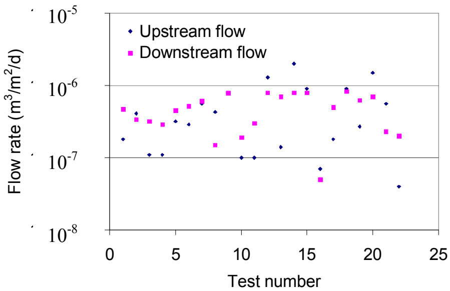


Figure 5. Synthesis of flow rate data obtained on virgin geomembranes (adapted from Touze-Foltz and Zanzinger 2009)

The softening point and the asphaltene content of samples from sites 5 and 6 were determined according to EN 1427 and NF T 60-115 respectively. Results obtained are presented in Table 3.

Table 3. Softening point and asphaltene content for geomembranes from sites 5 and 6

Site	softening point (°C)	Asphaltene content (%)
5	147-153	31-35
6	139-144	23-29

The characteristics of the virgin geomembranes are not known. Most often the grade of bitumen used is 110/30 for this kind of application. Thus one can consider that values of softening point given in Table 3 show an increase in the value, i.e. a hardening of the material. In parallel, an increase in the softening point value is systematically accompanied by an increase in the asphaltene content measured according to NFT 60-115 and an oxidation that results in an increase of the oxidation index, the resins content and the interaction peak. Values obtained for those various parameters (not shown here for oxidation index, resins content and interaction peak) undoubtedly reflect an increase of those compounds as compared to their content in the virgin geomembranes. None of the methods used allowed to make a distinction between the various samples.

4 DISCUSSION

The presence of cracks at the geomembrane surface though indicating an ageing of the bituminous geomembrane does not necessarily reveal a poor hydraulic performance of the geomembrane. But it is clear through those results that performing a hydraulic test is necessary to quantify the impact of the ageing of the geomembrane.

It is also clear from those results that oxidized bituminous geomembranes should not be left exposed if one wishes that they maintain their hydraulic performance on the long term.

5 CONCLUSIONS

The objective of this paper was to present the quantification of flow rates through oxidized bituminous geomembranes with an adaptation of the European standard EN 14150. Flow rates were measured for oxidized bituminous geomembranes coming from six different sites, ponds and dams. The age of the geomembranes was a long as 30 years.

All exposed geomembranes exhibited an increase in the flow rate though the materials compared to a virgin geomembrane of the same kind. This increase could be as large as 3500 times the limit of measurement of the flow rate in EN 14150.

In case the geomembrane was exposed but located under water the increase in the flow rate was much more limited, around one order of magnitude. In case of site 6 where the geomembrane was protected the level of watertightntess was comparable to the one that can be obtained with a virgin oxidized bituminous geomembrane.

In cases where the geomembrane was exposed, cracks could be observed at the geomembrane surface. Those cracks can be, but not necessarily, an indication of an ageing of the geomembrane. It is thus recommended that a hydraulic test be performed on the geomembrane to evaluate the change in watertightness rather than to base the analysis only on the presence of cracks.

Based on the results presented in this paper it is also recommended that oxidized bituminous geomembranes do not remain exposed if one aims at ensuring that they maintain their hydraulic performance on the long term.

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