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Biological filtration on sand of dunes – Filters fouling

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Abstract

The use of sand of dunes as a filtration support for domestic wastewater treatment demonstrated its efficiency at pilot scale. However, the filter receives non negligible amounts of suspended matter, leading to biological clogging owing to the colonization of the pores of the filtration media by biomass and related by-products. Fouling time-course was examined in this work. Measurements carried out at various column heights showed that the difference of porosity between the first and last layers can reach 2 %, while the decrease between the initial and the final state was above 7 % for all layers. Organic matter accumulation followed similar history than fouling, showing its involvement in the process and its preponderance in the fouling mechanism if compared to mechanical fouling. The amount of organic matter was mainly apparent in the two upper layers of sand and exceeded 2 % in the first sand layer after 7 days.

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Keywords : Fouling; Organic matter; Porosity; Sand bio-filtration; Wastewater treatment.

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1. Introduction

Slow biological filtration is a waste treatment booming field, which found increasing applications during these last years, especially due to the implementation of complementary processes, especially biological treatments. However, there is a lack of investigations dealing with secondary effluents treatment by means of slow biological filtration on sand, and especially more studies dealing with the evaluation of the bacteriological quality of the filtered effluents are needed [1]. This process is used since 1900 and is now widely used in municipal wastewater treatment. Some new improvements in the conception of the sand filtration plants should greatly enhance its demand

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for the treatment of municipal, industrial and domestic wastewaters worldwide [2]. Function of the pre-treatment efficiency, the filter receives a non negligible amount of suspended matter, leading to a biological clogging, owing to the colonization of the pores of the filtration media by the biomass and the by-products resulting from bacterial activity. However, there is a lack of experimental data dealing with the link between surface fouling and operational parameters; in the few studies which report on fouling, the amount of experimental data are too low to allow an evaluation of the operational conditions leading to fouling [3].The use of sand of dunes as a filtration support for the treatment of domestic wastewaters demonstrated its efficiency at pilot scale [4].Time-course of the fouling of the system and its evaluation as a function of the height of sand, and especially the matter organic deposit, was the objective of this work.

2. Materials and Methods

2.1. Pilot plant

The experimental device considered to study fouling is displayed in Fig.1. The filtration units were Polyvinyl chloride column of 35 cm height and 7.8 cm diameter. The sand layer was 30 cm height. Each filtration unit was provided with a drain system at the bottom of the column [5-7]. The flow was considered to be uniform on the cross section of the experimental device. The theoretical flow rate was 2.76 10^{-6} L s^{-1} [5, 7, 8].

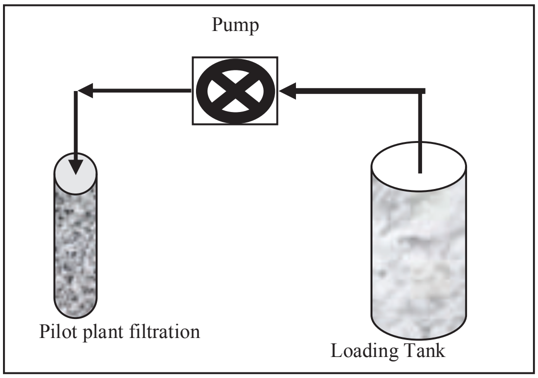

Fig.1. Experimental filtration device

The apparent flow rate was 0.21 cm h^{-1} for an initial sand porosity of 43.88 %. The average filtration rate at the beginning of experiments was thus 0.47 cm h^{-1}. For a complete purification of the wastewater, 7 filters were used in this work. All filters run independently for a working time in the range 1 to 7 days. The used sand came from the N'Goussa quarry (south Algeria) [4] which was uniformly spread in the columns. Filters were fed with synthetic water [9-11] at a mean flow rate of 0.40 L h^{-1}. The specificities of the used water are collected in Table 1.

Table1. Specificities of the water used

Parameter	BOD5 (mg O_2 L^{-1})	COD (mg O_2 L^{-1})	TKN (mg L^{-1})	SS (mg O_2 L^{-1})	pH
	200 ± 20	600 ± 10	36.4 ± 3	245 ± 15	6.94 ± 0.10

The sampling procedure was based on the non-reshaped soil sampling method using small polyvinyl chloride column of 28 mm diameter and 30 mm height. These cylinders are gathered together to constitute a unique pipe, which was axially put in the column before sand loading (Fig.2). After cessation of filter loading, the pipe was removed from the column and then the small sand cylinders contained in the pipe were dried at 105°C for 24 h.

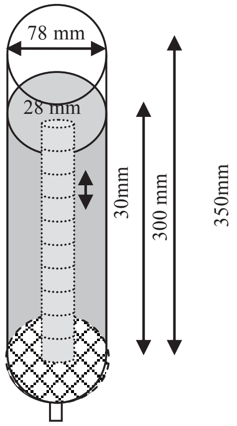

Fig.2. Schematic diagram of the filtration pilot

2.2. Analysis

Granulometric analysis followed the AFNOR standard (EN 872 – 1996) by replacing the 0.64 diameter sieve by the following set of diameter sieves: 0.063, 0.08, 0.125, 0.16, 0.2, 0.315, 0.5, 0.8, 1.0 mm. A mass of sand of 200 g was considered, which was sieved through the above series of sieves [12]. The granulometric analysis allowed to determine the following characteristic parameters:

- The effective size D_{10} which characterizes an opening sieve diameter which retained 90 % of the sand [13]. Conventionally, it corresponds to the mean diameter of the grain particles. The used sand had an efficient diameter DE of 0.11 mm.
- The uniformity coefficient represents the homogeneity of the diameters of the grain particles in the sample. Conventionally, for a uniform granulometry, C_U should be lower to 2-2.5, which was the case for the considered sand, owing to the measured C_U (1.72). This value also indicated that the sand was in agreement with the requirements of the slow filtration, namely $0.7 < C_U < 3$ [14].
- The rank coefficient C_c corresponds to the ratio between the apparent diameters for which 75 and 25 % of the particles have a lower diameter. This coefficient characterized the relative variation of the slope of the curve $C_c=d_{75}/d_{25}$, which was 1.37 for the used sand.
-The apparent density was determined by the cylinder method, which consists in the weighing of the axial cylinder after drying. The real density was measured by the pycnometer method, which consists in the use of CCl4 as an apolar liquid to fill the vacuum between the grain sands.
-Chemical Oxygen Demand (COD) was determined according to the AFNOR standard (NFT 90-101) by oxidation of the reductive materials contained in water using an excess of potassium dichromate.
-Biological Oxygen Demand (BOD5) was determined by the manometric method, which consists in the monitoring of the air pressure inside a vial containing a sample of wastewater. This measure is linked to the oxygen drop in the atmosphere of the vial and is expressed in mg O_2 L^{-1} [15].
-The electric conductivity was measured following the AFES standard (AFES, 1995) on a soil extract (ratio 1/10). For the studied sand, the conductivity was 3.3 ms/cm, namely a saline load of 1.91 %, indicating a low salinity of the sand, which can have an effect on the quality of filtred water [12,16].
-The Anne method following the AFNOR standard (X 31-109) was considered for the measurement of the organic matter. This method is based on the decomposition of the organic compounds using a sulphuric acid solution containing potassium dichromate.

3. Results and Discussion

The organic matter content of the used sand was 51 mg/g of soil (0.051 %), which corresponded to a low content [12, 16]. Sand analysis also showed a thin granulometry, an uniformity, a low organic matter, a high permeability, a low saline amount and an alkaline pH (8.46).The removal yields of suspended solids SS increased from 53.9 % after 1 day running to 77.2 % after 3 working days, that of the chemical oxygen demand COD increased after maturation from 74 to 94 % from 1 to 3 working days before decreasing to 50 % at the end of the run, and that of the Biological Oxygen Demand BOD_5 increased from 70 % removal to 90 % after 1 and 3 days working, respectively. The water pycnometer and the cylinder methods were considered for real and apparent density determinations, respectively. Soil porosity was determined by means of the following formula:

$$n\% = \left[1 - \frac{P_{app}}{P_{re}}\right] \times 100 \tag{1}$$

With n the soil porosity, P_{app} and P_{re} the apparent and real densities. Measurements were carried out in triplicates.

Figure 3 shows for each sand layer (as indicated in Fig.2) the time-courses of porosity during 7 working days. The observed divergences indicated low errors on the porosity values. Indeed the displayed data are the mean values of triplicated measurements and the observed standard errors were found in the range 0.03 – 0.11, namely too low to be noticeable on the figure.

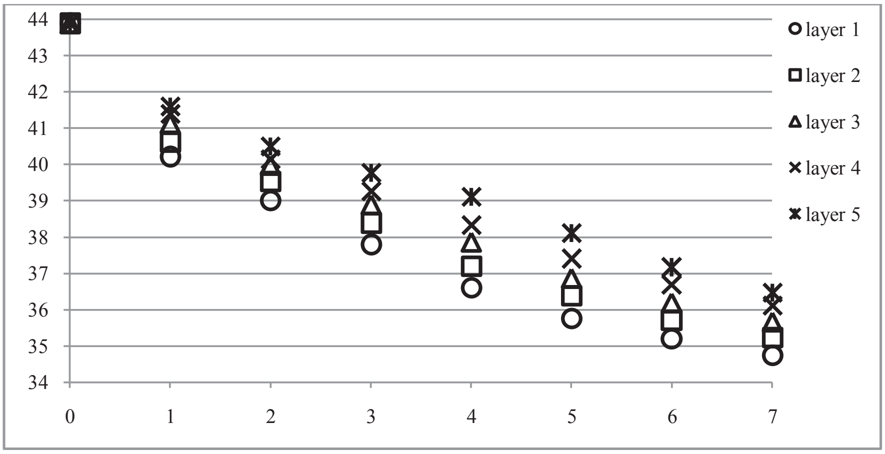

Fig.3. Time-courses of the porosity during 7 working days for each sand layer.

Lower porosity values can be observed at the upper of the filter, and the measurements carried out at various column heights showed that the difference of porosity between the first and the last layer can reach 2 % (Fig.3). Porosity decrease appeared nearly linear for a given sand layer and on overall was above 7 % for each layer on 7 running days. From the fifth working day, it can be noticed some water stagnation in the filter.

Wastewater flow through the filtration system induced a decrease of the porosity with time. The progressive clogging of the material interstices led to an increase of the pressure drop; the kind of filtration material and the quality of treated water have an impact on the fouling rate.

Filter clogging corresponds to the void fraction with regard to the total initial porosity, and is given by the following relation:

$$CO = \left[1 - \frac{n_f}{n_i}\right] \times 100 \tag{2}$$

With n_i and n_f, the initial porosity (43.88 %) and its final value recorded at the end of a running filter cycle respectively.The fouling rate varied with the filter depth, as shown from the differences observed between the different sand layers (Fig.4).

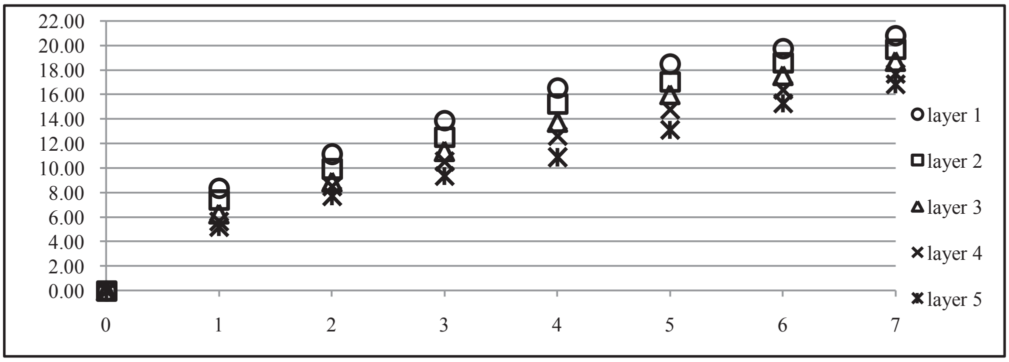

Fig.4. Time-courses of the fouling rate for each sand layer

Porosity decreased with the running time (Fig.3) consequently to an increase of the filter fouling (Fig.4), which can result from: (i) mechanical clogging due to settling of the filtration support and hence the reorganization of the solid skeleton of the filter layer; (ii) physical clogging due to suspended solid accumulation on the grains of sand, the filter acts as a sieve in the filtration mechanism [15]; (iii) and organic clogging, the consequence of dissolved matter adsorption on the grains of sand, especially the organic matter, as well as the formation of micro-organisms and algae [17,18], mainly at the surface of the filter, accounting for the differences observed between the superficial layers and the deep layers.

Time-courses of the organic matter amounts for each sand layer given by the Anne method [16] and at least triplicated are displayed in Figure 5. The observed standard errors were found in the range 0.0 – 0.13, namely too low to be noticeable on the figure. As expected, the organic matter content (Fig.5) varied conversely to the porosity (Fig.3).

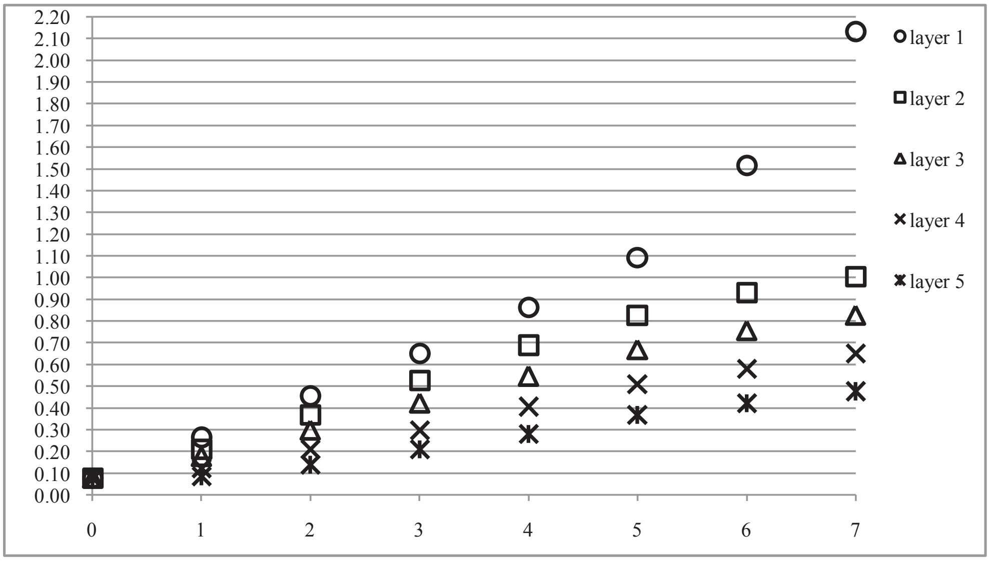

Fig.5. Time-courses of the organic matter accumulation for each sand layer

An increase was recorded from the first working day. Excepted for the superficial layer, this accumulation was almost linear until about 6 working days and then decreased. Contrarily, a noticeable increase of the organic matter accumulated on the first layer; the main part was therefore retained at the surface filter. Indeed, the slope of the curve for the first layer changed after 4 days running until a difference of 1.13 % organic matter between the first and the second layers after 7 days running.

After one working day, the difference between the upper and the last layer was close to 0.18 %, while at the end of running (7 days) this difference increase to 1.76 % This noticeable increase can be accounted by algal and microorganisms formation at the surface of the filter, owing to the high aeration in this area [19]. The mechanical clogging was caused by water flowing through the filter media. To assess fouling, porosity measurement was carried out on sand samples using drinking water. Results are displayed on Table 2.

Table 2. Mechanical fouling values (%)

	Time (day)					
Sand layer	1	2	3	4	5	6
1	0.93	3.07	5.05	5.46	5.75	6.23
2	2.09	3.23	8.98	9.21	11.30	12.66
3	2.43	4.27	9.23	9.23	10.44	12.16
4	2.84	5.53	10.43	10.73	11.09	13.09
5	4.43	6.34	9.16	10.12	11.75	13.37

Biological fouling was caused by suspended organic matter deposit; the corresponding amounts are displayed in Table 3.

Table 3. Biological fouling values (%)

	Time (day)					
Sand layer	1	2	3	4	5	6
1	0.26	0.46	0.65	0.86	1.09	1.52
2	0.21	0.37	0.53	0.69	0.83	0.93
3	0.18	0.30	0.42	0.55	0.67	0.76
4	0.12	0.21	0.30	0.41	0.51	0.58
5	0.09	0.14	0.21	0.28	0.37	0.42

Physical clogging was evaluated from the measurement of the mineral suspended solids, since organic suspended solids were already accounted in the biological clogging. Physical clogging was calculated by subtracting mechanical and biological deposit from the total amount of deposit:

$$CO_T = CO_{org} + CO_{mec} + CO_{phys} \qquad (3)$$

Where CO_T, CO_{org}, CO_{mec} and CO_{phys} were total, organic, mechanical and physical deposit, respectively.
The corresponding physical deposit amounts are collected in Table 4. Physical clogging was mainly due to suspended solids accumulation and corresponded to more than 60 % of the total amount of deposit. This kind of

fouling was mainly located at the surface of the filter; the difference between the superficial layer and the following layer was higher than 50 %, and increased with the working time. This kind of fouling was the consequence of the suspended solids contained in water (245 mg L^{-1}). Suspended solids were kept in the superficial layer when the suspended particle size was higher than the pores of the filter media.

Table4. Physical fouling values (%)

	Time (day)					
Sand layer	1	2	3	4	5	6
1	7.26	7.66	8.26	10.32	11.74	12.11
2	5.20	6.38	3.11	5.41	5.02	5.11
3	3.76	4.39	1.80	4.03	4.98	4.69
4	2.81	2.86	0.86	1.97	3.25	2.80
5	0.76	0.99	0.07	0.23	1.09	1.60

Mechanical fouling was the consequence of various factors: water flowing and settling of the filtration support under the effect of its weight, salt leaching owing to sand salinity, as well as the diffusion of the small particles from the upper to the bottom of the filter. Contrarily to the other fouling mechanisms, the mechanical one increased with the depth, since the compaction of the grains of sand and the water pressure increased from the upper to the bottom of the filter. Water was also involved through small particle transport from the upper to the filter bottom.

Among the different king of fouling, the biological one seemed to be the less important. It corresponded to 3.0 % of the total amount of deposit for the first filter and increased until 7.6 % after 6 days. This fouling was caused by the organic matter inputs from the wastewater, which can be suspended solids or dissolved matter. Above data showed that these inputs were mainly suspended solids, accounting for the distribution of the organic matter in the filtration layer, which decreased from the upper to the filter bottom. Microorganism and algae at the surface of the filter were also involved in this fouling.

4. Conclusion

Fouling was mainly observed in the two upper filter layers. The amount of organic matter deposit in the first layer was at least two folds higher than the amount found in the last layer, and that for all filters. Porosity decrease and organic matter increase must be highlighted.

Sand filter undergone three kinds of fouling during its running: mechanical fouling consequently to water flowing; physical fouling due to suspended solid retention; and organic and biological fouling resulting from organic matter accumulation as well as microorganisms and algal formation.

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