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Section: Environmental protection

Research of landfill drainage layer clogging

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Abstract

Landfills are the primary endpoints for the municipal solid waste materials after reduction, reuse, and recycling. The leachate drainage filling conductivity decrease in municipal waste landfills is researched and various solutions are offered. The leachate drainage filling conductivity decrease in municipal waste landfills is researched and various solutions are offered, but the problem remains. For modelling the leachate transport and clog mass accumulation within the porous was used a numerical model BioClog. The objective of all study is to establish the filling porosity change over a certain period of time by filtering the leachate from municipal waste landfills through experimental test columns, filled with various fillings and to compare with results, which are calculated with sophisticated mathematic model BioClog. All results are counted of tree different times (after 1 year, 15 and 30 years). These different times helps to compare the laboratory results. Also it is helps to be assumed clogging processes. Experiments and computer modelling results confirms the conclusion that tyre shreds are a material recommendable for the formation of leachate drainage layer in municipal waste landfills.

Keywords: landfill; lechate; drainage clogging.

Nomenclature

t_c	time of service (s)
L	length of leachate drainage layer (m)
B	thickness of drainage layer (m)
f_{Ca}	fraction of the calcium concentration in the clog material
ρ_c	density of clog material
v_f	specific clog mass volume
q_0	average top of infiltration
c_{L1}	calcium concentration

1. Main text

Landfills are the primary endpoints for the municipal solid waste materials after reduction, reuse, and recycling. Leachate is generated within the landfills from the percolation of water through the waste, release the biodegradation of organic waste and of moisture in the waste. Leachate contains both dissolved elements and suspended particles and compounds, many of which have the potential to impact the environment and human health. Many regulations in Europe Uninion require a low permeability liner systems (a geomembrane and compacted clay liner, or a geomembrane and geosynthetic clay liner) to be installed on the base and side slopes below the waste to minimize the migration of leachate to underground layers [2].

The leachate drainage filling conductivity decrease in municipal waste landfills is researched and various solutions are offered, but the problem remains, as over a longer period of municipal waste landfill operation the composition of municipal waste changes, thus affecting the composition of leachate which, in its turn, has a direct impact on clogging.

There are many factors that will influence leachate mounding within the lechate collection systems including: leachate chemistry (effect clogging and a reduction in the hydraulic conductivity of the drainage, leachate infiltration rate, hydraulic conductivity of the drainage material, pipe spacing, slope of te drainage layer to the pipes, and presence of a filter-separator

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layer between the waste and granular drainage layer. Analytical solutions have been proposed for estimating the thickness of the leachate mound within a homogeneous drainage material [7].

The world's attention was drawn to the problems only when the waste stayed dumped in the landfills for several decades. It was researched and various solution possibilities were analysed by I. R. Fleming, R. K. Rowe, D. R. Cullimore, J. F. Van Gulck, R. McIsaac, M. D. Amstrong, A. J. Cook. Latter scientists made wide and detailed analyses of Canadian landfills. German scientists L. Peeling, M. Brune, J. P. Giroud, as well as A. Paksy, W. Powrie, A. Knox from the United Kingdom also deal with the problems related to municipal waste landfills, and while the first group mentioned give more attention to the analysis of the problems and their causes, the second one develops new technologies to improve drainage layer functionalities.

For modelling the leachate transport and clog mass accumulation within the porous, a numerical model 'BioClog' was first developed by Cooke *et al.* [4] and subsequently updated after five years by Cooke and Rowe [3]. BioClog first was created 1D model and used by Cooke *et al.* [4]. The results showed that the volatile fatty acids and calcium concentrations were well estimated by the model when compared to the measured values. The calculated amount of clog mass within the columns coincided well with the measured laboratory results. Cooke and Rowe [3] employed BioClog-2D to model mesocosms and found that te model estimated the clog mass well in the upper regions of the saturated drainage layer but underestimated the clogging in the lower regions of saturated drainage layer [6].

The objective of all study is to establish the filling porosity change over a certain period of time by filtering the leachate from municipal waste landfills through experimental test columns, filled with various fillings and to compare with results, which are calculated with sophisticated mathematic model BioClog [9].

The main aims of this research:

- calculate the porosity changes of different composition of the column fillings;
- identify the thickness of accumulated layer on the column filling material;
- identify the change of porosity over time;
- compare laboratory investigation and modelling results.

Clogging processes are long-term ones, therefore it is important to employ mathematical models, describing clogging processes in the drainage layer of municipal waste landfills, to forecast the results of the researches made as well as for the evaluation of their reliability. The BioClog model provides a means of performing numerical modeling of leachate collection systems from landfills. However, the BioClog model is sophisticated that it is not likely to be used in regular design. A new practical technique is developed and calibrated against the sophisticated numerical model to estimate the life of landfills lechate collection systems [3, 10].

The landfill drainage layer is considered to be failure when changes the amount of leachate in leachate collection placement. Leachate mounding in landfill is mostly controlled by the:

1) leachate characteristics,
2) leachate infiltration rate,
3) drainage pipe spacing and slope to the pipes,
4) grain size distribution of the granular material (with large, uniformly graded, gravel giving much larger pore throats between voids that need to be clogged before the performance is significantly degraded),
5) hydraulic conductivity of granular porous media,
6) continuous geotextile layer.

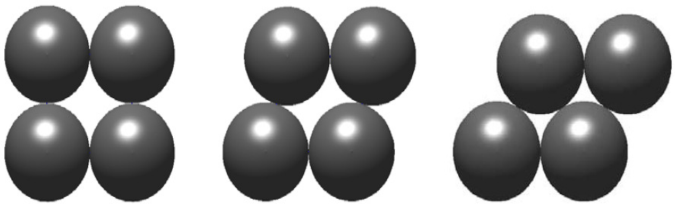
Several equations based on the simplified assumptions are used to predict the leachate head acting on the landfill bottom liner for a given infiltration rate, pipe spacing, base slope, and initial. Over the past decade, a numerical model (BioClog) for estimating the clogging of porous media permeated by leachate has been developed [3, 4, 7, 10]. BioClog simulates the growth and loss of five films on the surface of porous media (biofilm arising from acetate, butyrate and propionate degraders, inert biofilm, and inorganic solids film).

Cooke *et al*. (2005b) modelled the clogging of laboratory columns packed with pea gravel (having a similar nominal grain size as 6-mm glass beads) permeated with real landfill leachate. When comparing with the experimental data, it was found that the well estimated were the clog quantities and also volatile fatty acids and calcium concentrations from the pea gravel columns were well estimated by the numerical model. VanGulck and Rowe [9] reported the use of the BioClog to estimate the clogging of laboratory columns filled with 6-mm glass beads and permeated with both synthetic leachate and real leachate. As well as the distribution of clog mass, the changes of acetate, butyrate, and calcium concentrations in leachate were reasonably estimated. Using nominal grain size parameters, the model was better at examining the more uniform particles size than the highly variable particles. However using calibrated parameters, the BioClog provided quite reasonable fits to the porosity of the variable filling of columns over the test period until column termination.

Based on the field and laboratory finding that the calcium carbonate is the dominant fraction in the clog formation under anaerobic conditions in a landfill, Rowe and Fleming (1998) developed a practical model to estimate the service life (t_c) of leachate collection systems where relatively uniform gravel material is used for the drainage blanket. They conservatively assumed that all calcium entering the drainage layer immediately deposits as calcium carbonate in the system and the fraction (f_{Ca}) of the calcium in the clog material is constant with time as well as the bulk density (ρ_c) of the clog material. If the calcium concentration (c_{L1}) is assumed to be constan different packing arrangements in porous mediat with time, the service life of the collection system can be estimated directly from:

$$t_c = \frac{(L+2a)B\rho_c f_{Ca} v_f}{3q_0 c_{L1} L} \quad (1)$$

where q_0 is the average top infiltration; v_f is the specific clog mass volume (or porosity reduction) which is the difference between the initial porosity of clean porous medium and porosity of clogged porous medium (e. g., a hydraulic conductivity of 10–6 m/s); B is the thickness of drainage layer near the perforated drainage pipes; L is the length of leachate drainage layer (half of the pipe spacing); a is the length of the zone where clogging is likely to develop to the full thickness of the blanket drain.



a) b) c)

Fig. 1. Three different critical faces in porous media modified from Graton and Fraser 1935 (a) square face; b) specific rhombic face; c) rhombic face) [6]

Basic concept of the Bioclog model was done on Graton and Fraser studies. The main base of the model uses Graton and Fraser (1935) idealized a relatively uniform porous medium as uniform spheres of equal diameter (dg). Under these conditions, there are four stable, regular packing arrangements with three critical faces. These critical faces with four adjacent spheres on the same plane are described as the square face, the rhombic face, and the special rhombic face according to their facial shapes formed from the sphere centers (Fig. 1). The critical faces also determine the packing arrangement of spheres in the porous media. As shown in Figure 2, for eight spheres of equal diameter in three dimensions, there are four different packing arrangements each of which has three control faces in a packing unit, and such packing arrangements are named, with the number and name of critical faces, as: the cubic packing with three square faces the orthorhombic packing with two square faces and one rhombic face; the tetragonal-sphenoidal packing with one special rhombic face and two rhombic faces; the rhombohedral packing with three rhombic faces.

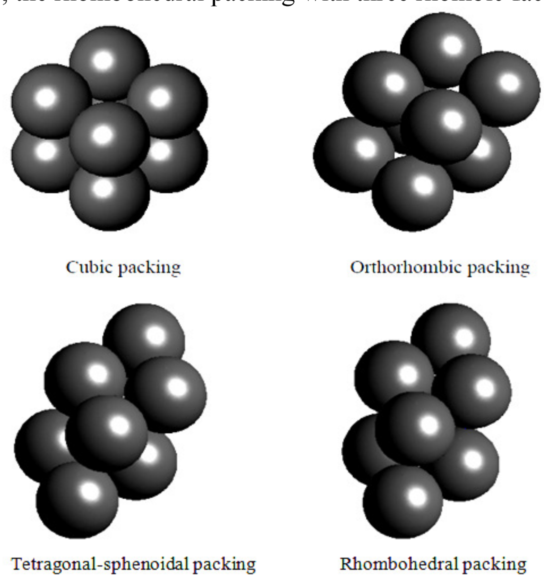


Fig. 2. Different packing arrangements in porous media used in Bioclog [6]

For the experiment, the leachate is taken from the leachate collection well of the municipal waste landfill. At the beginning of the column test the concentration of calcium, iron and suspended solids in the leachate is established.

Column fillings, which were simulated with Bioclog model: (a) gravel (35 – 62 mm granules), b) mixture of rubble with tired shreds, c) mixture of gravel and tired shreds, d) mixture of rubble and asphalt waste e) granite drainage rubble used in Lithuanian landfills).

The leachate passes through different column fillings and is collected individually under each column. 120 ml sample is taken from under each column every month. The method allows observe the changes in calcium, iron and suspended solids concentration. When their quantities decrease in the concentrate, it is possible to conclude, that the materials were trapped in the drainage filling, depositing on the surface of its materials. Thus the pores became smaller, porosity decreases and clogging occurs [1].

The methodology applied to compute the decrease of column filling porosity with BioClog model. The software evaluates the porosity decrease depending on the quantity of materials deposit on the pore surface. The following parameters are inputted into the software to solve the porosity change problem: column height and diameter, size of filling granules, initial filling porosity, one day leachate quantity, calcium concentration in leachate, concentrations of suspended solids. The detailed computation results are graphically plotted by Sigma Pro 8.0 software (Fig. 3).

2. Results

The conductivity decease of drainage systems in municipal waste landfills manifests itself not earlier than after five years of operation or even later making the modelling of conductivity decrease so important. It is very important to use numerical model for forecast the clogging processes in laboratory studies. As clogging processes are very multifunction and is very close with biological processes, therefor it is important to find a correct methodology.

Calcium concentration change, quantity of suspended solids and porosity measuring results obtained during the research were used to compute the forecasted conductivity decrease of the fillings analysed by applying Bioclog software. The in situ and laboratory tests served as the basis of the mathematical model, but the clogging processes were modelled in the saturated medium.

All results are counted of tree different times (after 1 year, 15 and 30 years). These different times helps to compare the laboratory results. Also it is helps to be assumed clogging processes.

The mathematically calculated filling porosity after 365 days, computed by modelling software Bioclog, was in the range from 30% to 42% depending on the material (Fig. 3). The porosity of rubble drainage, rubble drainage and asphalt, rubble drainage and tyre shred as well as of gravel and rubble shred fillings was higher by 2% per cent as the one obtained during laboratory testing. It was only the gravel filling porosity, obtained by the modelling software, which was by 2% lower compared with the test results. The results obtained by the modelling software may not only be compared with the ones of the actual tests; they also arrive to forecast the date after 10, 15 or 20 years.

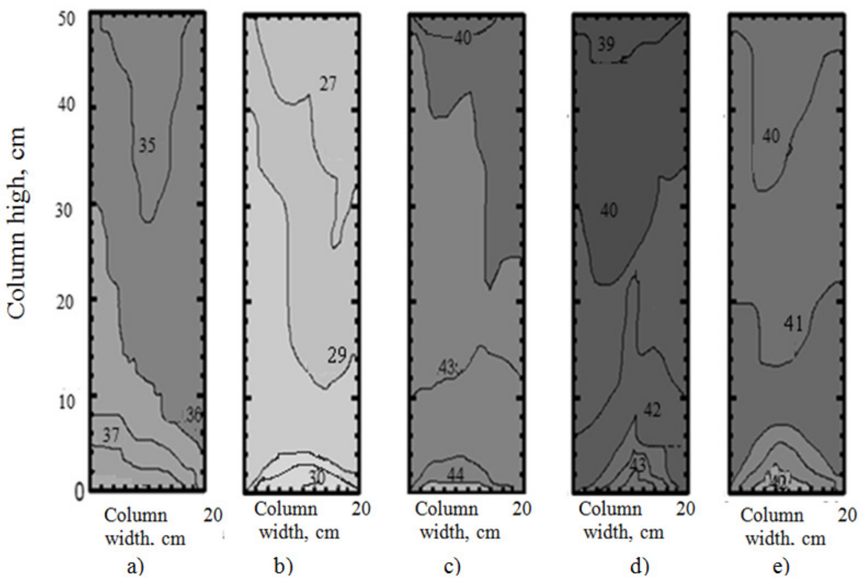


Fig. 3. Changes of porosity after one year in different fillers: a) – rubble used in landfill; b) – gravel mined at Lithuanian quarries; c) – mixture of drainage rubble and asphalt waste; d) – mixture of drainage rubble and tired shreds; e) – mixture of gravel and tired shreds mixture

During long time clogging of column fillings is changing from 23% till 16%. The biggest changes of porosity in different fillings after 15 years varies depend of the physical parameters of material. Figure 4 shows, that porosity of gravel mined at Lithuanian quarries in 15 years will decline from 29 till 16 percent. The different changes of porosity in each filling belong on all parameters, which are written down in the programme. Bioclog model calculates data using different packing arrangements. It's the main reason why in Figure 3–5 the porosity is changing in column length in different dispersion. As the leachate was leaching through column from the top of column, therefore after one year in all test porosity became smaller on the top and less changes on the bottom.

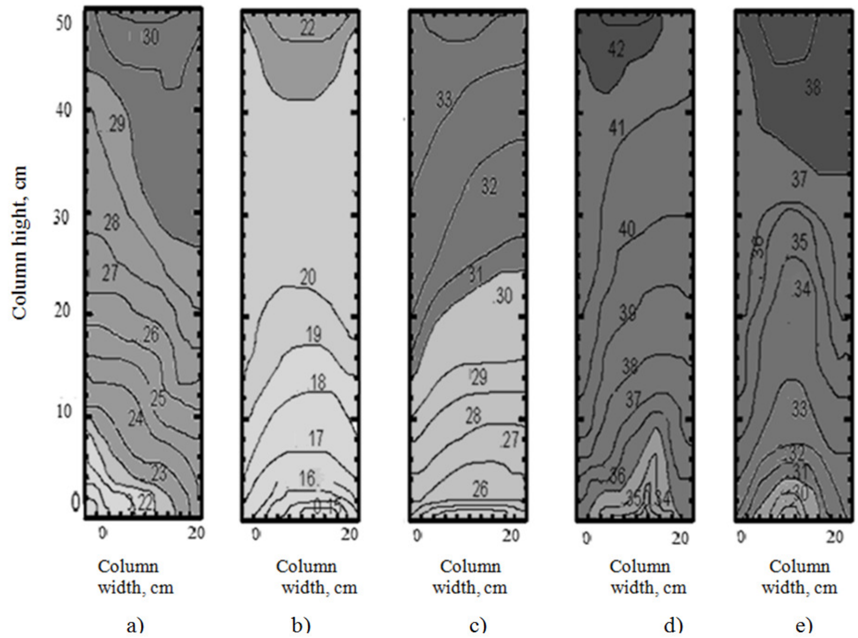


Fig. 4. Changes of porosity after 15 years in different fillers: a) – rubble used in landfill; b) – gravel mined at Lithuanian quarries; c) – mixture of drainage rubble and asphalt waste; d) – mixture of drainage rubble and tired shreds; e) – mixture of gravel and tired shreds mixture

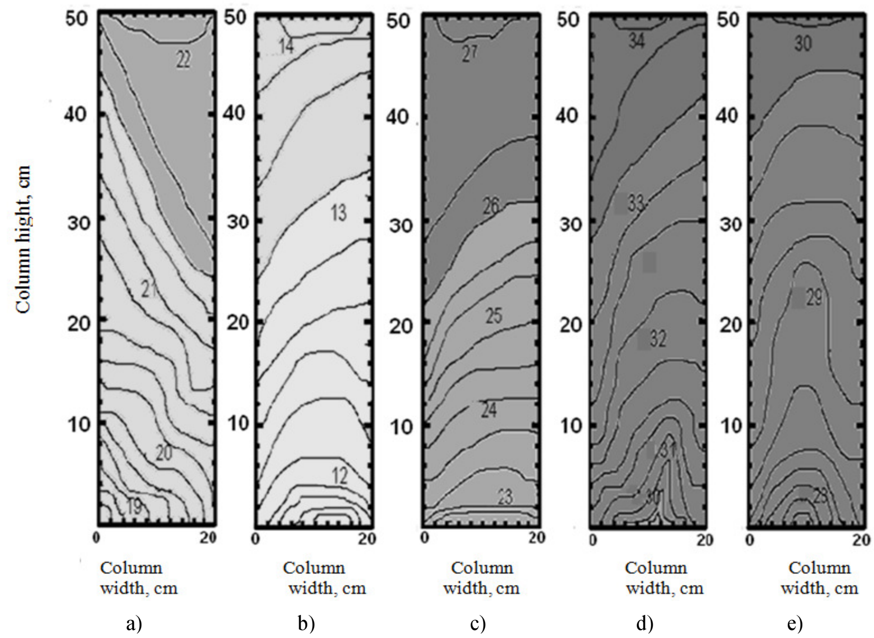


Fig. 5. Changes of porosity after 30 years in different fillers: a) – rubble used in landfill; b) – gravel mined at Lithuanian quarries; c) – mixture of drainage rubble and asphalt waste; d) – mixture of drainage rubble and tired shreds; e) – mixture of gravel and tired shreds mixture

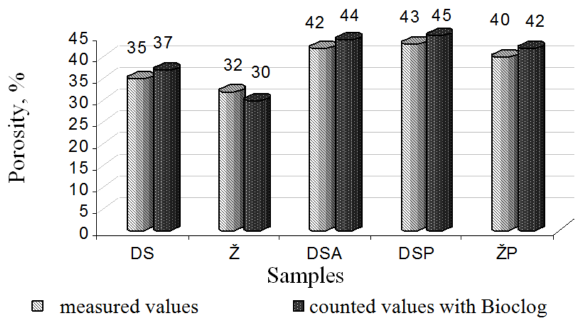


Fig. 6. Comparison of simulation and investigation results (DS – rubble used in landfill; Ž – gravel mined at Lithuanian quarries; DSA – mixture of drainage rubble and asphalt waste; DSP – mixture of drainage rubble and tired shreds; ŽP – mixture of gravel and tired shreds mixture)

As the difference between the data of laboratory testing and modelling was only 2%, it could be maintained that computation of the clogging process development by the software is very precise (Fig. 6).

The drainage layer structure developed, intended for the decrease of clogging processes in municipal waste landfill drainage systems, allows provides for the use of recycled materials (wasted tyred shreds).

3. Conclusions

The use of computer software Bioclog 12 for modelling had allowed to establish the smallest change (decrease) of the leachate collection system porosity over 30 years of landfill operation when it is composed of rubble drainage and tyre shred mix (by 24%). The largest porosity change (decrease) over the same period was observed in the sieved gravel filling (by 62%).

Both experiments and computer modelling results confirms the conclusion that tyre shreds are a material recommendable for the formation of leachate drainage layer in municipal waste landfills

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