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Study on production and transfer of leachate in a waste landfill

A. Baudoin & P. Pierson
IRIGM-LGM, Université J. Fourier, Grenoble, France

F. Weber
CREED / CGEA-ONYX, France

ABSTRACT: During the study of different landfill barrier systems conducted on a real site, operated by CGEA-ONYX, with financial help from the French Ministry of the Environment and the Agency for the Environment and Energy Control, the quantity of drained leachate and rainfall on site were measured.

For the past three years, the IRIGM-LGM has been working simultaneously on two complementary studies: characterisation of the waste in laboratory and numerical modelling of the hydraulic behaviour of waste. The experimental installation is used to define the hydraulic characteristics of the waste: permeability and water content, which depend on capillary pressure. Data obtained on site were also used to adjust the numerical computer model. The simulation is based on a model of hydraulic transfer in a porous medium. This is a finite-element, two-dimensional transient model.

This work is important for two reasons: before construction of the landfill site, it can help to evaluate the drainage system and leachate treatment installation; during operation, it may be possible to detect a barrier watertightness problem.

1 INTRODUCTION

A research programme aimed at evaluating the performance of several synthetic and mineral barrier systems to be placed underneath household waste storage centres (WSC) has been undertaken since 1991.

The main aim of this programme is to compare four different watertight barriers (compacted clay, geomembrane alone, geomembrane with clay, bentonitic composite), combined with the same drainage system. This study involves monitoring the system on a real site (Montreuil/Barse), backed up by laboratory experiments. The second aim of the study is to use the site installations to investigate a certain number of associated problems (instrumentation and methodology for simple monitoring, stability of geosynthetics placed on a slope, behaviour of landfill toppings, lixiviation of the waste for the entire service life of the WSC.

The Montreuil/Barse experimental landfill area thus provides an added dimension to the studies currently being conducted in laboratory or on scaled-down testing areas. Thanks to these full-scale site conditions, it is possible to take into account the real stresses acting on barrier-drainage systems during their specific application in WSC.

From the very beginning, it was considered essential to pool the skills of the various interested organisations, namely:

- public laboratories: CEMAGREF at Antony, LRPC in Nancy and IRIGM-LGM in Grenoble,
- a private operator: CGEA-ONYX and its research agency CREED,
- state funding agencies: French Ministry of the Environment through SRETIE and the Agency for the Environment and Energy Control (ADEME).

This full-scale site investigation is being run in parallel with laboratory work on waste lixiviation, the aim being to understand the characteristics and hydraulic behaviour of the waste. Two lines of research are involved here: first, experimental characterisation (permeability, water content, capillary pressure) in the waste columns and, secondly, finite-element numerical modelling based on porous media theory

2 DESCRIPTION OF SITE

The storage site is a disused clay quarry located in the Aube *département* some 30 km south-east of Troyes (a town of 160 000 inhabitants). The climate is of the oceanic type. Mean annual rainfall reaches 700 mm while the mean temperature is 10°C. Every day, the WSC receives 300 to 400 tonnes of household and commercial industrial waste.

2.1 The 4 experimental test cells [2].

The four test cells cover a 50 m x 50 m square, to a depth of 5.5 m. The sides have slopes of 1-in-2 and 1-in-1 (half and half), with a 1-m wide berm located 1.5 m from the bottom. The four barrier systems tested are as follows: compacted clay (60 cm), HDPE geomembrane, HDPE geomembrane + compacted clay (60 cm) and bentonitic geocomposite. Each cell is in fact equipped with a triple barrier system (fig. 1): the actual barrier studied, also known as active barrier according to French regulations, an intermediate barrier (HDPE geomembrane), the role of which is to recover leakage from the active barrier, and finally, a passive barrier consisting of original Gault clay with a minimum thickness of 5 m.

Two drainage systems are associated with each of the three barrier systems: normal drainage of leachates above the active barrier (30 cm of non-calcareous 20/40 crushed stone, 200 mm diameter PVC drain (fig. 2), and drainage of leaks above the intermediate barrier (HDPE draining geogrid, permeability = 10^{-4} m^2/s under a pressure of 200 kPa.

To avoid problems of watertightness at the joints, the leachates are removed by pumping (figs. 2 & 3).

2.2 Hydrological instrumentation

Meteorology:

Rainfall, temperature and air humidity are recorded at a weather station set up on the actual site.

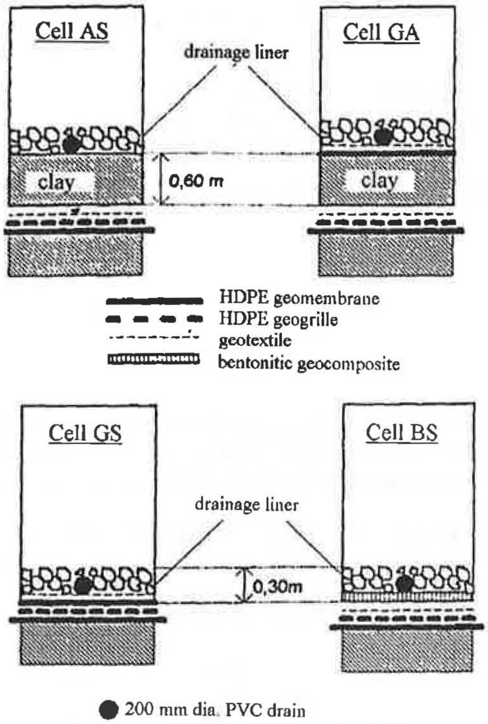

Fig. 1: The landfill barrier systems of the four cells.

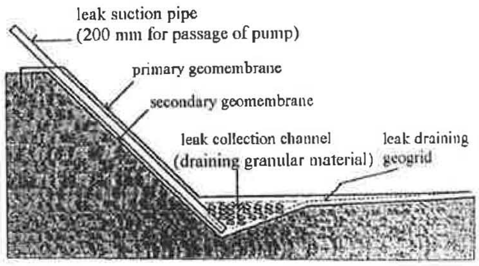

Fig. 2: Pumping of leachates

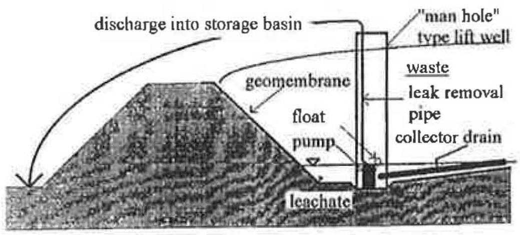

Fig. 3: Pumping of leaks

Leachate height and discharge:

The volume of liquid can be determined by recording the operating times of the lift pumps (normal pumping and leak pumping). The submersible pumps start up whenever the height of leachate reaches 30 cm at the lowest point in the test cell (where the dewatering shaft is located). The dates on which each pump is started up and shut down are recorded by a central monitoring unit to an accuracy of one second. Knowing the rated discharge of the pump, it is thus possible to determine the drained quantity over a given period of time.

3 EXPERIMENTAL LABORATORY STUDY

The waste is an extremely heterogeneous material which gradually transforms with time. Its composition plays a major role and must be defined as accurately as possible in order to be representative of the mean in reality. The National Institute of Applied Science (INSA) in Lyon investigated the composition of the household waste and, based on their results, the following "typical" waste was defined:

Paper, cardboard (strips < 2 cm)	4.5%
Crushed plastic	10.5%
Metal	16%
Glass	16%
Sand and gravel	21.2%
Organic matter (food waste)	31.8%

Using this typical waste material, the study was performed in two stages: drainage of the raw waste, then rehydration and characterisation.

3.1 Drainage

The waste materials were divided between 10 drums of 57.5 cm diameter, each containing 113 kg of waste [1]. These drums were distinguished by the density of the waste (compacted or not) and by the drainage system under the waste:

Drum No.	Density of waste	Height of waste	Drainage
1	variable	variable	undrained
2	0.58	0.74	"
3	0.58	0.74	"
4	0.76	0.57	"
5	0.76	0.57	"
6	0.58	0.74	geotextile
7	0.58	0.74	"
8	0.58	0.74	gravel
9	0.58	0.74	"
10	0.58	0.74	undrained

The following measurements were performed on the drums:

- volume of leachate, using a graduated container placed under the drum,
- temperature at the heart of the waste, by two thermocouples,
- chemical oxygen demand and pH of the leachate during the first month.

The drainage period then lasted 6 months during which the waste material dried out completely.

This operation is interesting from two standpoints:

- the test approximates the behaviour of waste in a WSC, after capping the cell,
- the liquids generated by the organic matter can be estimated.

3.2 Hydraulic drainage measurements

Monitoring of the quantities of leachate drained during the 6-month period (fig. 4) showed, above all, a significant disparity in collected volume.

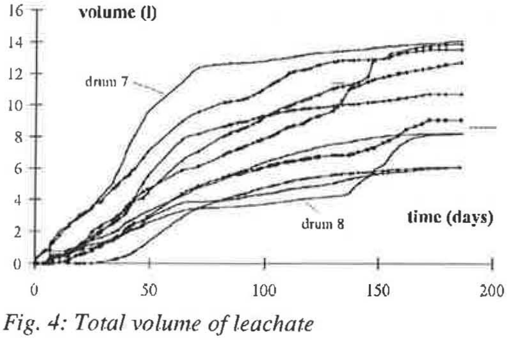

Fig. 4: Total volume of leachate

Assuming that the waste material is completely dry, which would seem to be the case, this would imply that the initial water content was not the same from one drum to the next, in spite of the precautions taken (the wastes were mixed together before being divided up and placed in the drums). The proportions of water (volume %) are in theory as follows:

Drum No.	Expected water content	Proportion of water removed (vol. %)
1	18%	6%
2	18%	5.8%
3	18%	7.7%
4	23%	4.1%
5	23%	4.1%
6	18%	6.8%
7	18%	7.7%
8	18%	4.8%
9	18%	4.3%
10	18%	7%

Moreover, the quantities of water produced by compacted waste (drums 4 and 5) are identical and less than that collected in any of the other samples. This would indicate that the initial compacting operation resulted in a certain equalising of the initial water contents by removing a liquid "surplus"; this surplus would be a quantity of liquid contained in the waste but which would drain away when subjected to the slightest mechanical stress.

In addition, drainage "steps" were observed in certain sample columns. For example, after 140 to 160 days, a significant rise in drainage rate was observed from drums 2, 3, 6 & 8, a fact that cannot be attributed to the drains placed under the waste because each of these drums has a different drainage system. It is possible that liquid accumulates at a particular site in the waste material for a certain time, and this pocket would then be drained in turn, although this theory needs to be verified.

The analysis of total volume percentages (fig. 5) provides complementary information on the previous graph.

Apart from the drums with extreme behaviour, No. 8 and to a lesser extent No. 7, it would seem that drainage kinetics are relatively similar from one

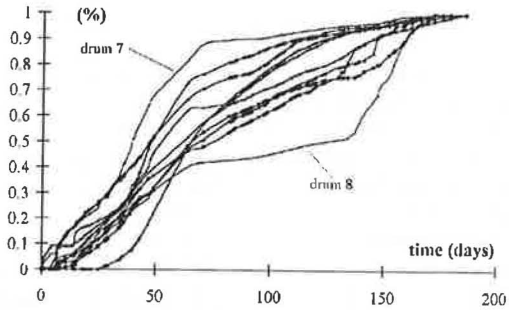

Fig. 5: Percentage of leachate drained

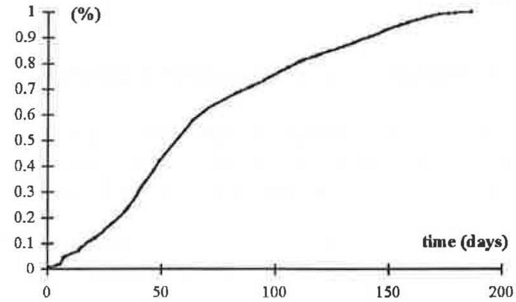

Fig. 6 Average percentage drainage

sample to another, taking into account the highly heterogeneous nature of the material.

A better overall picture can be obtained by plotting the average percentage drainage (excluding drum 8). The shape of this curve (fig. 6) is similar to that obtained by drainage in a porous medium, thereby substantiating, as a first approximation, the porous media hypothesis for the modelling procedure.

3.3 Characterisation of the waste material

The drained waste is then reused to estimate the hydraulic properties of the material. For this purpose, a sample is rehydrated with water and the water content, capillary pressure and permeability are then measured. In view of the requirements of the measuring instruments, it was necessary to sieve the waste to remove any excessively large pieces.

Several experimental measurements were taken:

- measurement of water content and capillary pressure on samples during drainage, after rehydration; these samples are then placed in an oven in order to determine the dry weight;

- measurement of permeability and capillary pressure on samples with a permanent flow of water passing through in order to measure the permeability (Darcy's law) for different waste saturation conditions;

- calibration of a humidity meter by reflectrometry with a view to using the instrument on a real site and in laboratory.

3.4 Instrumentation

Water content as a function of capillary pressure (or more precisely the capillary tension) is measured by means of a tensiometer inserted in the sample placed on a weighing balance, with a system for removing drained water.

To measure permeability, two tensiometers are used, inserted in a drum at different levels. A flow of water finely adjusted by a system of drippers, passes through this drum. Under steady flow conditions, the permeability can be calculated by measuring the discharge and the capillary tensions.

In addition, the authors plan to use a more direct method to measure the humidity in the waste in laboratory tests. For this purpose, a tube probe is currently being calibrated by reflectometry. This instrument consists of a probe inside a tube that can be lowered into the heart of the waste material. The humidity of the material can thus be measured at any point at different heights, thereby enabling the humidity profile to be plotted. In view of the simplicity of this measurement method, it should be possible to apply it to real sites at a later stage.

3.5 Measurement of characteristics

Given the fact that the experiments are ongoing, the number of measurements currently available is insufficient to draw any definitive conclusions at the present time. However, it is already possible to start analysing the first results [3].

Water content as a function of capillary pressure is measured by saturating the sample which is then drained and finally dried in an oven. The relative density of the dry waste is 0.45.

Mass (g)	Suction (m)	Mass water content	Volume water content
4123	0	142	64
4013	0.03	136	61
3791	0.1	123	54
3644	0.11	114	51
1700	7	0	0

Between the last two values, drainage was very slow whereas it is very fast when the waste is close to saturation. The permeability of the waste thus drops considerably as soon as the waste moves away from its saturated state. Moreover, extremely different hydration and drainage kinetics were observed. For example, dry waste absorbs liquid slowly (the majority drains away immediately), whereas wet waste drains slowly.

To measure the permeability, two tensiometers ($\Delta z = 12$ cm) are inserted in the sample which is subjected to a permanent flow of water. The results are as follows:

p_1 (Mb)	p_2 (mb)	K (m/s)
0	0	3E-3
-62	-50	1.7E-5
-81	-52	7.44E-6
-87	-50	6.36E-6

The permeability can thus be seen to drop dramatically for low tension values, which would seem to corroborate the previous analysis.

4. MODELLING

The theoretical basis for the modelling procedure is the assumption that the waste material acts as a roughly homogeneous porous soil at the scale of the storage cell. Compared to a water balance, this approach can be used to establish a calculated time-dependent relationship between the signal (rainfall) and the response (drainage). It is then possible to monitor in real time the behaviour of any storage site and thus to identify any abnormal operation of the barrier in the shortest possible time.

The finite-element computation code used is of the 2-dimensional type and is thus governed by Darcy's law according to the following relation:

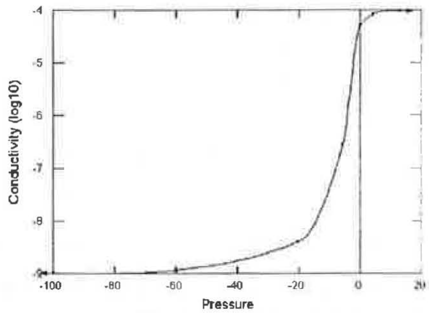

Fig. 7: Hydraulic conductivity versus suction

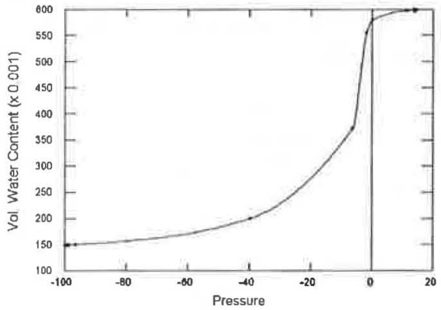

Fig. 8: Volume water content versus suction

$$\frac{\partial}{\partial x}\left(k_x \bullet \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \bullet \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \vartheta}{\partial t}$$

where:

H = total head
k_x = hydraulic conductivity in the x-direction.
k_y = hydraulic conductivity in the y-direction.
Q = applied boundary flux.
Θ = volumetric water content.
t = time.

This modelling procedure requires prior knowledge of permeability and water content variations as a function of capillary pressure. As a first approximation, the following laws have been chosen (figs. 7 & 8).

The modelled sample is a parallelepiped with 1 m x 1 m base and 0.75 m high (corresponding to the height of the drums).

The calculation result gives the change in capillary pressure and water content as a function of time (figs. 9 & 10).

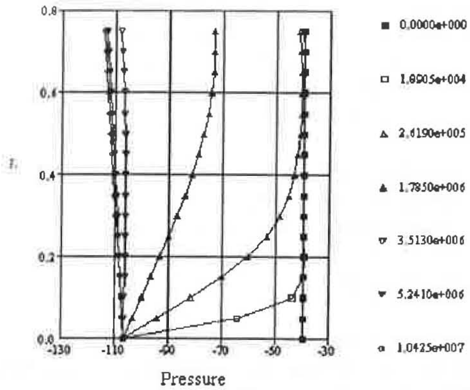

Fig 9: Suction in waste versus z

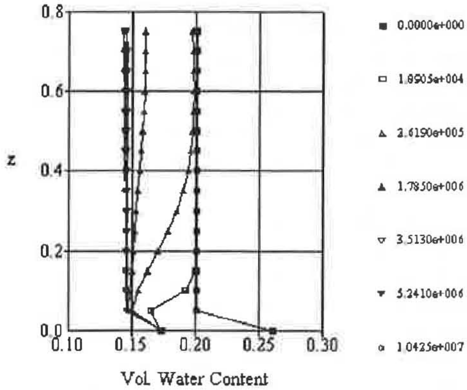

Fig. 10: Volume water content versus z

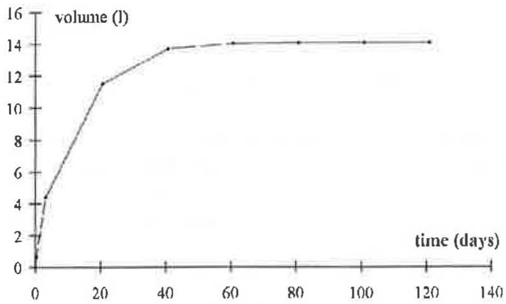

Fig. 11: Total volume of leachate versus time

After processing, it is also possible to plot the total volume of leachate (fig. 11). This curve is to be compared with the experimental drainage results.
It therefore seems that it is indeed possible to simulate the behaviour of the waste by a porous medium law the characteristics of which still have to

be defined, undoubtedly with a hysteresis to be allowed for.

The adjustment of the model based on the results obtained on the real storage site at Montreuil/Barse, as described in § 2, is currently underway and should soon lead to comparative results of model versus site.

5. CONCLUSIONS

Concerning the laboratory experiments, it was found that the behaviour of the waste material can be likened to that of a porous medium. The work performed on hydraulic characterisation has indicated two properties: significant hysteresis between hydration and drainage, a feature that will perhaps have to be taken into account in the modelling process, and a considerable drop in permeability of the material as soon as it moves away from its saturated condition.

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