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Analysis of permeability variation and biofilm growth in non-woven geotextiles filter barriers in contact with wastewater

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ABSTRACT

The clogging of non-woven geotextiles by microorganism (biologging) is a barrier to water flow in works within those materials. However, the biofilm can be positive during the time when clogging does not occur, as it allows the development of microorganisms which can remove various pollutants from wastewater (e.g. suspended solids, organic compounds, nitrogen, and phosphorus). The evaluation of the permeability variation of non-woven geotextiles in contact with wastewater was determined experimentally in four permeameters with static load. The experimental units were operated by cycles of 20, 40, 60 and 80 days, with the permeability measurement being carried out at the end of each cycle. At the end of each test, geotextile samples were taken for analysis of the growth and physical-chemical composition of the biofilm by scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDS). The results show that no bioclogging was observed in the geotextile matrix over a period of 80 days, although biofilm clusters were observed after 20 days of operation. Aerobic conditions were observed inside the permeameters throughout the period of operation, assuming that phosphorus was retained by adsorption and that oxidation of organic matter and ammonia occurred.

Keywords: Bioclogging, Non-woven geotextile, Permeability, SEM, EDS

1 INTRODUCTION

Clogging is a term usually used to characterize the malfunction of a filter, caused by an incompatibility between the dimensions of the filter pores and the particles of the material to be filtered, reducing the volume of voids, and decreasing the effective porosity of the sample. It causes a reduction in the hydraulic conductivity of the drainage medium (Fleming & Rowe, 2004). For geotextile filters, this process can have physical, chemical, or biological nature, depending on the situation where it is installed.

The use of geotextiles as filter materials in constructed wetlands, biofilters, stabilization ponds, wastewater and recycled water infiltration systems, wastewater drainage channels, mining ponds and landfills has been explored in recent years, being the second most consumed geosynthetic, behind only geomembranes (Lopes et al., 2021). Its use can bring technical and economic advantages, replacing traditional natural materials such as gravel and sand in these applications.

The clogging process in geotextile material can be developed due to either bacterial growth, mineral precipitation and/or also by soil migration between its fibers. Currently, three mechanisms are being studied: blinding, internal clogging, and blocking. The blinding process, or external clogging, occurs when the geosynthetic filters are in contact with unstable soils internally, as a result, if the hydraulic flow moves the base soil particles, these particles accumulate at the base of the soil-geotextile filter interface and a zone of low permeability is created (Palmeira, 2003; Vieira et al., 2010; Miszkowska et al., 2017; Silva & Lodi, 2020). Blockage can be developed when solid material adheres to the surface of the pores preventing the passage of water. Internal clogging occurs when small particles of solid matter enter the pores of the geotextile material and accumulate until they block the water flow. Some research pointed out greater physical clogging in woven geotextiles, while in non-woven geotextiles the blinding process is more likely to occur (Palmeira, 2003; Vieira et al., 2010; Silva & Lodi, 2020).

In geotextiles used in environmental sanitation and environmental geotechnical works that encounter water and wastewater, the microorganisms present in these waters can grow on the surface of the geotextile mesh, leading to the formation of a "biofilm". The biofilm is a complex of microorganisms (essentially bacteria) and biopolymers, which develops more quickly if there is an abundance of organic matter and nutrients, pH between 6 and 8, dissolved oxygen concentration (DO) above 2 mg/L and absence of inhibitor compounds (Albuquerque, 2003). When biofilm growth is exaggerated, it can lead to external or internal blockage of the pores of the geotextile matrix, reducing the empty space and leading to its clogging.

Biofilm formation on surfaces involves adhesion, growth, and detachment mechanisms to maintain the balance between active and less active microorganisms (Albuquerque, 2003). The connection between microorganisms (mainly bacteria) and the surface is established by the production of extracellular polymeric substances (EPS), which promote biofilm growth. EPS are highly hydrated polymers mainly composed of a mixture of polysaccharides, proteins, and extracellular DNA (Costa et al., 2018), recognized as important for communication between biofilm cells and the formation of biofilm structure. Biofilm shedding involves the release of parts of the “old” biofilm into the bulk liquid and can be influenced by hydrodynamic shear forces, pH, and the presence of toxic or inhibitory compounds (Albuquerque et al., 2012). Detachment is an important process, as it can influence biofilm accumulation and thickness, and therefore, the way in which bioclogging can develop.

Typically, it can take up to 1000 hours for biological activity to start, grow and reach an equilibrium condition in geotextile filters - steady state conditions – according to ASTM D1978 (2018). Therefore, it is important to understand the influence of biological fouling on geotextiles and the filtration capacity of geotextiles. Permeability is one of the tests that can be used to measure the progress of clogging over time. The application of scanning electron microscopy (SEM), with elemental analysis through energy dispersion X-ray spectroscopy (EDS), to geotextiles in contact with wastewater, can give important information on the growth and chemical composition of the biofilm on the surface of the material and help identify the extent of closure of voids. Thus, the objective of this research was centered on the evaluation of the variation over time of permeability in non-woven geotextiles in contact with wastewater, having introduced the innovation of characterizing the chemical composition of the biofilm and its extension in the geotextile grid through SEM and EDS.

2 MATERIAL AND METHODS

2.1 Laboratory experiments

The permeability tests were carried out according to ASTM D1987 (2018) in four cylindrical acrylic columns (permeameters), each one with an internal diameter of 100 mm and height of 200 mm, fed with a synthetic domestic wastewater and operated in vertical flow with a pattern of feeding-contact-drainage, according to the procedure presented in Morais, et al. (2022). The columns were filled only with geotextile and synthetic wastewater. The average head load used was 25 cm.

The four columns were operated in cycles of 4 days, being fed on the first day and drained on the fourth day, with the following duration:

- Permeameter 1: 5 cycles (20 days)
- Permeameter 2: 10 cycles (40 days)
- Permeameter 3: 15 cycles (60 days)
- Permeameter 4: 20 cycles (80 days)

At the end of each cycle, the water head load in each permeameter was measured. At the end of each experiment (i.e., after 5, 10, 15 and 20 cycles) small samples of the geotextile were collected for evaluating the chemical composition of biofilms through energy-dispersive X-ray spectroscopy (EDS) and scanning electrons microscopy (SEM) images a using Tescan VEGA.

2.2 Geotextile characteristics

A 100 mm diameter non-woven geotextile was used in each permeameter, composed by 100% polypropylene fibbers, mechanically joined by a needling process and later with thermofixation, with the characteristics shown in Table 1.

Table 1. *Characteristics of the geotextile used in the experiments*

Geotextile	Mass per unit area (g/m^2)	Permeability (m/s)	Thickness (mm)
GT300	300	6.3 x 10^{-2}	2.3

2.3 Synthetic wastewater

The synthetic wastewater was prepared based on the following composition (Albuquerque, 2012): buffer solution (8.50 g KH_2PO_4 + 21.75 g K_2HPO_4 + 33.40 g $Na_2HPO_4 \cdot 7H_2O$ + 1.70 g NH_4Cl/L), magnesium sulphate (22.50 g $MgSO_4 \cdot 7H_2O$/L), calcium chloride solution (36.43 g $CaCl_2 \cdot 2H_2O$/L), iron chloride solution (0.25 g $FeCl_3 \cdot 6H_2O$/L), solution of trace elements (0.04 g $MnSO_4 \cdot 4H_2O$ + 0.06 g H_3BO_3 + 0.04 g $ZnSO_2 \cdot 7H_2O$ + 0.032 g $(NH_4)6 \cdot Mo_7O_{24} \cdot 4H_2O$ + 0.0555 g EDTA ($C_{10}H_{14}N_2Na_2O_8 \cdot 3H_2O$) + 0.0445 g $FeCl_3 \cdot 6H$/L), sodium acetate solution (20.20 g $C_2H_3O_2Na \cdot 3H_2O$/L, organic source as acetate), ammonium chloride solution (20.30 g N -NH_4/L, nitrogen source) and potassium nitrate solution (13.7 g KNO_3/L, as phosphorus solution).

The geotextiles were inoculated with 2 mL of biomass previously acclimatized for two weeks in a semi-continuous reactor, which contained 6.68 mg/L SSV, 8.42 mg/L TSS, 311.20 mg/L COD, 11, 20 mg/L N-NH_4 and pH 7.40. Experiments were carried out with the synthetic wastewater (feed solution) with average initial loads of 450 mg COD/L, 25 mg NH_4-N/L and 19 mg PO_4-P/L, according to the first experiments used by Morais, et al. (2022).

3 ANALYSIS AND DISCUSSION

The permeability results over time are presented in Figure 1. There was a small decrease of permeability during the 10 cycles (permeameters 1 and 2), where the initial permeability was 2.7 x 10^{-2} m/s and the final was 1.6 x 10^{-2} m/s. Between 10 and 15 cycles operation (permeameter 3), permeability became stabilizing with values between 2.0 x 10^{-2} m/s and 2.3 x 10^{-2} m/s and values stabilized around 2.0 x 10^{-2} m/s between 15 and 20 cycles operation (permeameter 4). The greater permeability instability observed in the first 10 cycles may be related to the initial development of the biofilm, which will have influenced the flow pattern in the material matrix. After this period, the biofilm will have entered the stability phase (steady state) and the hydrodynamic behaviour began to stabilize leading to stable permeability values (around 2.0 x 10^{-2} m/s) between 15 and 20 cycles. Therefore, longer tests are needed to assess how long this stabilization is maintained, possibly with different types of geotextile and cycles of longer duration.

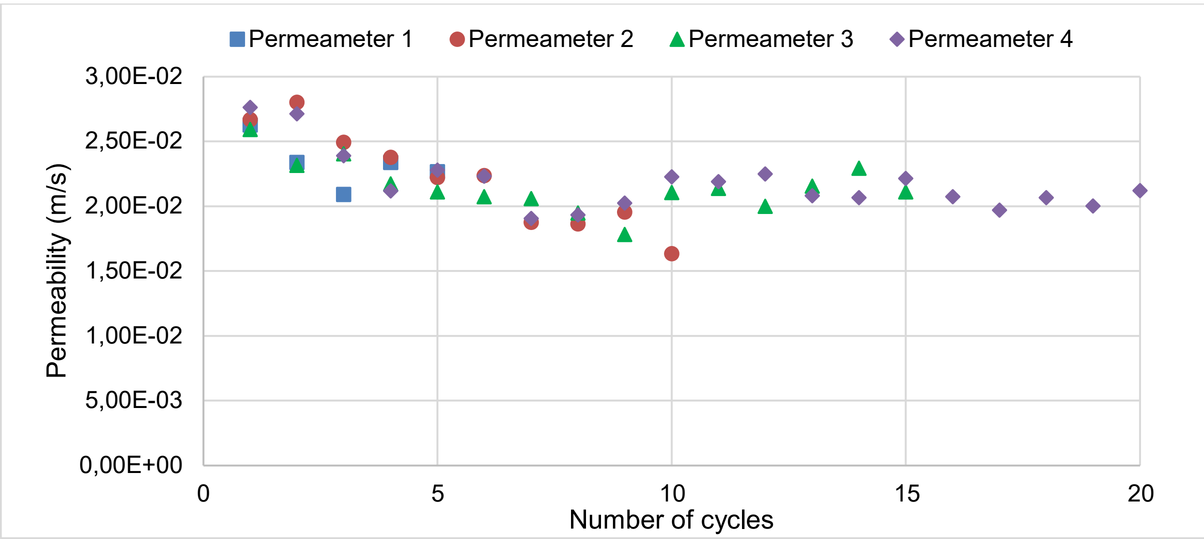

Figure 1. *Permeability during time for the samples.*

It can be said that the permeability variation was not significant over the cycles, although it fluctuated more in the first 5 cycles.

After the final cycle of each permeameter, small samples were cut to perform SEM images. Figures 2 and 3 show SEM images of samples taken from geotextiles in permeameters 1, 2, 3 and 4, respectively. The different magnitudes of the SEM images are justified to obtain a better visualization of the biofilms. The SEM methodology is illustratively useful to verify biofilm growth on the geotextile mesh. However, it is not possible to measure biofilm growth only by analysing the images over time, since the image depends on the sample cut zone. The analysis of the four figures allows observing a variation in biofilm growth in some points of the geotextile mesh. Chemical characterization by EDS was performed on the red dots shown in the four figures.

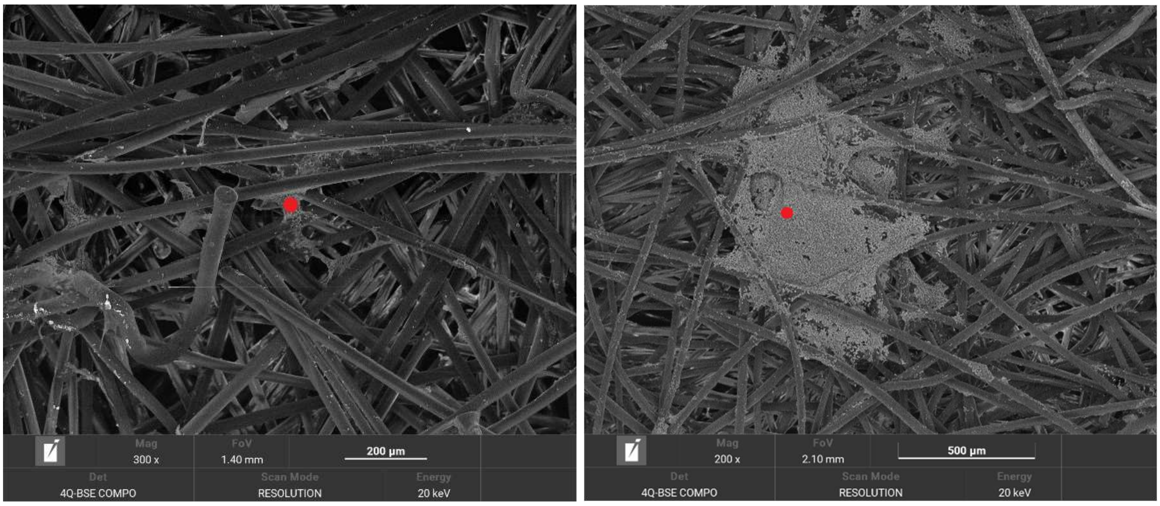

Figure 2. *Top view of permeameter 1 (left). Top view of permeameter 2 (right)*

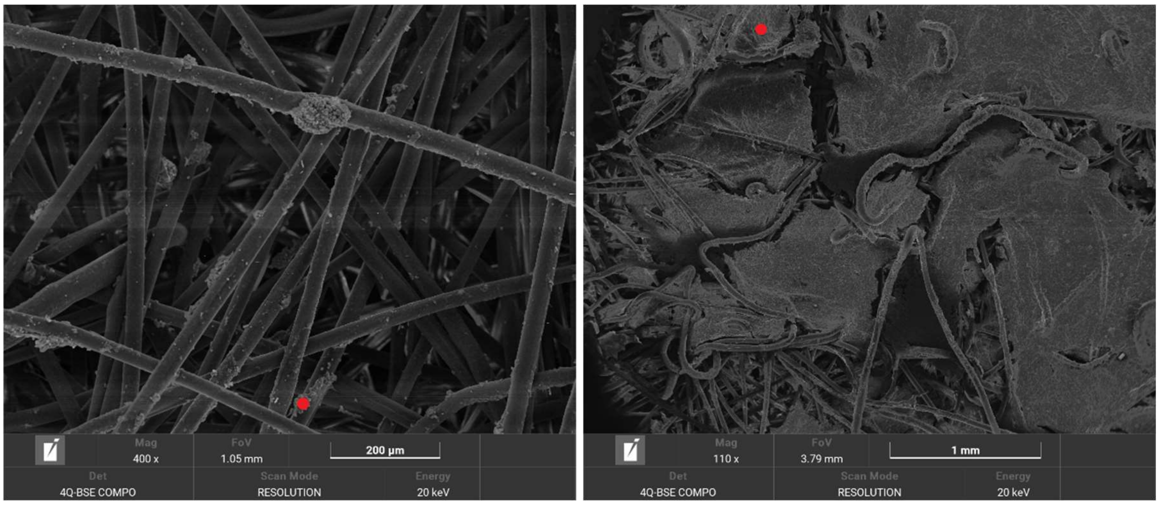

Figure 3. *Top view of permeameter 3 (left). Top view of permeameter 4 (right)*

In Figure 2 (left) it can be observed several colonies of biofilm already established on the surface of the geotextile fibers after 20 days of contact with wastewater. Despite presenting a larger biofilm region in the sample taken from Permeameter 2 (Figure 2 on the right) than on the sample from Permeameter 3 (Figure 3 on the left), it does not necessarily mean that it is well adhered between the fibers of the geotextile. A simple flow through it can wash it all away if not well fixed in the fibers. Therefore, the images seem to indicate that there was already a significant microbiological activity and some biofilm adhesion on the geotextiles of the permeameters. During the period of operation of the permeameters, some biofilms stabilized heterogeneously in parts of the biofilm matrix. The factors associated with this preferential location at different points on the grid are not well known, but it is believed that they are areas of lower velocity and higher concentration of wastewater compounds (Albuquerque, 2003).

Cross-sectional images are of great importance to identify biofilm clusters and to follow the clogging caused by microorganisms. Figures 4 and 5 show cross-sectional images of the geotextile samples, where it is possible to see a greater accumulation of biofilm on the surface of the geotextile. Reinforcing the idea that clogging happens at the surface (Silva & Lodi, 2020).

In general, SEM images obtained from geotextile samples after contact with wastewater for up to 80 days show that only a few biofilm colonies have already developed. Therefore, the installed biofilm was not enough to develop clogging, which explains the low and little variable permeability values.

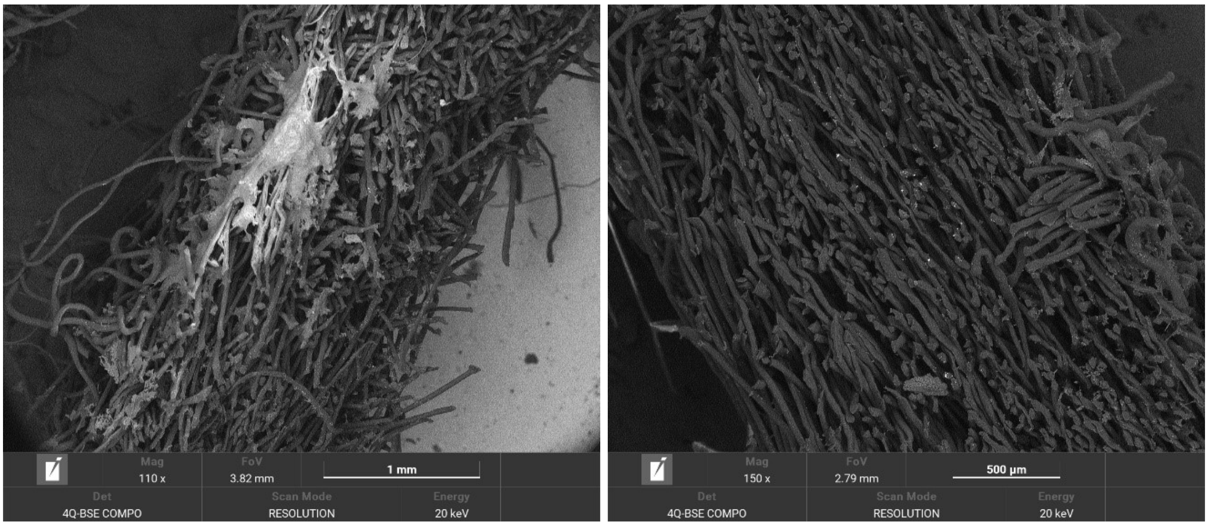

Figure 4. *Cross section of permeameter 1 (left). Cross section of permeameter 2 (right)*

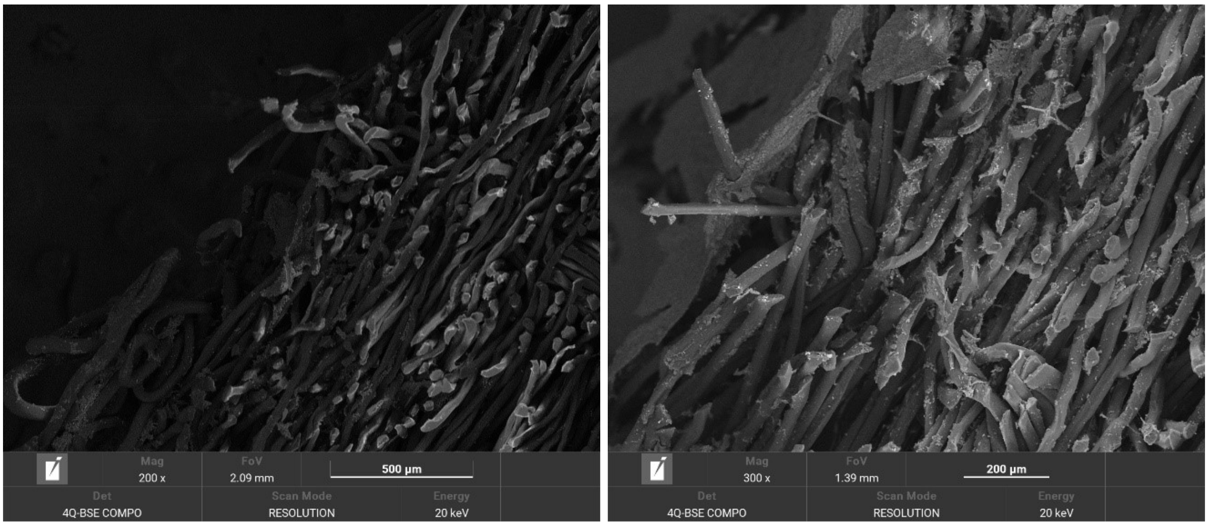

Figure 5. *Cross section of permeameter 3 (left). Cross section of permeameter 4 (right)*

Chemical characterizations of the samples chosen for SEM (rede points in images of Figures 2 and 3) were performed using EDS method and the results are presented in Table 2.

Table 2. *Main chemical elements found in biofilm.*

Elements	GT1	GT2	GT3	GT4
Calcium	0.79%	1.55%	0.73%	3.59%
Magnesium	1.90%	2.71%	5.14%	1.98%
Oxygen	90.57%	83.96%	76.22%	78.10%
Phosphorus	3.82%	10.80%	15.60%	15.32%
Potassium	0.68%	0.08%	1.21%	0.37%
Sodium	-	-	-	0.17%
Silicon	0.66%	-	-	-
Sulphur	1.59%	0.30%	1.10%	0.47%

Analysed biofilm samples presented large percentages of oxygen, being the base element in the composition, therefore indicating aerobic conditions in the permeameters. Most chemical elements show similar values in the four samples, except for phosphorus (P) which was three to four times lower in sample GT1 (Permeameter 1) than in GT2, GT3 and GT4. This increase in P over time may be related to its retention in the biofilm due to adsorption mechanisms. Oxygen decreased over time, which may be related to its use in the oxidation of acetate (source of organic matter in synthetic wastewater) and ammoniacal nitrogen (source of nitrogen in synthetic wastewater).

In sample GT4 more elements such as calcium, magnesium and a relevant percentage of phosphorus were found. It is understood that, over time, the biofilm starts to create more biochemical reactions, releasing some of its "old" structure through the flow of liquids through the geotextile mesh and the elements of the biofilm that have stronger connections with each other. It is expected that, for longer test times, better formed biofilms will be found, with a greater number of compounds and, consequently, a greater number of biochemical interactions.

4 CONCLUSIONS

From the results obtained in this study, the following conclusions were drawn:
- No bioclogging was observed in the geotextile matrix over a period of 80 days for the operating conditions used.
- The SEM images show the formation of biofilm clusters after 20 days of contact between the geotextiles and the wastewater.
- SEM images on the cross section of the geotextile show that biofilms develop mainly on the surface of the matrix.
- The EDS analysis shows that there were aerobic conditions inside the permeameters, possibly with retention of phosphorus and oxidation of organic matter and ammonia.

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