Environmental conditions for the ochre formation in geotextile filters

[1]Luiza Gabriela Cruz dos Santos Correia, [2]Maurício Ehrlich, [3]Marcos Barreto de Mendonca

[1,2]Dept. of Civil Engineering, COPPE, Federal University of Rio de Janeiro, RJ 21945-970, Brazil; e-mail: luizagcorreia@gmail.com
[3]Dept. of Civil Engineering, POLI, Federal University of Rio de Janeiro, RJ 21945-970, Brazil.

ABSTRACT: Clogging by ochre may be considered a major threat in the performance of filters and drainage systems. The environmental conditions including the chemo-microbiological aspects involved for the ochre formation and clogging of geotextile filters used in drainage systems are discussed. Column tests are being carried on using samples of geotextiles as filters with the inoculation of iron bacteria under three different filter submersion conditions. The concentration of dissolved oxygen, pH, and iron retention rate are being monitored during the column tests. Biofilm formation on the geotextile filters is being evaluated through the analysis of EDS (Energy Dispersive X-ray detector) and scanning electron microscopy.

Keywords: Geotextile, clogging, ochre.

1 INTRODUCTION

Ochre is an orange and gelatinous substance resulted from chemo-microbiological reactions between substances contained in the water, especially the iron ions. This substance is responsible for problems related to hydraulic performance of wells and drainage systems. This occurs because of the growth of microorganisms under the supply of nutrients, such as iron ions, which provides the formation of a substance adhered to solid surfaces of drainage systems, resulting in a reduction of voids available for seepage water. As a result, clogging processes take place in drainage systems, which compromise its operation efficiency. Some studies have been carried out aiming to understand the ochre formation process, in particular emphasizing the studies of Kuntze (1982), who found that the permeability loss of drainage systems is mainly due to chemical and biological clogging. Ford (1979) highlighted the fundamental importance of the presence of soluble iron in the groundwater in the clogging process of draining systems by ochre.

Several cases related to the clogging of drainage systems by ochre are reported in the literature. Puig *et al.* (1986) studied two typical cases of clogging of drainage systems by ochre in road works in France, which revealed the presence of active microorganisms involved in iron biogeochemistry. Forrester (1995) discussed the process of the clogging of drainage systems and highlighted the presence of filamentous aerobic bacteria and a substantial concentration of iron ions (Fe^{2+}) as necessary factors for the formation of ochre. Mendonca et al. (2003) and Mendonca and Ehrlich (2006) focused on these phenomenon and demonstrated through laboratory studies that ochre is the result of biofilm formation developed by iron bacteria that colonize the solid surfaces in the interface between the aerated and non-aerated regions in drainage systems involving natural or geotextile filters. Correia et al. (2017) have demonstrated through column tests the effect of filters submersion on the formation of ochre and clogging.

This study has the main objective to verify more deeply the microbiological processes involved in ochre biofilm formation and evaluate the environmental conditions involved. Tests are underway in order to deep analyze the process related to the fixation of dissolved iron in the geotextile filters. During those tests dissolved oxygen concentration, pH and the rate of iron retention are being evaluated. Electrodes located in the column monitor the dissolved oxygen and pH. Through orthophenanthroline method, the concentrations of Fe^{2+} and Fe^{3+} in the inward and outward flow the iron retention rate is being determined.

2 BIOGEOCHEMICAL PROCESSES RELATED TO OCHRE FORMATION IN DRAINAGE SYSTEMS

Ochre formation basically occurs when dissolved iron ions find favorable electrochemical conditions for oxidation and precipitation. The form of the iron element present in the environment depends on purely chemical aspects, electrochemical potential, partial pressure of oxygen, pH, temperature and pressure (Garrels, 1960). The dynamics of ochre formation can be divided into four stages: (1) iron solubilization in the fluid, (2) migration of the dissolved iron, (3) iron precipitation and (4) ochre dehydrating and aging.

Under normal environmental conditions, when dissolved iron ions, Fe^{2+}, are submitted to increase oxygen partial pressure, they tend to be oxidized to Fe^{3+}. When iron ions (Fe^{2+} or Fe^{3+}) are chemically associated with organic matter, forming organometallic complexes, they are not influenced by environmental conditions and remain dissolved in the water, even in conditions that are favorable for chemical precipitation. In natural environments, the chemical oxidation reaction rate of Fe^{2+} to Fe^{3+} is relatively slow. Nevertheless, the iron oxidation and, hence, precipitation can be catalyzed by the action of some species of microorganisms, causing a huge increase of the reaction rate that contributes significantly to potential ochre formation.

Microbial growth at surfaces is associated with an increased number of cells in a population, which is denominated biofilm. Biofilm is a biological system where bacteria are organized into a coordinated community. Bacterial cells are surrounded by a matrix denominated exopolymers, which is generally a mixture of polysaccharides, proteins and nucleic acids that bind cells (Madigan et al., 2016). It is concluded that ochre is the result of biofilm formation, since certain species of bacteria (iron bacteria), as previously mentioned, colonize the interface between the aerated and non-aerated regions of drainage systems, as this is an enabling environment to meet their nutritional demands, mainly iron ions and oxygen (Mendonca and Ehrlich, 2006). Moreover, the dominance of the ferric compounds gives an orange color to the biofilm.

As mentioned by Mendonca and Ehrlich (2006), there are two different microbial activities for iron oxidation and precipitation, which occur more frequently at neutral pH, especially with the species *Gallionella ferruginea*, *Sphaerotilus natans* and *Leptothrix ochracea*: (1) acquisition of chemotrophic energy where enzyme proteins synthesized by microorganisms act as catalysts and greatly increase the oxidation reaction rate to meet their energy demands, and (2) organometallic complex digestion (heterotrophic bacteria), where organic complexes of these or some other elements such as nitrogen, may be used by certain microorganisms and, with the release of the inorganic part into the middle, becomes free to undergo new chemical or microbial transformations (see Figure 1).

Aerobic iron oxidant bacteria characteristic can be found in the genera *Gallionella* (freshwater) and *Mariprofundus* (marine). Some species of these two genera form a structure similar to a peduncle, containing iron hydroxide ($Fe(OH)_3$) derived from the oxidation of Fe^{+2}. This iron-embedded peduncle contains an organic matrix in which $Fe(OH)_3$ accumulates as it is secreted from the cell surface (Madigan *et al.*, 2016).

3. EXPERIMENTAL STUDY

Column tests with upward flow keeping the filter elements (geotextile filters) submerged under different water depths were performed. The column tests consist in percolation of fluid in permeameters to simulate the ochre formation. The permeameters have samples of geotextiles on their upper surfaces under different submersion heights. Diluted specific nutrients are used in the flowing fluid and the iron bacteria introduced in order to simulate environmental conditions. The main objective of the study is to verify the occurrence of ochre formation in geotextile filters in these different conditions in laboratory and consequently to evaluate the environmental conditions involved in its formation.

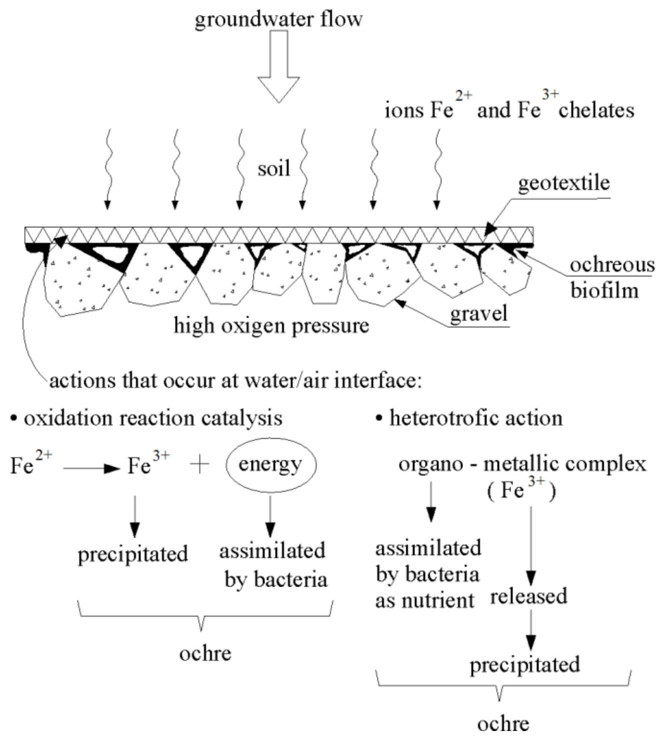


Figure 1. Schematic drawing of the formation of ochre in geotextile filters (Mendonca and Ehrlich, 2006).

Samples of ochre were collected from the natural environment to obtain the iron precipitating microorganisms to be used in the tests. The samples were collected from a forest area in Rio de Janeiro (Tijuca Forest), where humidity, temperature and freshwater conditions were favorable to the presence of iron precipitating bacteria. To promote the iron bacteria grow, the collected material was inserted in a 100 ml erlenmeyer flask with the culture medium shown in Table 1.

Table 1. Composition of the culture medium added to water in the fluid.

Substance	Concentration (gram/Liter)
Ammonium sulfate, $(NH_4)_2SO_4$	0,5
Sodium nitrate, $NaNO_3$	0,5
Potassium phosphate dibasic, K_2HPO_4	0,5
Magnesium sulfate, $MgSO_4.7H_2O$	0,5
Calcium chloride dehydrate	0,13
Sodium chloride, NaCl	9,5
Ferric ammonium citrate	10

First set of tests were performed using six filtration columns (three pairs of duplicate testing) measuring 50 mm high and 100 mm internal diameter under upward flow forced by a peristaltic bomb. The column was set up using glass beads in the bottom part and, on top, a woven geotextile filter whose characteristics are shown in Table 2. Each pair of duplicate columns was subjected to a different height of water depth (see Figure 2) and an upward flux was forced by a peristaltic bomb. In Figure 2, L is the distance between the geotextiles and the water table. A pair of columns had the top coincident with the water level in order to ensure an air/water interface in the geotextile with maximum oxygen saturation. The second and third pairs of columns were submerged in water at depths (L) of 20 mm and 45 mm, respectively.

Table 2. Characteristics of geotextile used in the column tests.

Polymer	Polypropylene
Weaving	Woven
Thickness (mm)	0.4
Permeability (mm/s)	0.36
Permitivity (cm^{-1})	0.9
Filtration opening, AOS, (mm)	0.8

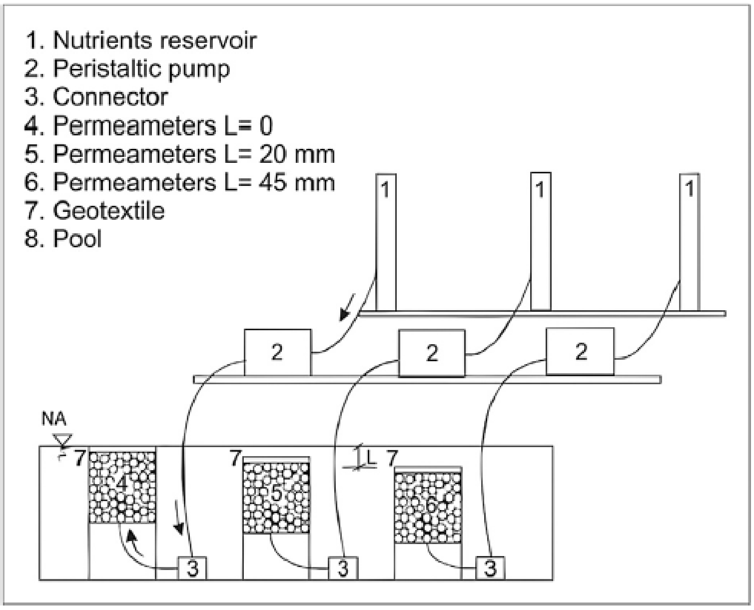


Figure 2. Schematic representation of the columns tests.

In order to verify the biofilm formation in the geotextile filters after tests, scanning electron microscopy (SEM) was performed to observe clogged pores and microorganisms adhered to the filaments of the geotextiles.

4. RESULTS

The sample of ochre collected in the field had characteristics similar to those described in the literature, as orange color and gelatinous consistence (see Figure 3). After a portion of 1mL of this material was inserted into a test tube with the culture medium described in Table 1. The prepared culture medium has yellow color but with the presence of iron bacteria, it becomes orange after about three days and formed a brown ring on the sides of the test tube as can be seen in Figure 4.

After the column tests, the samples of geotextile were removed and observed by scanning electron microscopy (SEM). In Figure 5, the results of scanning electron microscopy are shown for the geotextiles filters after the tests with water depths of 0 mm (Sample 1), 20 mm (Sample 2) and 45 mm (Sample 3). Biofilm formation in each pair of tests (duplicate conditions) was similar.

Figure 5a shows the geotextile filter which was kept in contact with the atmosphere (Sample 1). It can be observed that the spaces between the filaments of the geotextile were substantially filled by the material. Figure 5b shows a similar biofilm formation in Sample 2, which was located 20 mm below the water surface, but the voids between the filaments of that geotextile filter were not completely filled and also not as well adhered to the filaments. Figure 5c indicates that Sample 3, which was located 45mm below the water surface, showed an even less intense and adherent biofilm formation compared to the samples 1 and 2.

Aiming to analyze in more detail a biota existing in ochre, new samples with the same characteristics were collected in the same forest area. Samples of ochre were stored from the same place and forwarded for analysis. A collected plot from one sample observed under a fluorescence microscope (see Figure 6a to Figure 6d). A blue fluorescent substance was used that binds to the DNA of the microorganisms present, thus identifying the presence of extracellular material or exopolymer, as previously mentioned, which indicates microbial colonization. Red fluorescence, however, identifies chlorophyll (see Figure 6d).

The outline in red indicates the presence of a structure similar to an empty capsule composed of iron oxide that in a certain period sheltered the cell and was later left, thus preventing the cell from being trapped in a crust. This structure resembles the characteristics of microorganisms of the genus *Gallionella,* which is very common in freshwater regions. Figure 6d shows the presence of chloroplast, an organelle present in plant cells and other photosynthetic organisms, which indicates the diversity of materials and substances contained in ochre that also is responsible for the clogging in drainage systems.

Figure 3. Ochre collected for the study.

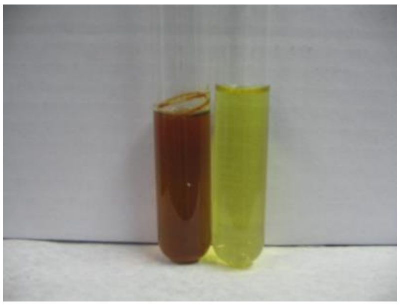
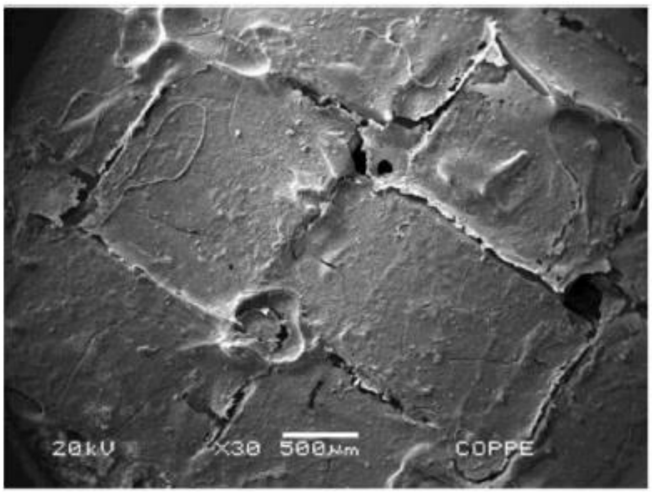
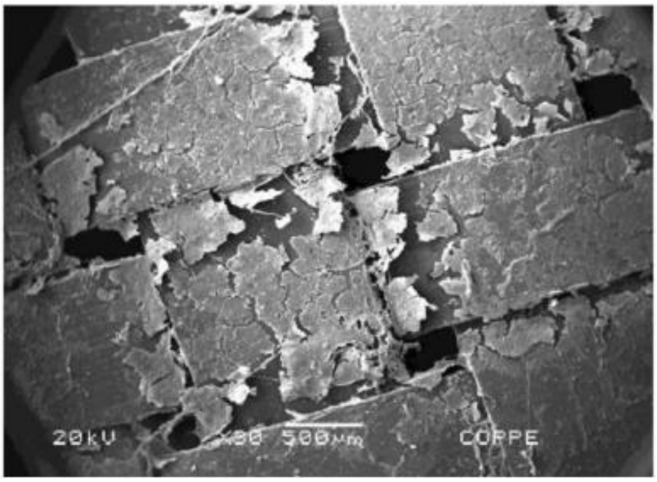


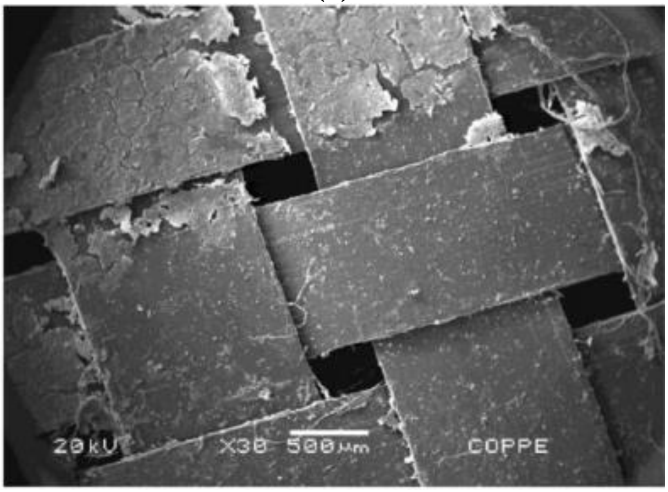
Figure 4. Test tubes with culture medium, the left with ferrobacteria inserted.



(a)

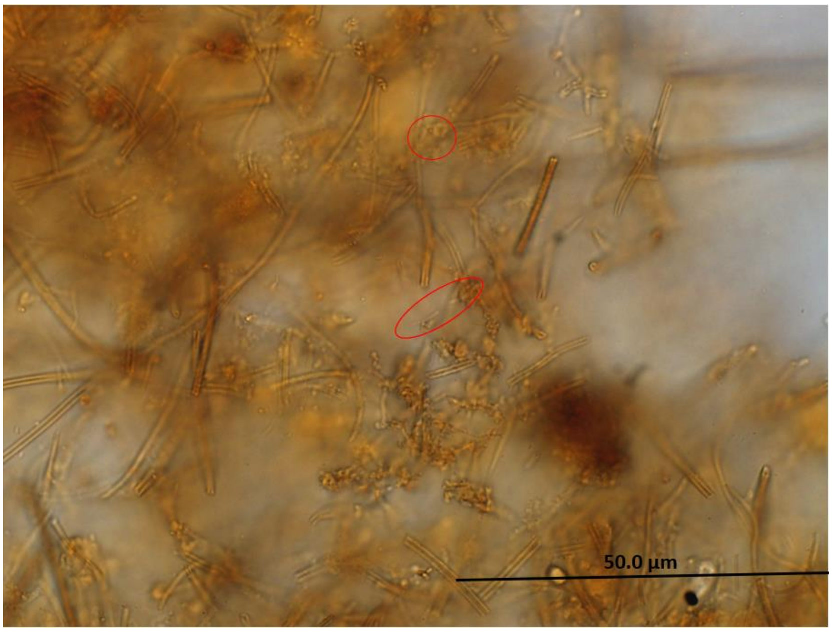


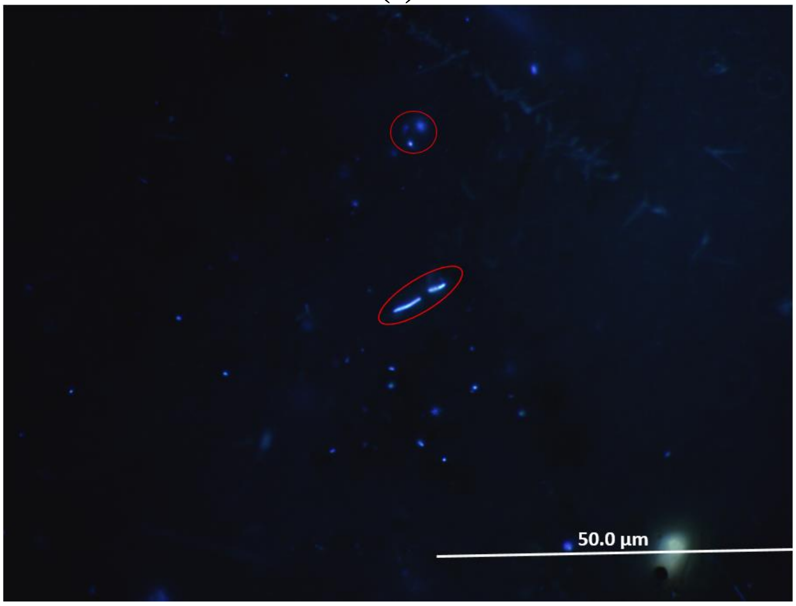
(b)

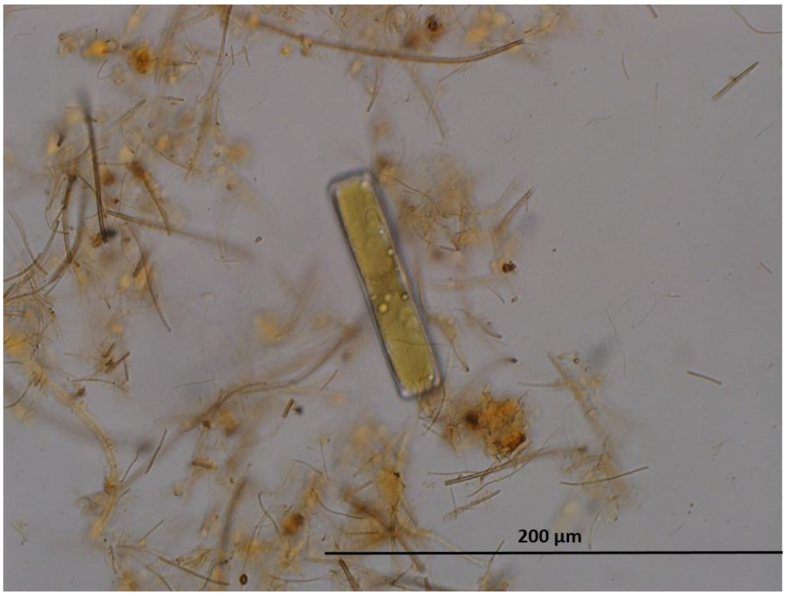


(c)

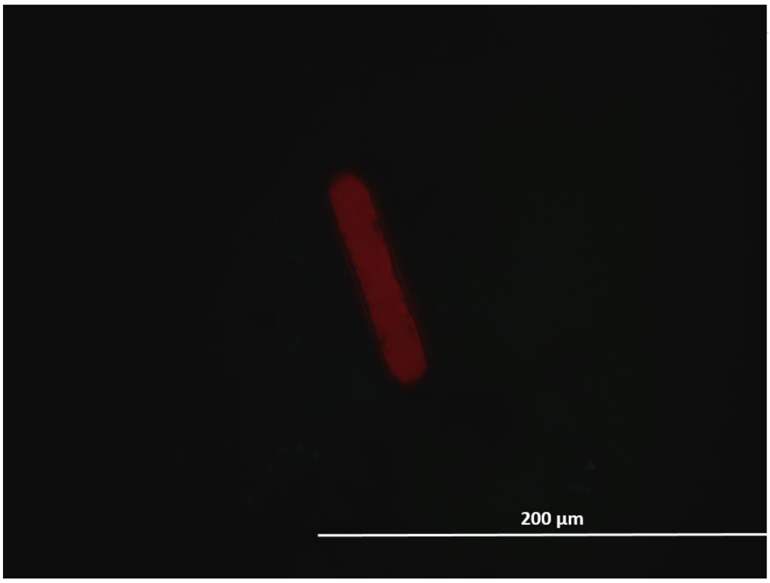
Figure 5. MEV's samples (General Setup and biofilm details): (a) Sample 1, (b) Sample 2, and (c) Sample 3.



(a)


(b)


(c)



(d)

Figure 6. (a) and (c) Ochre in microscope. (b) and (d) Ochre in microscope using the fluorescence microscope.

5. CONCLUSIONS

Column tests were performed to simulate ochre formation in geotextile filters, with the inoculation of iron bacteria, nutrients and iron under upward flow. The tests were carried out in duplicate conditions, keeping the filters submerged under different water depths. For the performed tests, ferruginous bacteria was collected from ochre sample from natural environment. Fluorescence microscope analyses showed in the samples, the presence of extracellular material or exopolymer, which indicates microbial colonization. The observed structure resembles the characteristics of microorganisms of the genus *Gallionella*, which is very common in freshwater regions.
After the column tests, the samples of geotextile were removed and biofilm formation on the filters were evaluated through analysis of scanning electron microscopy. Biofilm formation in each pair of tests was similar. Results indicate a higher ochre formation on the tests with the filter located at surface and a decrease of it with the increase of the depth of the filter submersion. In the geotextile filter, which was kept in contact with the atmosphere, the spaces between the filaments of the geotextile were substantially filled by the ochre. In the geotextile filter located 20 mm below the water surface, the voids between the filaments of that geotextile filter were not completely filled and not as well adhered to the filaments. In the geotextile filter located 45mm below the water surface, the tests showed an even less intense and adherent biofilm formation compare to the others. Additional tests are underway, during those tests dissolved oxygen concentration, pH and the rate of iron retention are being evaluated. Electrodes located in the column monitor the dissolved oxygen and pH. Through orthophenanthroline method, the concentrations of Fe^{2+} and Fe^{3+} in the inward and outward flow the iron retention rate is being determined. Those results may correlate to the fixation of dissolved iron in the geotextile filters.

6. REFERENCES

Correia, L.G.C.S., Ehrlich, M., Mendonca, M.B., 2017, The effect of submersion in the ochre formation in geotextile filters, Geotextiles and Geomembranes 45, p.p. 1-7

Forrester, K. 1995. “Ochre clogging in subsoil drains.” Landslides, D. H. Bell, ed., Balkema, Rotterdam, The Netherlands, 1761–1766.

Ford, H. W. 1982. “Biological clogging of synthetic drain envelopes.”Proc., 2nd Int. Drainage Workshop, Washington, D.C.

Kuntze, H.,1982. Iron clogging in soils and pipes, analysis and treatment. German Assoc. for Water Resources and Land Improvement, Bulletin 10, Pitman.

Madigan, M. T., Martinko, J. M., Dunlap, P. V., Clark, D. P., 2016. Microbiologia de Brock. Ed. Artmed.

Mendonça, M.B., 2000, Avaliação da Formação do Ocre no Desempenho de Filtros Geotêxteis. Tese de D.Sc., COPPE/UFRJ, Rio de Janeiro, RJ, Brasil.

Mendonça, M.B., Ehrlich, M., Camarota, M.C. - Conditioning factors of iron ochre formation on geotextile filters. Canadian Geotechnical Journal (ISSN: 0008-3674), volume 40 (6), 2003, pág 1225-1234.

Mendonça, M.B., Ehrlich, M., 2006, “Column test studies of ochre biofilm formation in geotextile filters”. Journal of Geotechnical and Geoenvironmental Engineering, v. 132, pp. 1284-1292.

Puig, J., Gouy, J.L. Labroue, L., 1986, “Ferric clogging of drains”. In: Proc., 3rd Int. Conf. on Geotextiles, v.4, pp. 1179-1184, Viena, Áustria.