Biological clogging resistance of tubular drainage geocomposites in leachate collection layers

Blond E.
SAGEOS / CTT Group, St-Hyacinthe, Quebec, Canada
Fourmont S.
AFITEX, Champhol, France
Bloquet C., Budka A.
SITA, Paris, France

ABSTRACT: If drainage geocomposites are frequently used for gas or rain water drainage, their application for leachate collection in the bottom of landfills remains very limited, essentially because of the lack of knowledge regarding their sensitivity to biological clogging. In order to better understand the behavior of tubular drainage geocomposites with respect to biological clogging and consequently assess their applicability in leachate collection layers (LCL), a research project focusing on this matter was initiated. It was conducted on a class 2, non-hazardous landfill located in the centre of France. Actual, fresh leachates were circulated through 'draintube' tubular drainage geocomposites over 18 months. This paper presents the key findings of this project.

First, the drainage capacity actually needed to meet regulatory requirements were analyzed and compared to the risks of development of biological clogging. It is shown that the current practice significantly overestimates the flow of leachate that is likely to access the LCL over its entire life, and thus overestimates the drainage capacity actually needed once the landfill is in operation.

The experimental method used to evaluate the behavior of tubular drainage geocomposites against biological clogging is then presented, as well as the results. It is shown that after 18 months of operation in anaerobic conditions, the drainage geocomposite was still not clogged.

Based on these evaluations, it is concluded that the application of draintube drainage geocomposites in LCLs in replacement to a fraction of the granular layer shall not be governed by considerations related to biological clogging. It is recommended to design the granular layer with respect to other concerns such as geomembrane protection, which will typically allow usage of lower quality granular materials or thinner layers, while increasing the available storage capacity of the landfill.

1 INTRODUCTION

Drainage geocomposites are more and more used by landfill operators as a substitution to granular materials, especially in landfill covers. However, only a few landfills have elected to install these products in the bottom, flat portion of the landfill because of the lack of information regarding the long term hydraulic performance of these products.

However, partial replacement of the granular layer by a geosynthetic drainage layer would represent a significant saving of high quality granular materials, which are more and more difficult to find in several regions of the world. It would also increase the storage capacity of the landfill and reduce the quantity of trucks needed to bring in the granular material, thus the carbon footprint of the landfill.

Considering the installation of drainage geocomposites in the flat portion of the leachate collection layer of landfills thus represents an alternate design which is worth considering from both economical and environmental prospective.

However, the selection and design of drainage geocomposite for this type of application is considered to be an engineering challenge involving relatively harsh conditions such as permanent high stresses and a relatively aggressive environment due to the permanent exposition to leachate.

2 PERFORMANCE REQUIREMENTS

2.1 *Analysis of the regulatory requirements*

The French national legislation applicable to the LCL in landfills requires a granular layer with a minimum thickness of 0.50 m, with a hydraulic conductivity greater or equal to 10^{-4} $m.s^{-1}$ in the bottom of the landfill. In addition, there is a performance requirement addressing the head of leachate on top of the geomembrane, which shall always be lower than 0.30 m anywhere in the landfill.

As a consequence, only 0.30 m out of the 0.50 m required by the regulation are actually used for drainage purpose, the remaining 0.20 m being solely specified as a security measure, as well as to fulfill other functions such as mechanical protection of the geomembrane. Given that these 'other functions' can and are typically addressed with proper operating rules of the landfill – such as requiring installation of selected wastes in direct contact with the drainage layer – they will not be considered any further in this document.

From the above discussion, it is possible to conclude that the replacement of 0.20 m of the granular drainage layer by a drainage geocomposite specifically designed to fulfill this function represents an opportunity to increase the landfill storage capacity, to potentially reduce the costs and the carbon footprint associated to this component of the structure, while meeting the regulatory requirement applicable to the drainage function, which is to maintain a maximum head of leachate of 0.30 m above the geomembrane. This proposition is described on Figure 1.

In order to assess that the hydraulic capacity of the drainage layer (0.30 of m gravels + drainage geocomposite) will always be sufficient, it takes to:

– Identify what are the actual needs over the life of the drainage layer;
– Be able to predict the long term behavior of the drainage layer, which are essentially creep and clogging.

2.2 *Analysis of the quantity of leachate generated in a landfill*

The quantity of leachate generated in a landfill varies as the landfill is being filled up, as well as with the quantity of precipitations received over the time. According to Bellenfant (2009), there are essentially two critical stages which can be considered: first, the period over which the cell is being filled up, which typically lasts between 1 and 5 years, second, the period of time which follows installation of the cover.

During the first stage, the quantity of leachate which is generated is the most important, essentially because there is no cover and all the rainfall actually reaches the wastes. On the other hand, other parameters have also been identified as having a significant influence on the volume of leachate collected in the LCL:

– The thicker will be the wastes, the more evaporation will take place, reducing the quantity of leachate reaching the LCL (Bellenfant, 2009);
– Some techniques used in the operation of the landfill will modify the quantity of water penetrating the waste, thus the leachate generated (type of daily covers, slopes, etc)

The LCA model (SITA, Creed, EIA, 1998) provides an estimation of the quantity of leachate generated, considering the number years over which a cell has been in operation and the presence – or not – of a cover:

- 0 to 18 months : 20% of the precipitation;
- 18 mo to 5 years: 6.6% of the precipitation;
- 5 to 10 years: 6.5% of the precipitation;
- 10 years and over, with a geomembrane cover: 0.2% of the precipitation.

As a consequence, it is reasonable to consider that the LCL is a critical component of the lining system only during the first couple years over which the landfill will be in operation. Although the flow of water going through the drainage layer is actually equal to the rainfalls during the first weeks or months of operation, when there is little or no waste actually stored into the cell, it rapidly decreases by a factor of 5 after only 18 months. Moreover, once a cover will have been installed, the quantity of leachate to be drained by the leachate collection layer will be an insignificant fraction of what it was during its first weeks of operation.

It is thus possible to state that even if the performance of a drainage collection layer designed to absorb the rainfall received in a given area is reduced by a factor of 5 after 18 months, it will still fulfill its function and meet the regulatory requirements. This statement can also be made considering a performance reduced by a factor of 500 following installation of a geomembrane cover.

Consequently, the global performance of a LCL system will not be endangered as long as the total transmissivity remains higher than 20% of the initial transmissivity after 18 months.

In this study, the objective is to reduce the thickness of the granular drainage layer from 0.50 m to 0.30 m. If no drainage geocomposite is installed to compensate for this reduction, the transmissivity of the 0.30 m gravel layer will be 0.30 / 0.50 = 60% of the initial transmissivity.

A thorough investigation of clogging mechanism and an extensive review of field clogging experience was presented by Rowe (2005). Rowe suggests that 'clogging' of the gravel layer can occur after periods

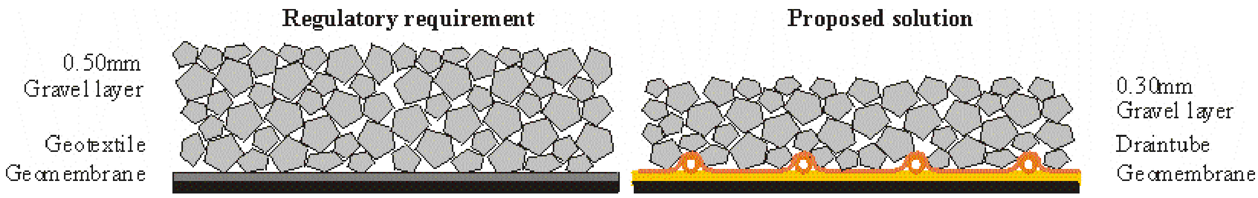

Figure 1. Proposed solution

of time which can vary between a decade to a century, depending on the design of the LCL and the properties of the leachate. Basing on the estimation of a 'normal' clogging time of at least 10 years, assuming that after 18 months, the transmissivity of the granular layer is likely to be at least 50% of what it was initially can be considered to be a realistic hypothesis. As a consequence, it can be estimated that the 60% residual transmissivity caused by the reduction of the thickness of the drainage layer may be reduced to 30% in case the granular layer would lose as much as half of its drainage capacity during the first 18 months.

It was shown above that after 18 months, the quantity of liquid to be drained is reduced to 20% of the original quantity. As a consequence, it is proposed to consider as a minimum performance requirement that the drainage geocomposite shall not be clogged after 18 months of service, in order to allow the granular drainage layer to lose as much as 2/3 of its capacity without endangering the global performance of the LCL.

After this period of 18 months, any drainage performance provided by the geocomposite will only increase the safety factor applicable to the drainage capacity of the drainage layer, as the actual flow rate of leachate will continue to decrease over the year down to about 1/500 of the initial capacity of the drainage layer.

On the other hand, Rowe (2005) also recommends to give special attention to the locations in the landfill where the circulation of leachate is the most critical, such as in the vicinity of the drainage collection pipes, which is considered to be a good practice by the authors.

2.3 *Other factors affecting the long term performance of drainage layers*

Among the stresses which have to be considered in the design of LCL, creep and biological or chemical clogging are among the key factors. GRI GC8, which is widely used in North America for the design of drainage geocomposites, indeed recommends an approach based on the usage of safety factors applicable to the initial transmissivity of the geocomposite, using :

$$FS = \frac{\theta_{allow}}{\theta_{req'd}} \quad (1)$$

$$\theta_{allow} = \frac{\theta_{100}}{RF_{CR} \cdot RF_{CC} \cdot RF_{BC}} \quad (2)$$

where θ_{100} is transmissivity measured in accordance with ASTM D4716 (after 100 hours seating time), and RF are reduction factors addressing:

- RF_{CR} = creep deformation;
- RF_{CC} = chemical clogging;
- RF_{BC} = biological clogging.

Besides the creep, biological and chemical clogging potential, the GRI GC8 approach also indirectly includes other limiting factors such as geotextile intrusion by requiring consideration as a reference value the transmissivity measured after 100 hours under experimental conditions which reproduce geotextile intrusion.

However, the approach developed in GRI GC8 focuses solely on the drainage geocomposite and its performance, but does not analyzes it as part of a drainage structure. This approach is appropriate for some applications where drainage geocomposites are the sole component actively contributing to the drainage, such as for the drainage of rainwater in veneers and landfill covers, sports fields, as well as for secondary drainage layers (also called leak detection layer), etc. For a selected number of applications, GRI GC8 also proposes various values applicable to these safety factors.

However, issues such as the design life considered to determine these safety factors are not clearly defined in the standard and could generate divergences in the interpretation of their significance. Moreover, it was not possible for the authors to identify any scientific justifications for these values, which are also discussed and questioned by several authors including Zhao et al. (2012).

Overall, although the preferred approach for the design of drainage geocomposites may vary depending on the application and hypotheses considered, there is a broad acceptance regarding the fact that creep and biological / chemical clogging are the key factors affecting the performance of drainage geocomposite used in LCL and that an improvement of existing design guidance would be welcomed.

If biological clogging and chemical clogging are likely to occur in every type of product, one of the particularities of tubular drainage geocomposites is the tubular shape of the core and its ability to resist very high stresses while confined in soil. Saunier et al. (2010) have observed that the transmissivity of tubular drainage geocomposites was not affected by normal load nor by creep up to normal stresses as high as 2500 kPa and test durations up to 100 hours. They conclude that the creep reduction factor can be neglected as long as the product is confined in soil. As a consequence, biological and chemical clogging can be considered to be the only factors which are likely to affect the performance of tubular drainage geocomposites.

3 FIELD INVESTIGATION

3.1 *Experimental issues related to the evaluation of the Biological clogging resistance of drainage geocomposites*

Several factors shall be considered for proper evaluation of the performance of any product in contact with leachate. These are:

1- Nature of the leachate. Leachates composition depends on the nature of the landfilled materials, oxygenation, operating conditions of the landfill, etc. The nature of landfilled materials may change tremendously depending on local regulations, existence of recycling programs, wealth of the community and other factors.

As a consequence, observations made on a given landfill may be applicable only to very similar landfills, but cannot be generalized to any type of landfill. In example, a landfill receiving mostly industrial waste, or construction debris, will not generate the same type of leachate than a landfill receiving a significant fraction of organic waste – i.e. in communities where composting programs are not implemented.

2- Age of the leachate. Leachate properties are likely to change over time, especially the ones involving biological (BOD) or chemical (COD) activity, which are of particular interest for the evaluation of the performance of a geocomposite drainage layer against biological or chemical clogging.

It is thus important to make sure that the leachate circulating through the geocomposite will be as 'fresh' as possible. Transportation to a laboratory to run a laboratory controlled experiment has not been considered yet to be a realistic option as the changes of properties of the leachate would be too significant. For the experimental evaluation of this project, it was thus decided to bring the experiment to the landfill, instead of trying to develop strategies to try to bring the leachate to the laboratory.

3- Temperature. Temperature of the leachate will influence the nature of the microorganisms which are likely to develop in the area of interest and generate the biomass which could eventually clog the drainage layer. It is thus important that the environment in which the system will be evaluated stays at a temperature as close as possible to the temperature which is likely to be experienced in the bottom of landfills.

For this project, the test temperature was selected considering that only the first two years of service are of interest to the authors. Although it is known that the temperature at the bottom of landfills can exceed this value after several years of service (Rowe et al, 2006), a test temperature controlled within a range of 20 to 30°C was considered to be as close as possible to realistic service conditions in the LCL during the first two years of activity of the landfill.

4- Presence of oxygen. Once wastes are installed on the LCL, the distance and tortuosity of the path linking the LCL and the air is sufficient to consider that the presence of oxygen in the vicinity of the geosynthetics drainage layer is very unlikely. As a consequence, anaerobic conditions shall be preferred for these evaluations as they better reflect the conditions prevailing in the bottom of landfill.

3.2 *Scope of the field study*

The study was conducted on a landfill identified as 'class 2' under the French designation, which describes sites designed to receive municipal solid wastes and non-hazardous industrial wastes. For this type of landfill, the wastes include a significant fraction or organic matter resulting of normal human activity and are thus known to develop biologically active leachate.

Two products were tested. Both were tubular drainage geocomposites 'draintube', which consist in the combination of a series of 25 mm diameter perforated corrugated pipes entrapped between two layers of non-woven polypropylene geotextiles, as described on Figure 2.

The upper geotextile of the tested product, in contact with the granular drainage layer, was composed of special fibers including silver ions in their formulation as a biocide agent.

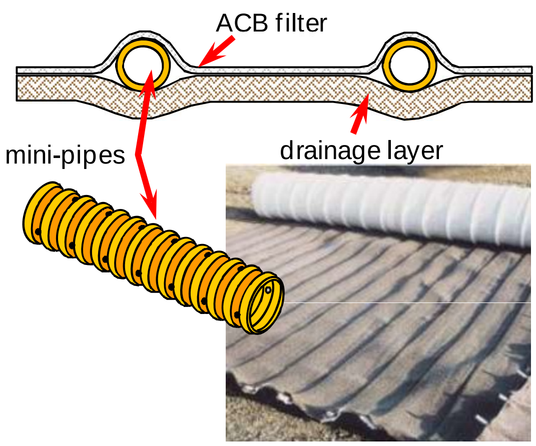

Figure 2. Tested drainage geocomposite

3.3 *Set-up of the experiment*

The objective of the study was to validate that a tubular drainage geocomposite would not clog while exposed to a circulation of leachate in a condition similar to what would be experienced on-site. As a consequence, the test cells, which are described in the next chapter, were installed in a bungalow located in the perimeter of the landfill, at immediate proximity of a well where the fresh leachate could be easily pumped and injected into the test cells (Figure 3).

With the test set-up installed in this particular location, it was possible to meet the first requirement identified above, which is to ensure circulation of fresh, representative leachate into the drainage geocomposite.

In order to meet the high temperature requirement, the bungalow was maintained year round at a temperature of 25±5°C, in order to maintain a biological activity of a similar nature than what is likely to be experienced by the geosynthetic drainage products in the bottom of landfill during their first years of operation.

Figure 3. Location of the bungalow

3.4 *Test cells*

Preservation of anaerobic conditions was ensured by the design of the test cell, which is presented below. This design was developed in order to observe in one single test the clogging potential of both the filter and the core (perforated pipe).

To do so, the leachate was circulated through a gravel layer first, then through the geotextile, and was collected through the exit of the pipe on one end of the cell, as described on Figure 4.

On the other hand, preservation of anaerobic conditions was achieved by positioning the outflow weir above the top of the cell to maintain the whole system submerged, as well as using relatively small diameter pipes to inject the leachate into the cells.

Although the tested product is not sensitive to normal load, preserving a normal load in the range of 100 kPa was considered to be an additional feature adding to the representativity of the test. This was achieved over the duration of the project by controlling the compression of calibrated springs, as described on Figure 5.

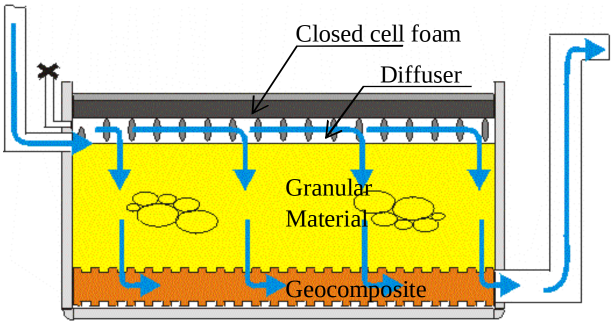

Figure 4. Section of a test cell

Figure 5. Control of the normal stress

3.5 *Leachate injection*

The system used to control injection of a fixed quantity of leachate in the conditions of the test is described on Figure 6. It basically permits to inject the leachate in three steps:

First, pumping a significantly larger volume of leachate into a ‘buffer reservoir’ located above the cells. After this step, a pause was respected to permit harmonization of the temperature of the leachate with the temperature of the room.

In a second step, a first series of electro-valves were opened simultaneously to allow flow of the leachate from the buffer reservoir into smaller calibrated reservoirs, each of them being equipped with an overflow in order to control the presence of a fixed volume of leachate once the large container has completely emptied itself into the small, calibrated reservoirs.

Finally, a second series of electro-valves were opened to permit flow of the leachate into the test cell a short time after stabilization of the second step.

One single standard pump was thus needed to inject leachate into the ‘buffer reservoir’. This pump, as well as the opening and closing of all the electro-valves were controlled using timers.

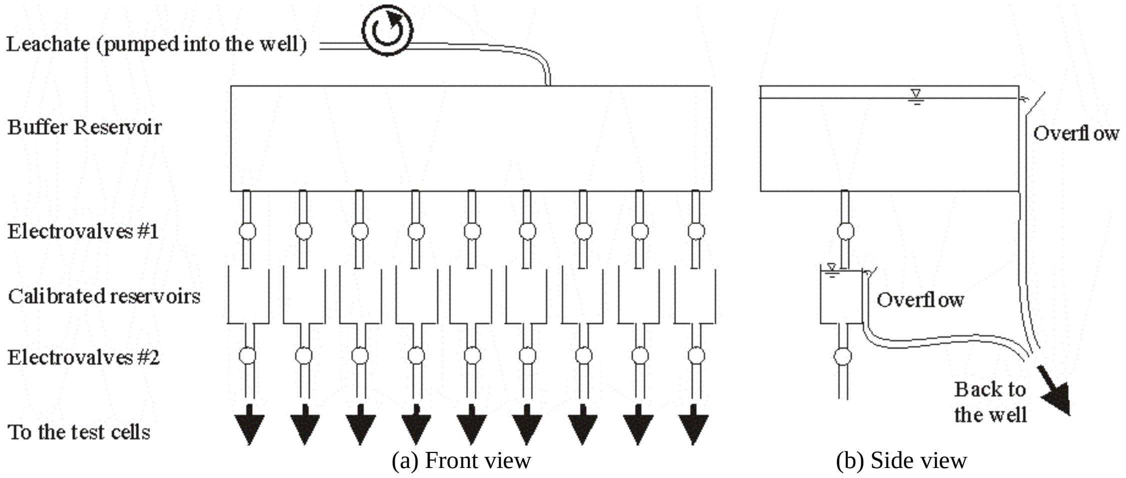

Figure 6 : leachate injection system

Overall, this system did allow injection of one liter of leachate into the test cells 10 times per day, every 144 minutes, which was considered sufficient to maintain a constant supply of 'food' to the microorganisms likely to develop into the system, while maintaining the selected test conditions.

3.6 *Monitoring technique*

As mentioned in the beginning of this paper, this project has involved a collaborative effort from the landfill owner, a geosynthetics manufacturer, and a laboratory. In addition to the supply of the test area, the personnel available on-site was used for periodic control of the experiment, as well as to perform very simple measurements and to report their observations to the laboratory.

The monitoring technique was thus designed in order to ensure the performance of this approach. As the objective of the project was to observe a lack of clogging after 18 months, a simple measurement of the time needed for leachate to percolate through the system under fixed conditions was adopted.

A container was thus installed in parallel to the pipe used to inject the leachate. A falling head infiltration test was then performed using the same path as the one used by the leachate itself.

Although this technique cannot be used to quantify potentially minor adverse effect of the leachate on the system, the blocking of any component of the system can be easily detected.

Figure 7 presents the system used to monitor the infiltration rate. The time needed for the water to enter the system was measured between by observation of the water level traveling between the lines marked as 'H_0' and 'H_1'. An 'infiltration rate' was calculated, expressed as the velocity of the water entering the cell, under an average head of 0.15 m (0.15 m being half of the allowable head according to the regulation).

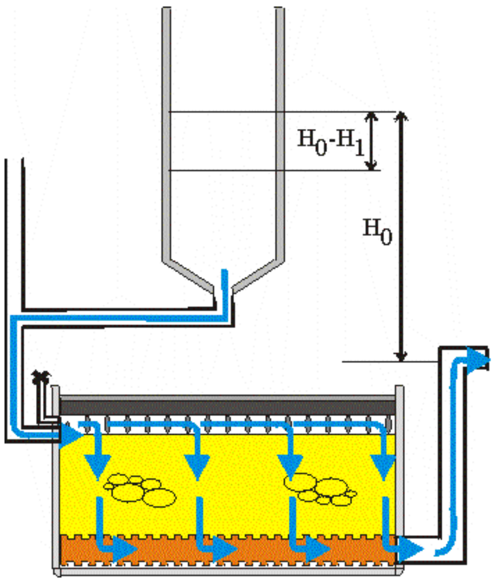

Figure 7. Periodic monitoring system.

The values measured over time were then normalized to the initial measurements, considering the average value measured during the first month of operation of the system. This ratio was identified as a 'clogging index', and was used for further analysis. This ratio is presented in Equation 1.

$$\log \qquad index = \frac{V_{initial}}{V_t} ging \qquad (1)$$

In case any component of the system would clog, the velocity of the water would become very low, and a high clogging index would be calculated. In case this scenario would occur, the monitoring strategy adopted was to dismantle the test cell in order to observe visually, and through additional laboratory measurements if necessary, the nature of the clogged component.

Although this monitoring technique has shown its performance, it is important to mention that observations made using this technique remain qualitative and cannot be used to determine a safety factor, for

Table 1: Tested geocomposites properties

	Norme	type 'A'	type 'B'
Test cell number		1, 4, 7	3, 6, 9
Mass per unit area of the filter (g/m²)	EN 9864	160	240
Mass per unit area of the cushion (g/m²)	EN 9864	800	800
In-plane transmissivity (σ = 400 kPa, i=0.1, m²/s)	ISO 12958	$5{,}7\times10^{-4}$	$5{,}7\times10^{-4}$
Antibacterial treatment		Embedded, non-leachable silver ions	

example in the sense which is described in GRI GC8 as they are not related to a transmissivity.

3.7 *Additional observations*

At the end of the project (given that no significant clogging could be detected using to the above-described technique), the systems were dismantled in order to observe the quantity of biomass accumulated on the system, and to proceed with photographic observation, measurement of the remaining pore volume and weighing the quantity of biomass accumulated in the gravel, etc.

3.8 *Experimental program*

Three configurations were tested, and each of them was replicated three times. As a consequence, a total of nine test cells were installed and monitored over the duration of the project.

Two out of the three configurations involved tubular drainage geocomposites, with two different types of anti-bacterial filter, as specified in Table 1. The third configuration was involving only gravels, which are shown on Figure 8. The gravels were selected according to the current regulatory requirements prevailing in France. These were crushed gravels, sieved between 20 and 40 mm.

An overview of the complete test set-up is presented on Figure 9.

Figure 8. Gravels (dimensions of the cell: 250 mm x 250 mm)

Figure 9. Overview of the apparatus

4 OBSERVATIONS

4.1 *Restriction to the flow of liquid (clogging)*

Figure 10 presents the evolution with time of the clogging index for each of the three configurations. It can be observed that after 18 months, none of the systems had lost their efficiency with a 'clogging index' in the range of 3 to 5.

After completion of the 18 months period of testing, the test cells were dismantled in order to collect the biomass accumulated into each of the components and to conduct thee additional observations presented in the following paragraphs.

4.2 *Residual volume of voids in the gravel*

In order to determine the residual porosity at the end of the test, the quantity of water which was able to flow out of the previously fully saturated cells was collected and compared to the total volume of the inside of the cell. This measurement led to measured void volumes ranging from 27% to 34% for all the three solutions, showing the presence of a significant amount of voids in the granular drainage layer. Individual results are presented on Table 2.

4.3 *Weight of biomass and fine particles trapped into the components*

After measurement of the volume of voids, the accumulated biomass and minerals trapped into the system were collected at the end of the project using the following step-by-step procedure:

- Washing of the gravel and test cell in clear water;

- Filtration of the so-collected biomass on a geotextile;
- Drainage of the water away from the biomass;
- Weighting of the wet biomass;
- Drying of the biomass in the air, at room temperature;
- Weighting of the dry residual material.

The corresponding measurements are compiled and presented on Table 2. It can be observed that a significant amount of biomass has developed into and immediately above the geotextiles (standard cushion located under the gravel, or cushion component of the tubular drainage geocomposite), which is consistent with previous observations (Rowe 2005).

4.4 *Visual observations*

A few examples of the dismantled systems are presented on Figures 11, 12 and 13.

Although biomass could be observed in the gravel and the geotextile, the pipes were not clogged and obvious voids permitting the flow of water through the gravel could be observed. These observations were overall consistent with the other observations made within this project.

5 DISCUSSION AND CONCLUSIONS

This project was conducted thanks to a partnership between a landfill owner, a geosynthetics manufacturer and a laboratory. The objective was to assess whether draintube tubular drainage geocomposites could be used as a partial replacement of gravel in the design of leachate collection layer (LCL) in the bottom of landfills.

In a first step, actual drainage capacity required for the LCL throughout its life were confirmed considering the presence of waste acting as a hydraulic buffer, and eventually of a geomembrane cover. Existing investigations were used to consider as a work hypothesis that only 20% of the precipitations actually reach the LCL after 18 months of service, and 0.2% once the landfill cover is installed.

Considering these drainage requirements, it was

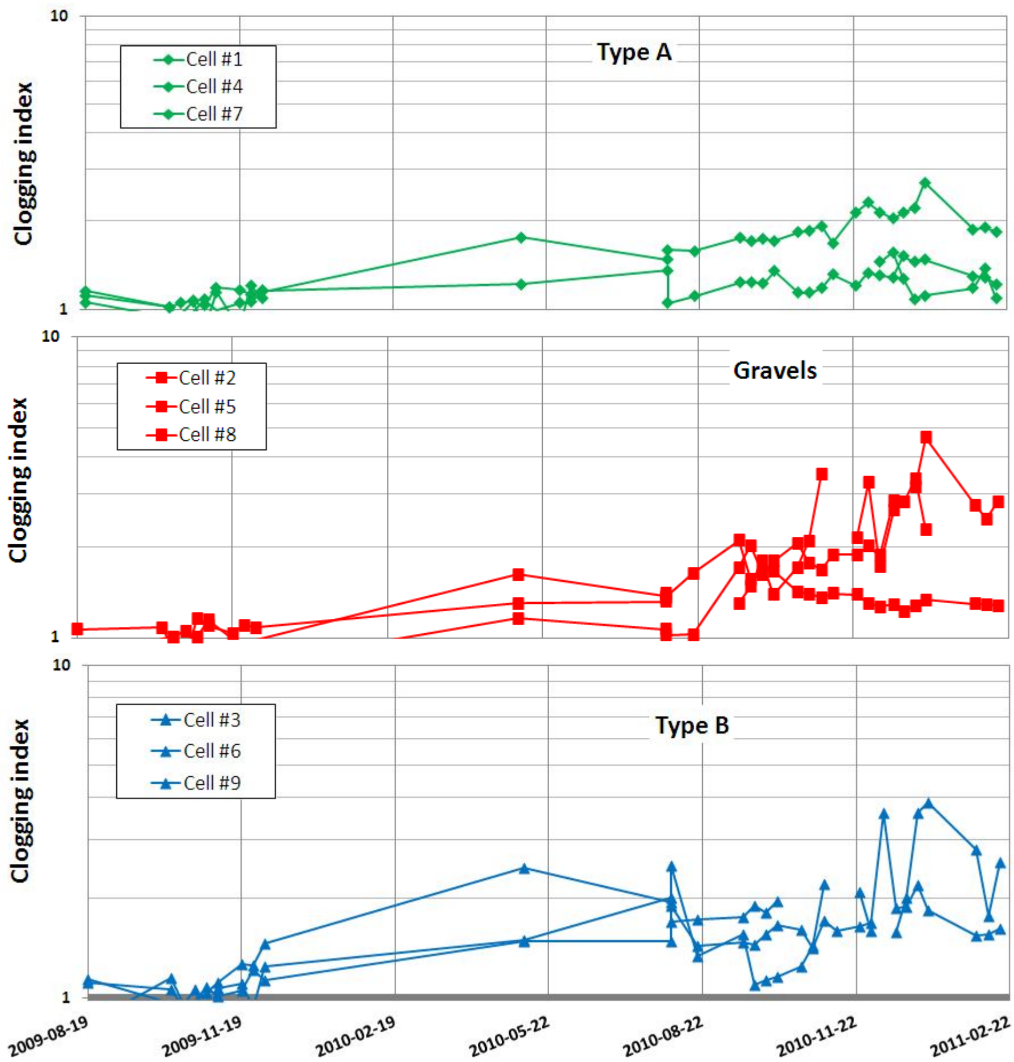

Figure 10. Clogging index

possible to conclude that installing a drainage geosynthetic in addition to 0.30 m of gravel represents a solution which can meet all the performance-based regulatory requirements related to LCLs, but the minimum gravel thickness of 0.50 m.

This statement is made considering that:

- The hydraulic transmissivity of the tubular drainage geocomposite is similar to the one of a 0.20 m thick layer of gravels complying to the regulatory requirements
- An actual service life of 18 months can be expected from the geosynthetic drain before it clogs. After this 18 months period, a complete loss of drainage capacity of the geosynthetics drain would not affect the actual performance of the whole system.

An experimental confirmation that existing tubular drainage geocomposite can meet these requirements was conducted. The actual resistance to biological clogging of two grades of tubular drainage geocomposites with a filter involving chemically enhanced fibers was investigated. Both products were evaluated during 18 months in a ‘class 2’ landfill according to the French regulation (municipal solid waste and non-hazardous industrial wastes).

Based on the results obtained, it is possible to conclude that both styles of tubular drainage geocomposites which filter includes a non-leachable silver-based treatment (biocide agent) did not experience any significant clogging. However, it was not possible to detect any difference between the two products.

As a consequence, and considering that the tubular drainage geocomposite is not likely to experience creep because of its particular structure, it can be concluded that a LCL consisting of a 0.30 m layer of gravels installed on top of one of the tested tubular drainage geocomposites will be appropriate to maintain a head of leachate smaller or equal to 0.30m on top of the geomembrane, and thus meets the performance-based requirements of the French legislation for LCLs.

Figure 11. Cell 8 : reference without tubular drainage geosynthetics

Figure 12. Cell 4 (type A): Side view of the tube

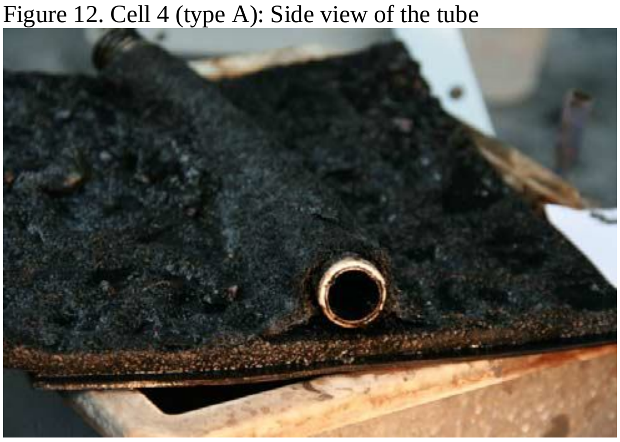

Figure 13. Cell 7 (type A) – Side view of the tube

Table 2: Compilation of the measurements made while dismantling the test cells

	Cell #	Void ratio	Mineral particles		Biomass	
			In the gravel	On the Draintube (or geotextile)	In the gravel	On the Draintube (or geotextile)
		%	Kg/m²	Kg/m²	Kg/m²	Kg/m²
Type A	1	34%	0.288	1.472	6.016	5.856
	4	33%	0.736	1.696	6.912	6.464
	7	27%	0.672	1.696	7.040	5.408
Gravel	2	30%	0.608	0.800	4.832	4.448
	5	32%	0.480	0.896	5.344	7.104
	8	30%	0.736	0.992	5.184	5.184
Type B	3	33%	0.256	1.456	5.696	6.448
	6	34%	0.640	1.808	6.464	6.352
	9	30%	0.928	2.064	6.656	6.160

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