Biological Clogging Resistance of Tubular Drainage Geocomposites in Leachate Collection Layers

Blond E., eng., SAGEOS / CTT Group, St-Hyacinthe, Quebec, Canada, eblond@gcttg.com
Fourmont S., AFITEX, Champhol, France, sfourmont@draintube.net
Saunier P., Afitex-Texel, Ste Marie, Canada, psaunier@draintube.net

ABSTRACT
Although drainage geocomposites are frequently used for rainwater drainage or gas collection system in landfill covers, their application in leachate collection layers is rather limited. The authors believe that a key limitation to their use in leachate collection is a lack of knowledge of their sensitivity to biological clogging, and its consequence on the capacity of the Leachate collection layer (LCL) to meet landfill regulations prevailing in the US and Canada. In the first section of this document, a literature review was conducted of the actual drainage needs applicable to the LCL. This review led to the conclusion that leachate flow potentially reaching the LCL over the lifespan of a “dry tomb” landfill is significantly lower than what is required in the early stages of its life. This observation allowed for a larger tolerance to biological clogging of a drainage geocomposite if combined with a granular drainage layer meeting reasonable requirements with respect to biological clogging resistance. In the second section of this paper, the long term performance of tubular drainage geocomposites was investigated. Fresh leachate originating from a class 2, non-hazardous landfill located in the center of France, was circulated through a tubular drainage geocomposite during an eighteen months’ time period under anaerobic conditions, without any observation of clogging. In the third section of this paper, the results are analyzed and interpreted. Based on this research and analysis, it is suggested that the tested tubular drainage geocomposite could replace a fraction of the granular drainage layer of a Leachate Collection System (LCS) in a dry tomb landfill.

1. INTRODUCTION

Drainage geocomposites are used with an increasing frequency by landfill designers to substitute granular materials, especially in landfill covers. However, drainage geocomposite installations on the base of the landfill as a drainage component of the Leachate Collection System (LCS) are rather limited. The authors believe that a key limitation to their use on this particular location is a lack of knowledge of their sensitivity to biological clogging, among other fears and design challenges associated to the relatively harsh operating conditions at this location (i.e., high stress combined with potentially aggressive leachate). However, redesigning the drainage layer in order to permit partial replacement of the granular by a drainage geocomposite could represent a significant cost saving of high quality granular drainage materials, which can be expensive when they must be hauled in from distant quarries to the landfill, and also voluminous when compared to drainage geocomposites. Using geocomposites would therefore increase the waste storage capacity of the landfill and reduce the number of trucks, thus decreasing the carbon footprint of the landfill. Therefore, the installation of drainage geocomposites as a component of LCS in landfills is an alternative approach with both economic and environmental benefits.

The primary objective of the study was to validate that a tubular drainage geocomposite would not clog within 18 months, while exposed to fresh circulating leachate in a condition similar to what would be experienced in-situ and could therefore be used as a partial replacement of gravel in the design of leachate collection layer (LCS) at the bottom of landfills. The secondary objective was to assess landfill regulations in the US and Canada to determine if replacement of a fraction of the drainage layer by this tubular drainage geocomposite (Figure 1) would meet regulatory requirements.

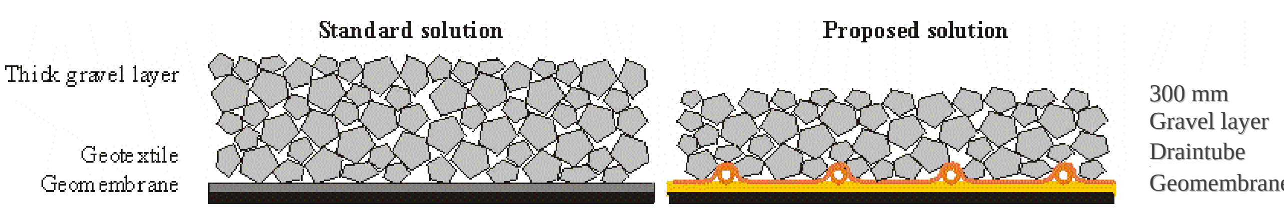

Figure 1. Typical and Proposed LCS Design cross section

2. PERFORMANCE REQUIREMENTS

2.1 Regulatory Requirements

The head of leachate on the lining system and the thickness of the drainage layer are the two requirements which are commonly described in the various regulations prevailing throughout North-America.

In the vast majority of the cases, LCS must be designed to maintain the leachate head on the liner to 0.3 m or less. Landfills in EPA-approved jurisdictions must have a state or tribe approved performance design (EPA 1993). In the EPA-approved solid waste program in the State of California, a blanket LCS is required for a Class II municipal solid waste landfill, which the LCS must ensure no buildup of hydraulic head on the liner, but the thickness of the LCS is not specified (Title 27, California Code of Regulations).

In Canada, landfill regulations are mandated by provinces or territories, not the federal government. In some jurisdictions (i.e. Alberta), leachate head must be monitored, but there is no specified limit or design requirements for LCS thickness, thus no regulatory limits on the use of geocomposites in the LCS (Government of Alberta 2010). In Newfoundland, the LCS must be a minimum of 0.3 m in thickness plus a 0.375 m cushion layer between the LCS and the waste, with a maximum leachate head of 0.3 m (Government of Newfoundland and Labrador 2010). In the province of Ontario, the combination of the primary LCS and the cover must maintain leachate head on the liner at 0.3 m or less for a service life of 100 years and the infiltration rate through the final cover is required to be equal to or greater than 0.15 m/year (Ontario Regulation 232/98). This forced infiltration means that there will be leachate generation long after installation of the final cover, thus a continued potential for leachate generation, and therefore biological clogging.

As a consequence, the potential replacement of a fraction of the granular drainage layer by a geocomposite with sufficient hydraulic performances can be considered to be feasible for landfills located in jurisdictions which do not prescribe a minimum thickness of the drainage layer. Another factor that could potentially present some restrictions to this design is the prescribed design life of the LCL, i.e. under the Ontario regulation, which could require further investigations.

In order to assess that the hydraulic capacity of the drainage layer (0.30 m of gravel including the drainage geocomposite) will be sufficient to meet the performance requirement (maximum head of leachate of 0.30 m), it is necessary to:

- Identify the required capacity of the drainage layer; and
- Predict the long term behavior of the drainage layer (i.e. creep and clogging).

2.2 Hydraulic Requirements - Review of the Quantity of Leachate Predicted in the Literature

The key hydraulic design criteria for LCS systems are that the head on the liner needs to be smaller than the prescribed value (typically 0.3 m) and that the liquid thickness in the LCS be less than the thickness of the drainage layer thickness throughout the entire design life of the landfill. Typically the McEnroe equations are used to determine the liquid supply rate in the LCS system. The majority of the North American designers probably use the HELP model which uses the McEnroe equations as well. The more recent literature recommended double-checking the HELP model calculations with approximate solutions with Giroud's Equation (1992, 1995).

As an alternative design approach to predict leachate generation rates, Bellenfant (2009) states that there are two stages to consider; while the cell is being filled (~1 to 5 years), and after the final cover is installed (10's to 100's of years).

During the first stage, the quantity of leachate which is generated is the greatest, because there is no final cover and all the rainfall reaches the waste. Additional parameters have been identified as influencing the volume of leachate collected from the LCS:

- More evaporation will take place when there is thicker waste, therefore reducing the quantity of leachate reaching the LCS (Bellenfant, 2009);
- Techniques used in the operation of the landfill will change the quantity of water penetrating the waste, and also the leachate generated (i.e., type of daily covers, slopes).

The LCA model (SITA, Creed, EIA, 1998) provides an estimation of the quantity of leachate collected from the LCS relative to the precipitation, considering the number years that a cell has been in operation and the presence – or not – of a cover:

- 0 to 18 months with no cover, 20% of the precipitation quantity;

- 18 months to 5 years with no cover, 6.6% of the precipitation quantity;
- 5 to 10 years with no cover, 6.5% of the precipitation quantity;
- 10 years + with a geomembrane cover: 0.2% of the precipitation quantity.

Although the amount of water collected from the LCS is almost as much as the precipitation during the first weeks or months of operation when there is little or no waste in the cell, it rapidly decreases after only 18 months. Moreover, once a low permeability cover has 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. As a consequence, it is reasonable to consider that the LCS is a critical component of the lining system during only the first few years that the landfill is in operation if the landfill final cover is designed to allow only a nominal amount of precipitation to enter the landfill.

It is thus possible to state that even if the performance of a drainage layer designed to absorb the rainfall in a given area is reduced to 20% of its initial capacity after 18 months, it will still fulfill its function and meet regulatory requirements as a LCL when the landfill is operated in the conditions considered in the LCA model. The same approach can be used to state that a sufficient performance would be offered by a LCL presenting as little as 0.2% of its initial capacity following installation of a geomembrane final cover.

These numbers appear promising considering the observations reported by Rowe (2005), which suggest that clogging of the gravel layer can occur after a period of time that can vary between a decade to a century, depending on the design of the LCS and the properties of the leachate.

2.3 Long Term Performance of Geocomposite Drainage Layers

Among the issues which have to be considered in the design of LCS, creep, and biological/chemical clogging are among the key factors as outlined by GRI GC8, which is widely used in North America for the design of drainage geocomposites.

$$FS = \frac{\theta_{allow}}{\theta_{req'd}} \tag{1}$$

With

$$\theta_{allow} = \frac{\theta_{100}}{RF_{CR} \cdot RF_{CC} \cdot RF_{BC}} \tag{2}$$

where θ_{100} is the transmissivity measured in accordance with ASTM D4716 (after 100 hours seating time with in-situ conditions), and the RF are Reduction Factors addressing:

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

Besides the creep, chemical, and biological 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 in-situ conditions which reproduces geotextile intrusion.

However, the reduction-factor approach developed in GRI GC8 focuses solely on the drainage geocomposite itself and its long term performance, not as a component of a LCS. Issues such as the length of the design life used to determine these reduction factors are not clearly defined in the GRI GC8 standard, and could generate divergent interpretation of their significance. Moreover, it was not possible for the authors to identify any published scientific justifications for these proposed values in the GRI-GC8 standard, which have been discussed in-depth by several authors including Zhao et al. (2012).

Although the preferred approach to the design of drainage geocomposites may vary depending on the application and assumptions 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 LCS and that an improvement of existing design guidance would be welcomed.

Although biological and chemical clogging are likely to occur in every type of product, one of the strengths of tubular drainage geocomposites is the 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 or creep up to normal stresses as high as 2500 kPa and test durations up to 100 hours. It was concluded that the creep reduction factor in GRI GC8 can be neglected as long as the product is confined in soil. As a consequence, it is suggested that biological and chemical clogging can be considered to be the only factors which are likely to affect the performance of tubular drainage geocomposites.

2.4 Leachate Composition

Several landfill leachate characteristics should be considered for proper evaluation of the performance of any product in contact with leachate. The nature of waste 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.

- Leachate composition;
- Age of the leachate;
- Temperature, which influences the growth of biomass; and
- Anaerobic conditions to reflect the conditions prevailing in the bottom of a landfill.

The leachate characteristics considered here is located in Section 3.2, Experimental Set-Up.

3. INVESTIGATION

3.1 Scope

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 waste includes a significant fraction of organic matter resulting of normal human activity and is thus known to develop biologically active leachate.

3.2 Experimental Set-Up

Two tubular drainage geocomposites were tested, and compared to gravel. These consist of a series of 25 mm diameter perforated corrugated pipes sandwiched between two layers of non-woven polypropylene geotextiles (Figure 2). The upper geotextile (in contact with the granular drainage layer above), is composed of special fibers made with silver ions acting as a biocide agent (ACB filter).

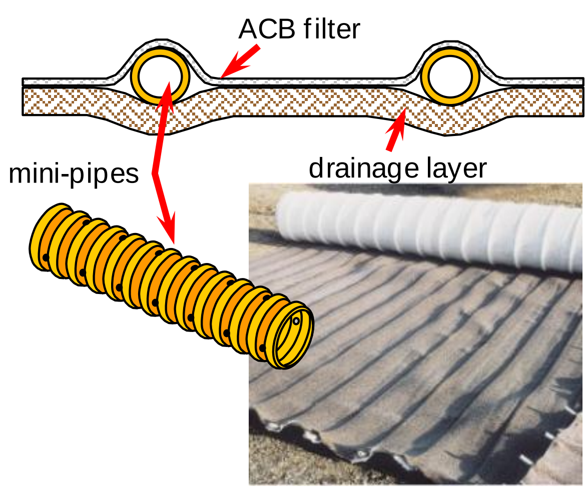

Figure 2. Tested tubular drainage geocomposite

Issues related to leachate composition outlined above have been taken into account in the experimental design. Transportation to a laboratory to run a laboratory-controlled experiment was not considered to be a realistic option as the change of properties of the leachate would be too significant; it was thus decided to bring the experimental setup to the landfill. The test temperature was controlled within a range of 20 to 30°C 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, Koerner and Koerner 2006), the selected temperature range was considered to be as close as possible to service conditions in the LCS during the first two years of activity at the bottom of the landfill.

The test cell design was developed in order to observe the clogging potential of both the filter and core (perforated pipes) of the geocomposite. The test cells were installed in a building located near the perimeter of the landfill, close to a leachate sump, where fresh leachate could be easily pumped and injected into the test cells. The building was maintained at a temperature of 25±5°C year round in order to maintain a biological activity of a similar nature than what is likely to be experienced by the geosynthetic drainage products at the bottom of landfill during their first years of operation. Preservation of anaerobic conditions was ensured by the design of the test cell, which was achieved by positioning the outflow weir above the top of the cell to submerge the interior of the cell in leachate, and relatively small diameter pipes were used to inject the leachate into the cells. The leachate was circulated through a gravel layer first, then through the geocomposite, and collected through the exit of the pipe on one end of the cell, (Figure 3). Although the tested product is not sensitive to normal load, a normal load in the range of 100 kPa was used to represent conditions at the base of a landfill cell within 18 months of operation. The normal load was achieved by controlling the compression of calibrated springs (Figure 4).

3.3 Leachate Injection

The system used to control injection of a fixed quantity of leachate in the conditions of the test is described as follows:

1. A large volume of leachate was pumped into a 'buffer reservoir' located above the cells, then allowed time to equilibrate with room temperature.
2. The first series of electro-valves were opened simultaneously to allow flow of the leachate from the buffer reservoir into smaller calibrated reservoirs, each equipped with a valve to control the leachate to a fixed volume.
3. 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 standard pump was needed to inject leachate into the 'buffer reservoir'. The pump and the electro-valves were controlled using timers. Overall, this system allowed injection of one liter of leachate into the test cells ten times per day, (at a frequency of 144 minutes), which was considered sufficient to maintain a constant supply of nutrients to the micro-organisms likely to develop into the system, while maintaining the test conditions.

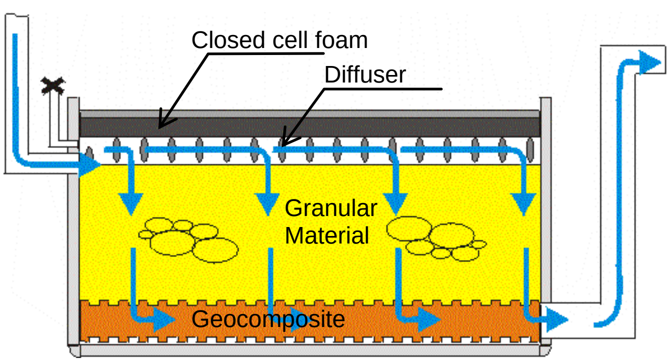

Figure 3. Cross section of a test cell

Figure 4. Control of the 100 kPa normal stress

3.4 Monitoring Technique

As mentioned at the beginning of this paper, this project 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 simple measurements and to report their observations to the laboratory.

The monitoring technique was designed 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 5 presents the system used to monitor the infiltration rate. The time needed for the water to enter the system was measured by observation of the water level traveling between the lines marked ‘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 for many regulations). From these observations, a clogging index was defined as the ratio between the infiltration rate at a given time, and the initial infiltration rate.

3.5 Experimental Program

Three configurations were tested, and each was replicated three times for a total of nine test cells. Two out of the three configurations involved tubular drainage geocomposites with anti-bacterial filters (Table 1). The third configuration was involving only gravel (Figure 6). The gravel was selected according to the current regulatory requirements prevailing in France: crushed gravel, sieved between 20 and 40 mm. An overview of the complete test set-up is presented in Figure 7.

Table 1: Tested geocomposite properties

	Standard	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	

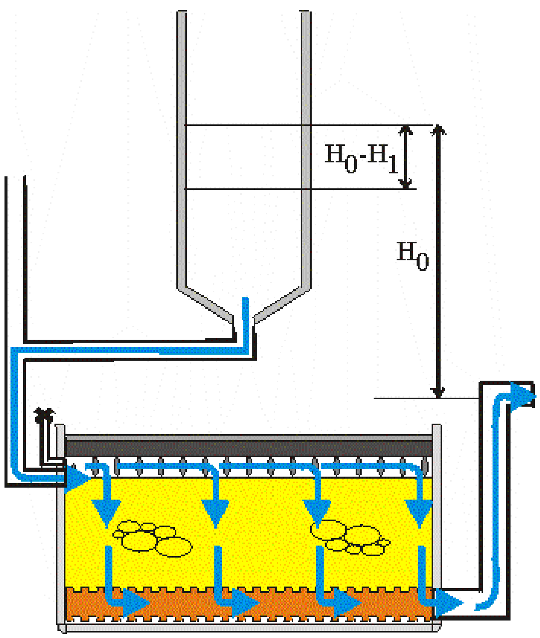

Figure 5. Periodic monitoring system.

Figure 6. Gravel (dimensions of the cell: 250 mm x 250 mm)

4. OBSERVATIONS

No significant clogging could be detected using the technique described above. At the end of the test, the cells were dismantled to observe the quantity of biomass accumulated in the system and to proceed with observations, measurement of the pore volume, and weighing the quantity of biomass accumulated in the gravel.

4.1 Clogging

Figure 8 presents the change of the clogging index with time for each of the three configurations. After 18 months, it was observed that none of the systems had lost their efficiency, with a 'clogging index' in the range of 3 to 5.

Figure 7. View of the 9 cell test apparatus

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 that freely flowed out of the saturated cells was collected and compared to the total volume of the inside of the cell. It was found that the measured void volume ranging from 27% to 34% for all three drainage types, demonstrating the presence of a significant amount of voids in the granular drainage layer (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 procedure:

- Gravel and test cell were washed in clear water;
- Biomass in the water was filtered from water on a geotextile;
- Wet biomass was weighed;
- Biomass was dried in the air, at room temperature;
- Dry residual material was weighed.

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

Table 2: Measurements conducted after testing

	Cell #	Void ratio	Mineral particles		Biomass	
			In the gravel	On the geocomposite	In the gravel	On the geocomposite
		%	Kg/m^2	Kg/m^2	Kg/m^2	Kg/m^2
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

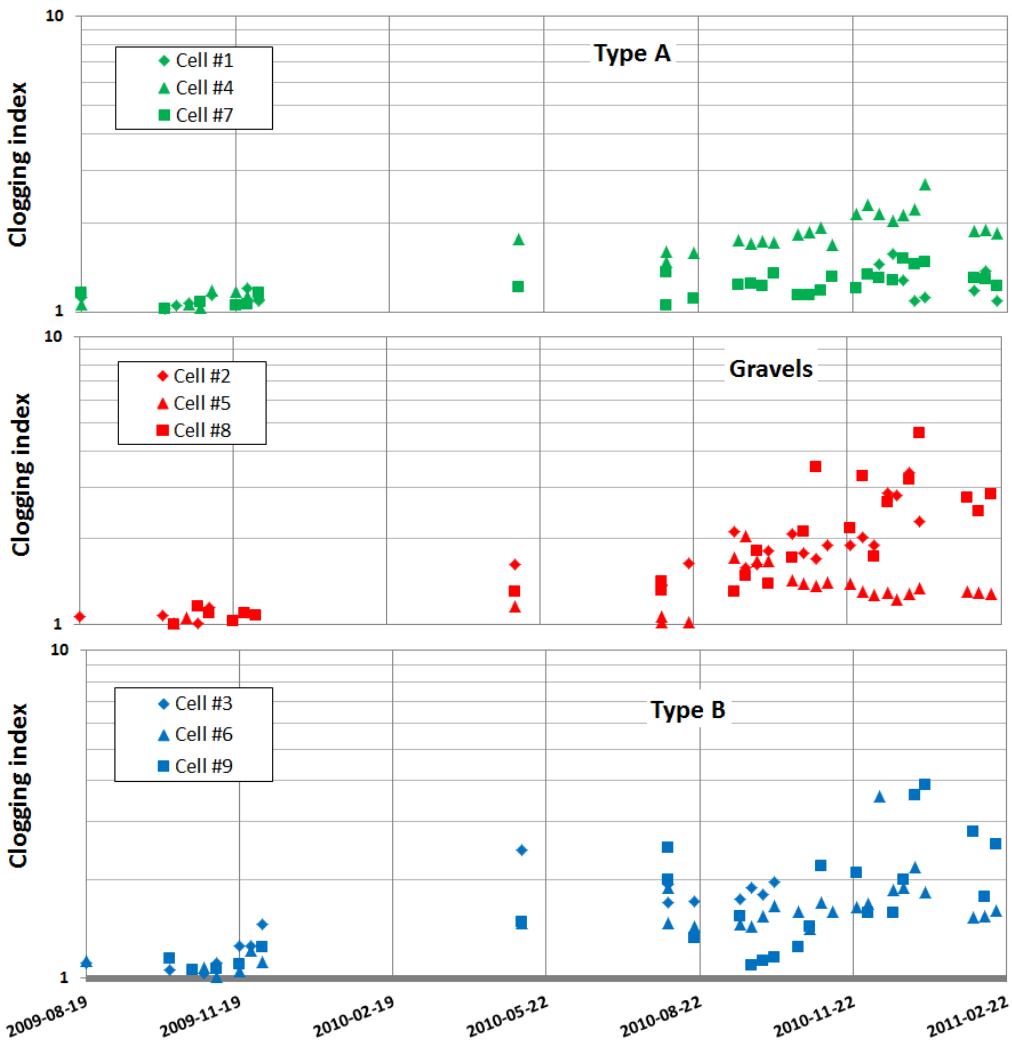

Figure 8. Clogging index

4.4 Visual Observations

Although a shiny black film of biomass could be observed in the gravel and as well as on the geotextile of the tubular drainage geocomposite, connected void spaces were still existent, allowing water to flow through the gravel and the geocomposite. These observations were consistent within the entire set of experiments ran. No visual evidence of buckling or damage of the pipes arising from the combination of leachate exposure and normal load could be observed. Examples of the dismantled drainage components are presented in Figures 9, 10, and 11.

5. DISCUSSION AND CONCLUSIONS

A thorough literature review was conducted regarding the regulatory required and actual drainage capacity of the LCS over the life of a "dry tomb" landfill. This literature review led to the conclusion that leachate flow potentially reaching the leachate collection layer of a "dry tomb" landfill is significantly less at the end of its lifespan, than what is required in the early stages of its lifespan. This particular observation allowed for some flexibility regarding the long term performance of geocomposite drainage layers with respect to chemical and biological clogging. Specifically, the highest anticipated leachate supply rates are anticipated during the early stages of the landfill; while once the final cover is installed the anticipated leachate supply rates have significantly dropped off.

This particular observation is basically in line with the second component of this research; which shows that although clogging increases over time; the drainage media may not completely clog, thus still allowing the reduced leachate supply to be removed from the bottom liner and meeting the set goals of maintaining the hydraulic head below the prescribed threshold (typically 0.3 m).

Figure 9. Gravel in cell 8.

Figure 10. Side view of the geocomposite in cell 4 (type A).

Figure 11. Side view of the geocomposite in cell 7 (type A).

On the other hand, experimental confirmation was presented herein that a tubular drainage geocomposite incorporating a geotextile treated with silver ions as a biocide agent can remain functional for up to 18 months, when exposed to leachate in representative conditions as what would be present at the bottom of a LCS in an active landfill classified as 'class 2' (municipal solid waste and non-hazardous industrial waste) under the French regulation. Both styles of tubular drainage geocomposites and the gravel used as the control did not experience complete clogging to the point they would be no longer functional after 18 months of testing. However, it was not possible to detect any statistical difference in clogging between the various configurations due to the preferred monitoring strategy.

Based on these considerations, it is possible to conclude that replacement of 0.50 m of gravel by a tubular drainage geocomposite and 0.30 m of gravel represents a solution which can meet the performance-based regulatory requirements related to LCSs in dry tomb landfills in many jurisdictions, with the following assumptions:

- The system composed of the drainage geocomposite + gravel layer is designed to fulfill the drainage requirements prevailing at the initial stage of the life of the landfill, when mainly rainfall water is to be drained, and
- The 0.30 m gravel layer is designed to fulfill the drainage requirements prevailing after 18 months, which is only a fraction of the initial requirements.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. Melissa Chappel, Ph.D. (CTT Group), for fruitful discussions regarding regulatory requirements related to drainage layer performance requirements prevailing on the North American Market.

REFERENCES

Bellenfant G. (2009). Modélisation de la production de lixiviat en centre de stockage de déchets ménagers, Thèse de doctorat présentée à l'INPL, 178 pages.

California Code of Regulations, Title 27, Environmental Protection—Division 2, Solid Waste.

Environmental Protection Agency (1993) Criteria for Solid Waste Disposal Facilities : A Guide for Owner's/Operators (EPA-530-SW-91-089).

Fourmont S., Bloquet C., Haddani Y. (2008). Partial replacement of the granular layer at the bottom of a landfill: short and long term monitoring of drainage geosynthetics. EuroGeo 4, United Kingdom, 6 pages.

Giroud, J. P., Zhao, A., Tomlinson, H. M. & Zornberg, J. G. (2004). Liquid flow equations for drainage systems composed of two layers including a geocomposite. Geosynthetics International, 11, No. 1, 43–58

Government of Alberta (2010). Standards for Landfills in Alberta, Government of Alberta.

Government of Newfoundland and Labrador (2010). Guidance Document: environmental Standards for Municipal Solid Waste Landfill Sites, Government of Newfoundland and Labrador, St. John's.

Koerner, G.R., Koerner, R.M. (2006). Long term temperature monitoring of geomembranes at dry and wet landfills. *Geotextiles and Geomembranes* 24:72-77.

NF EN 9864 (2005). Géosynthétiques - Méthode d'essai pour la détermination de la masse surfacique des géotextiles et produits apparentés.

NF EN ISO 12958 (2010). Géotextiles et produits apparentés - Détermination de la capacité de débit dans leur plan

GRI Standard-GC8 (Standard guide for determination of the allowable flow rate of a drainage geocomposite, 2001).

Ontario Ministry of the Environment (1998). Landfill standards: a guideline on the regulatory and approval requirements for the new or expanding landfill sites, Ontario Ministry of the Environment, Ontario Regulation 232/98. The Queen's Press, Toronto.

Schroeder, P.R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W. and Peyton, R.L. (1994), "The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3", EPA/600/R-94/168b, U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Cincinnati, OH.

Rowe R.K. (2005). Long term performance of contaminant barrier systems, *Géotechnique* 55: 631-678.

Saunier P., Ragen W., Blond E. (2010). Assesment of the resistance of Draintube drainage geocomposites to high compressive loads. *9th International Conference on Geosynthetics*, Brazil.

Zhao A., Blond E., Recalcati P. (2012). Drainage Geonet Composites and Performance Assessment. EuroGeo 5, Valencia, Spain (in press).