Quality Control of Non-Woven Geotextiles Used in a Drainage System in an Old Remedial Landfill

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Abstract: For the past 40 years, non-woven geotextiles have been used as filters and drainage materials in geo-environmental works, especially on sites such as municipal waste landfills. Proper selection of non-woven geotextile filter layers is essential to ensure efficient operation and durability of drainage systems (Koda 2000). Geotextiles are easy to transport and install, their main advantage is to help to minimize clogging effect of drainage. The growing use of geotextiles in environmental projects needs research on performance of geotextiles in leachate collection systems on landfills. It appears that non-woven geotextiles may not drain water as effectively as was initially expected. This paper presents results of laboratory tests of water permeability, in the normal direction to the plane of unworn and worn non-woven geotextile samples taken from the Radiowo landfill after more than 15 years of exploitation. The permeability tests were performed under different loads. The measurements were conducted according to national standards. The aim of the research was to determinate water permeability under various exploitation and loading conditions. The results obtained allowed to trace changes in water permeability of non-woven geotextile samples and to verify the effectiveness of applied geofilters on old municipal-waste landfill conditions.

INTRODUCTION

Geotextile can be defined as „a textile material used in geo-environment". Geotextiles include non-woven and woven polymeric materials as well as natural materials, e.g. jute, manufactured using textile processes (Nahar et al. 2010). Non-woven geotextiles are used for filtration, drainage, separation and reinforcing (Palmeira and Tatto 2015, Liu and Chu 2006, Iryo and Rowe 2003).

The filtration and drainage functions of geotextiles are especially desirable in waste landfills (Palmeira and Gardoni 2000). Compared to granular drainage layers these materials are cost-effective, also the use of traditional natural materials (gravel and sand) is difficult due to restrictions on their exploitation or their scarcity in a given region (Bergado et al. 2001, Bhandari and Han 2010, Hong and Wu 2011, Palmeira et al. 2008, Palmeira and Silva 2007, McCartney et al. 2005). However, filter layers and drainage in landfills are exposed to more severe clogging mechanisms than in other types of engineering works. Leachate is a complex mixture that may cause chemical, biological and physical clogging of filters, the problem is more complicated because of the characteristics and nature of the fluid (Palmeira et al. 2008, Palmeira and Gardoni 2000). For example, the heavy nutrient loading associated with movement of leachate through the drain causes microbial activity, leading to various forms of slime formations associated with biologically induced precipitation of minerals to form clogged material. Biofilm may result in total or partial occlusion of void spaces of the drainage medium and reduce the hydraulic conductivity (Fleming and Rowe 2004). Unfortunately, the potential for clogging in landfills in practice is not fully understood (McIsaac and Rowe 2007). As observed by Koerner (1997), many of test methods are not fully standardized as far as their test procedures are concerned (Nahar et al. 2010). Of course, phenomena such as clogging can be observed not only in drainage systems in landfills. A geotextile structure can be deformed during or after its installation in each drainage system by bacterial growth and mineral precipitation, and also by soil migrating between its fibres (Koerner and Koerner 2015, Palmeira and Gardoni 2000, Rollin and Lombard 1988).

Non-woven geotextiles used in filtration and drainage applications should meet the following important objectives: permeability, retention and anti-clogging capabilities. The permeability criterion requires large pore sizes to ensure suitable water discharge whereas geotextile pores should be small enough to retain a significant amount of soil particles. Geotextile filter design methods, in order to guarantee retention capability, are based on relationship between soil grain size and a characteristic pore size (retention criteria). Permeability is ensured by examining the relative permeability of geotextile and the soil (permeability criteria). Regrettably, clogging may occur despite acceptable design criteria. For that reason, the clogging potential of the soil-geotextile or leachate-geotextile system is necessary as a criterion for use of non-woven geotextile in hydraulic and drainage applications (Wu et al. 2008).

The objective of this paper is to examine water permeability in normal direction to the plane of unworn and worn geotextile samples taken from the drainage ditches at the Radiowo landfill (Fig. 1) under a compressive stress of 2, 20 and 200 kPa. The landfill is situated in the northwestern part of Warsaw, capital City of Poland. The main role of the ditches 2 m wide at the bottom with 1:1.5 slopes was to collect leachate from the landfill and precipitation water from the slopes. At the landfill leachate water was discharged into a recirculation system. This design was provided favourable hydraulic conditions by forcing a lowered groundwater level inside the peripheral cut-off wall in relation to the natural water level around the landfill site (Fig. 1). Leachate was collected through the retention trenches and passed on to storage tanks, in turn, water was pumped to the crown of the landfill (Koda 2000). Drainage/retention ditches were made in 2000 and have been operated without any problems for over 12 years. In 2011, a plan was made to substitute retention ditches with a pipe drainage system and to direct leachate into municipal sewage system. During the modernization works, samples of the analyzed geotextile were collected.

Examining water permeability helps to affirm that clogging affects hydraulic properties of geotextile used in drainage applications, because water permeability is a parameter that determines the application usability of this product in drainage systems.

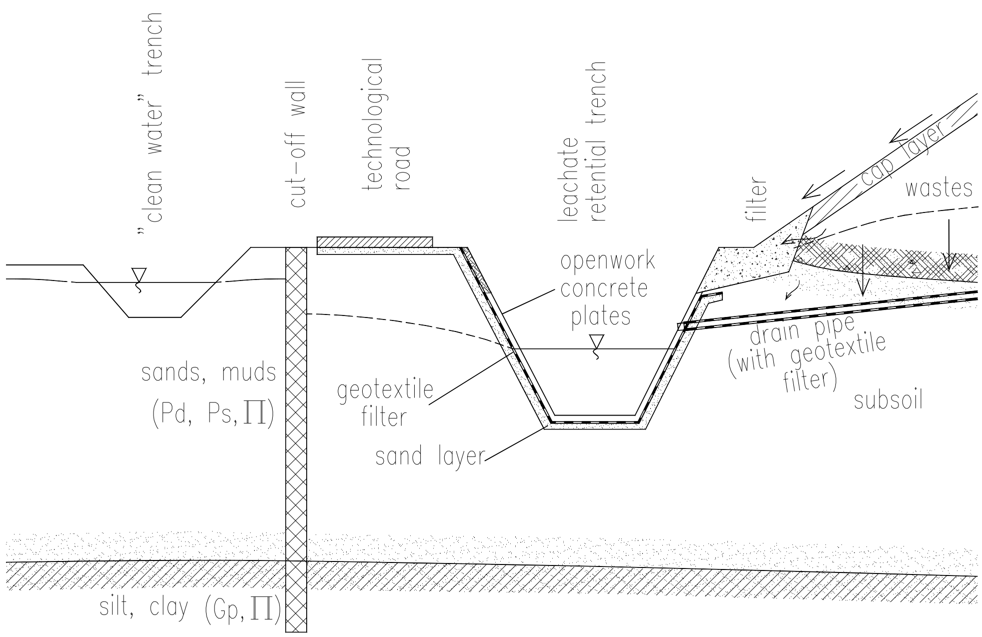


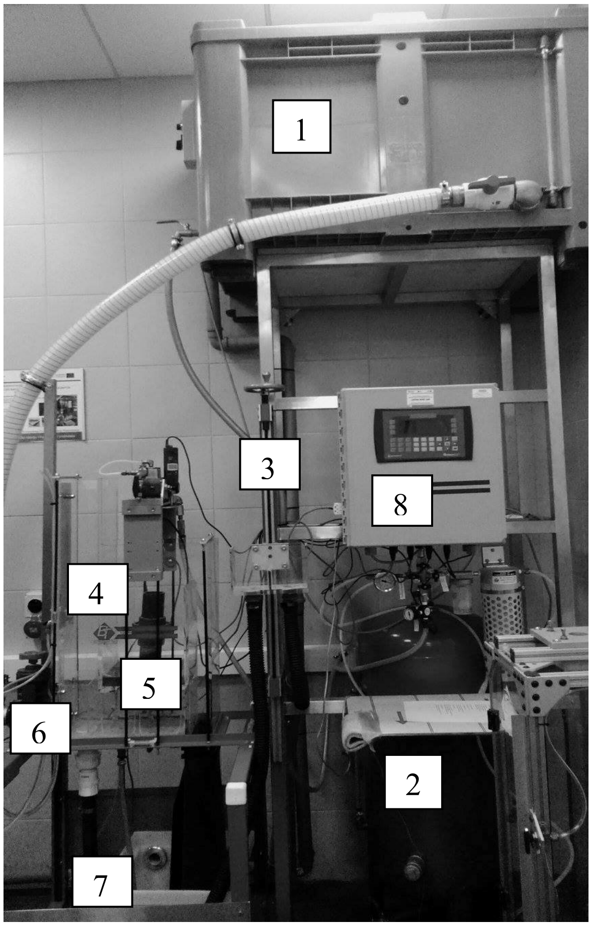
FIG. 1. Scheme of drainage ditches construction at Radiowo landfill site (Koda and Paprocki 2000).

TEST PROGRAM

Equipment and methodology used in the test

The experimental work consisted in determining water permeability characteristics perpendicularly to the plane with and without a load in specified time. Fig. 2 presents the laboratory equipment, located in the Laboratory Water Center at Warsaw University of Life Sciences.

Testing the velocity of flow without the load involved measuring the water flow velocity perpendicularly to the plane of a geotextile sample, in a specified time and an appropriately set hydraulic gradient.



Legend:
1- Water tank
2- Water deareation tank
3- Adjustment of head loss
4- Glass device
5- Sample holder (Fig. 3)
6- Throttle valve
7- Water collection tank
8- Recording equipment

FIG. 2. Laboratory equipment used for determination of geotextile water permeability characteristics in normal direction to the plane.

In the case of experiments without load, the hydraulic gradient on the specimen was 56, 42, 28 and 14 mm. The surface of each of specimen was 0.001963 m^2. The specimens were placed under water containing a wetting agent at laboratory temperature, and were left to saturate for 24 hours. Then the specimen was placed in the cylinder. A supporting mesh was used in the cylinder to avoid deformation of material by the pressure of water flowing through the holder installed in the device measuring water permeability (Fig. 3). The actual volume of water was determined based on the average from three readings/measurements.

Testing the velocity of flow for specimens under load was carried out in a similar manner, with the values of hydraulic thrust being subsequently: 50, 60 and 70 mm. Levels of glass aggregate and supporting steel meshes were used in the cylinder to avoid deformation of material and reproduce the soil/ground conditions similar to the site (Fig. 3). To the prepared specimen a piston was applied, with the loads of subsequently: 2, 20 and 200 kPa according to EN ISO 10776:2012.

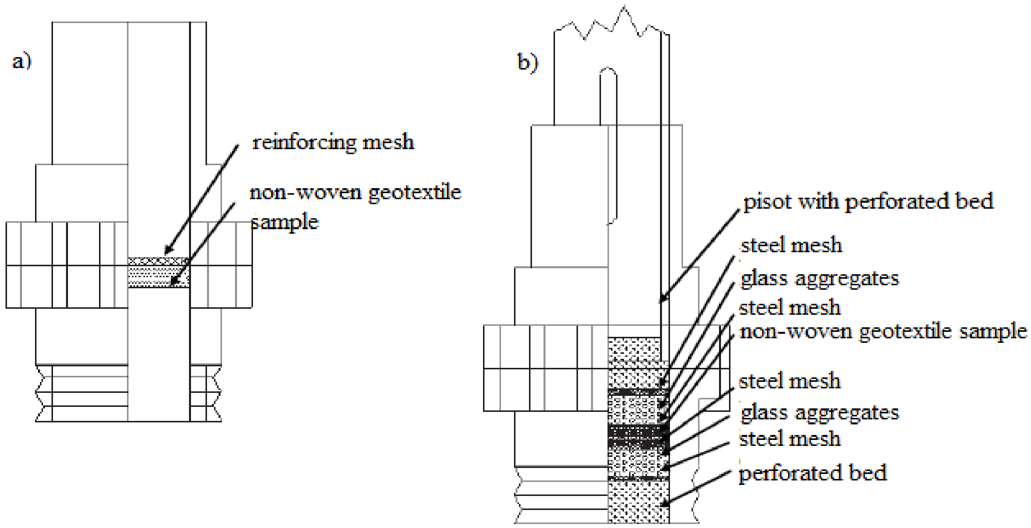


FIG. 3. Cylinder with tested specimen: a - without load, b - under load (Stępień et al. 2012).

Materials

The study used unworn (Fig. 4a) and worn non-woven geotextile (Fig. 4b). The worn geotextile was taken from drainage ditches at Radiowo landfill (Fig. 1). Tests of worn non-woven needle-punched polypropylene geotextile with surface mass of 500 $g \cdot m^{-2}$ were carried out 12 years after geotextile had been placed in the system, and the results were presented by Stępień et al. (2012). Then the samples were stored for 3 years in a constant humidity chamber and were subsequently tested once again. The results of those tests are presented in this paper.

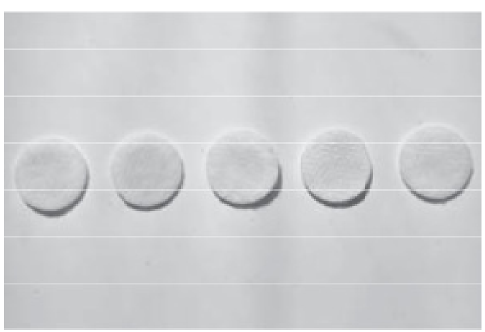
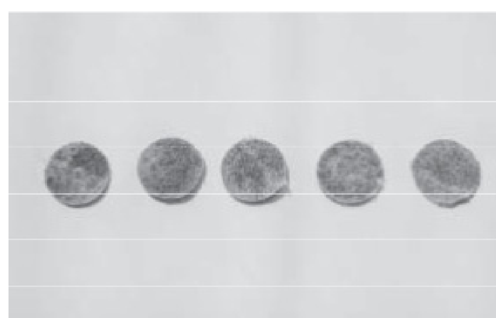
a)  b) 

FIG. 4. Geotextile samples after test: a – unworn, b - worn.

RESULTS AND DISCUSSIONS

After the flow tests without the load, carried out for each sample, with a determined hydraulic thrust, the flow velocity was calculated using the following empirical formulae (PN-EN ISO 11058:2010).

$$v_{20} = \frac{V \times R}{A \times t}\ [m \cdot s^{-1}] \qquad (1)$$

where:

$$R_t = \frac{\eta_T}{\eta_{20}} = \frac{1{,}762}{1 + 0{,}0337T + 0{,}00022T^2}\ [-] \qquad (2)$$

$$\eta_T = \frac{1{,}78}{1 + 0{,}0337T + 0{,}00022T^2}\ [mPa \cdot s] \qquad (3)$$

V – water volume measured [m^3],
R_t –correction coefficient for water of temperature of 20ºC,
T –water temperature [ºC] during the tests,
A- exposed specimen area [m^2],
t - time measured to achieve the volume V [s],
η_T - dynamic viscosity at TºC [mPa·s] test temperature,
η_{20} - dynamic viscosity at 20ºC [mPa·s].

For specimens tested under the load of 2, 20, 200 kPa, the EN ISO 10776:2012 standard recommends to calculate the flow velocity indicator using the following formula:

$$v_{N50/\sigma} = \frac{V}{A \times t}\ [m \cdot s^{-1}] \qquad (4)$$

Having compiled test results, the flow velocity indicator (V_{H50}) was calculated for hydraulic thrust equal to 50mm, based on the obtained curve equation. Also water permeability coefficient (k_n) was calculated for the same value of hydraulic thrust:

$$k_n = \frac{V \times g}{A \times t \times \Delta h}\ [m \cdot s^{-1}] \qquad (5)$$

where:
g –thickness of tested material under given load [m],
Δh - pressure differential under and over the specimen, expressed as the height of water column [m].

Based on statistical analysis, Fig. 5 presents the relationship between the velocity of water flow and the hydraulic thrust for tested worn and unworn geotextile samples.

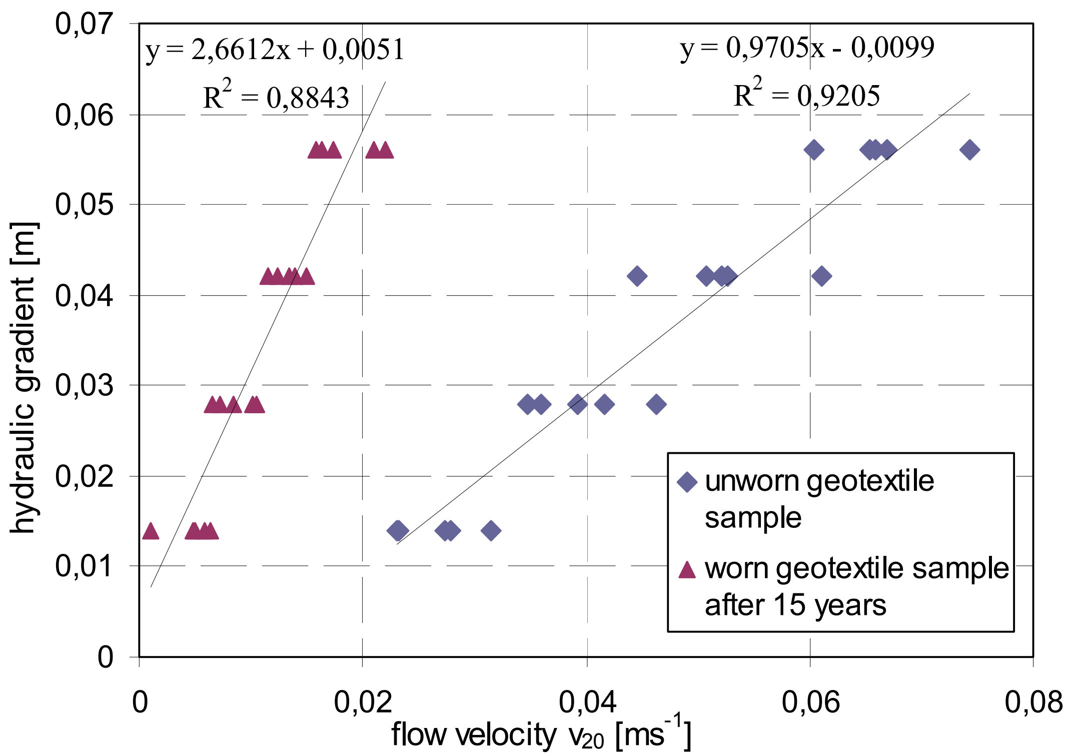


FIG. 5. Flow velocity characteristics for tested non-woven geotextile samples.

Based on the obtained results, it was concluded that the flow velocity for the worn geotextile is roughly 4 times lower than the flow velocity for the unworn one. The decrease in permeability of the worn geotextile results from both mechanical and biological clogging of the drainage systems of municipal landfills (Rowe and Yu 2010, Gordoni, et al. 2010). Table 1 compares the calculated flow velocity coefficients for the geotextiles examined under load.

After 3 years of sample storage in the constant humidity chamber, water flow velocity coefficient at the gradient of 50 mm decreased by 2 % for the unloaded geotextile, and decreased by 1, 11 and 5 % for the geotextiles subjected to respective loads of 2, 20 and 200 kPa. This indicates that even during storage biological processes occur in the geotextile and promote decrease of the material's water permeability.

Table No. 1. The values of flow velocity index for tested non-woven geotextile samples unworn and under load after 12 years (Stępień et al. 2012) and after 15 years of exploitation.

Load (kPa)	**Flow velocity index V_{H50} ($m \cdot s^{-1}$)**			**Decrease of flow velocity index (%)**		
	Non-woven geotextile			Non-woven geotextile		
	unworn	worn after 12 years	worn after 15 years	unworn	worn after 12 years	worn after 15 years
Without load	0.0642	0.0177	0.0165	100	72	74
2	0.0285	0.0102	0.0094	56	42	43
20	0.0236	0.0087	0.0062	63	51	62
200	0.0129	0.0049	0.0038	80	72	77

Coefficients of water permeability are presented in Table 2. Work presented by Giroud (1982) suggests that the permeability of the geotextile installed in a soil must be only 10 times greater than the soil permeability at all times. At the Radiowo landfill, the permeability coefficient of the soil adherent to the geotextile is $k_{soil}=5 \cdot 10^{-6}–1 \cdot 10^{-5} m \cdot s^{-1}$, hence the condition is met even for the most unfavourable case, i.e., a most clogged geotextile under the maximum load of 200 kPa.

Table No. 2. The values of water permeability coefficient for tested non-woven geotextile samples under different loads.

Load (kPa)	**Permeability coefficient of normal direction to the plane k_g ($m \cdot s^{-1}$)**			**Decrease of permeability coefficient of normal direction to the plane (%)**		
	Non-woven geotextile			Non-woven geotextile		
	unworn	worn after 12 years	worn after 15 years	unworn	worn after 12 years	worn after 15 years
Without load	0.0080	0.0029	0.0020	100	64	74
2	0.0034	0.0019	0.0011	57	34	45
20	0.0027	0.0016	0.0007	66	45	65
200	0.0014	0.0008	0.0004	82	72	80

CONCLUSIONS

Mechanical, biological and chemical elements may alter hydraulic properties of the geosynthetics, therefore, proper determination of the content of the leachates filtered through the material is important. In the case of the investigated polypropylene geotextile, the variability of the clogging was caused by varied size of the general suspended solids present in the leachates flowing through that material and by the conditions of varied loading.

The tests revealed that the decrease in the water permeability coefficient of the geotextile was ca. 80% after 15 years of use, and the decrease was also present under storage conditions. Even precisely controlled storage conditions are not sufficient to prevent progressing growth of microorganisms. Such decrease did not restrict operation of the drainage system, however.

Decrease in the geotextile's water permeability under load should be also noted in the case of landfill drainage systems. It is of importance due to the fact that the systems are often bearing severe mechanical load of landfilled waste layers.

The investigation highlights some deficiencies of the currently applied standards. In the case of Equation 4, water temperature is not accounted for, although it affects viscosity. It should therefore be noted that it is necessary to introduce new methodology that would include investigation of water permeability under load.

REFERENCES

Bergado, D.T., Youwai, S., Hai, C.N. and Voottipruex, P. (2001). "Interaction of Nonwoven Needle-Punched Geotextiles under Axisymmetric Loading Conditions." *Geotextiles and Geomembranes* 19: 299-328.

Bhandari, A. and Han, J. (2010). "Investigation of geotextile-soil interaction under a cyclic vertical load using the discrete element method." *Geotextiles and Geomembranes* 28: 33-43.

EN ISO 10776:2012 "Geotextiles and geotextile-related products. Determination of water permeability characteristics normal to the plane, under load."

Fleming, I.R. and Rowe, R.K. (2004). "Laboratory studies of clogging of landfill leachate collection and drainage systems." *Canadian Geotech. Journ.* 41: 134-153.

Gardoni, M.G.A., Senra Prado, T. and Cyrino Neto, D. (2010). "Evaluation of the Biological Clogging on the Geotextile Drainage Systems of landfills." *Proc. 6th Intl. Congress on Environmental Geotechnics,* Vol. 2, New Delhi: 919-922.

Giroud, J.P. (1982). "Filter criteria for geotextiles." *Proc. 2nd Int. Conference on Geotextiles*, Int. Geot. Soc., Vol. 1, Las Vegas: 103-108.

Hong, Y.-S. and Wu, Ch.-S. (2011). "Filtration behaviour of soil-nonwoven geotextile combinations subjected to various loads." *Geotextiles and Geomembranes* 29: 102-115.

Iryo, T. and Rowe, R.K. (2003). "On the hydraulic behavior of unsaturated nonwoven geotextiles." *Geotextiles and Geomembranes* 21: 381-404.

Koda, E. (2000). “Design of leachate drainage systems in old sanitary landfills.” *Annals of Warsaw Agricultural University, Land Reclamation* 29: 97-106.

Koda, E. and Paprocki P. (2000). “Durability of leachate drainage systems in old sanitary landfills.” *Proc. of the 3th Intl. Conference of Filters and Drainages in Geotechnical and Environmental Engineering*, Warsaw, Balkema ed., 215-222.

Koerner, R.M. (1997). "Designing with Geosynthetics." *Geo-textile Fabrics Report*: 98-120.

Koerner, R.M. and Koerner, G.R. (2015). "Lessons learned from geotextile filter failures under challenging field conditions." *Geotextiles and Geomembranes* 43: 272-281.

Liu, L.F. and Chu, C.Y. (2006). "Modeling the slurry filtration performance of nonwoven geotextiles." *Geotextiles and Geomembranes* 24: 325-330.

Mc Cartney, J.S., Kuhn, J.A. and Zornberg, J.G. (2005). "Geosynthetic Drainage Layers in Contact with Unsaturated Soils." *Proc. of the 16th ISSMGE Conference: Geotechnical Engrg. in Harmony with the Global Environment*, Osaka.

McIsaac, R. and Rowe R.K. (2007). "Clogging of Gravel Drainage Layers Permeated with Landfill Leachate." *J. Geotechnical & Geoenv Engrg.*, Vol. 133 (8): 1026-1039.

Nahar, K., Ferdous, W., Mofiz, S.A. and Ferdous, K. (2010). "A Simplified Mechanism for the Vertical Permeability Test of Geo-textile." *Intl. J. of Civil & Environmental Engrg. IJCEE-IJENS*, Vol. 10, No. 02: 29-33.

Palmeira, E.M. and Gardoni, M.G. (2000). "The influence of partial clogging and pressure on the behaviour of geotextiles in drainage systems.” *Geosynthetics Intl.*, Vol. 7, Nos. 4-6: 403-431.

Palmeira, E.M., Remigio, A.F.N., Ramos, M.L.G. and Bernardes, R.S. (2008). "A study on biological clogging of nonwoven geotextiles under leachate flow." *Geotextiles and Geomembranes* 26: 205-219.

Palmeira, E.M. and Silva, A.R.L. (2007). "A study on the behaviour of alternative drainage systems in landfills." *Introd. Lecture in Proc. of the 11th Intl. Waste Manag. and Landfill Symp.*, Cagliari: CISA, Environ. Sanitary and Engrg. Centre, Italy.

Palmeira, E.M. and Tatto, J. (2015). "Behaviour of geotextile filters in armoured slopes subjected to the action of waves." *Geotextiles and Geomembranes* 43: 46-55.

PN-EN ISO 11058:2010 Geotextiles and geotextile-related products - Determination of water permeability characteristics normal to the plane, without load (in Polish).

Rollin, A.L. and Lombard, G. (1988). "Mechanisms Affecting Long-Term Filtration Behavior of Geotextiles." *Geotextiles and Geomembranes* 7: 119-145.

Rowe, R.K. and Yu, Y. (2010). "Factors Affecting the Clogging of Leachate Collection Systems in MSW Landfills" *Proc. of the 6th Intl. Congress on Environmental Geotechnics,* Vol. 1, New Delhi: 3-23.

Stępień, S., Osiński, P. and Koda, E. (2012). "Laboratory tests of water permeability under load of non-woven geotextile exploited at landfill site". *Acta Sci. Pol. - Architectura* 11(4): 41-50.

Wu, Ch-S., Hong Y.-S. and Wang, R.-H. (2008). "The influence of uniaxial tensile strain on the pore size and filtration characteristics of geotextiles." *Geotextiles and Geomembranes* 26: 250-262.