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Chemical and physical characteristics of dune sand filters after operation

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ABSTRACT

Wastewater flow through a sand filter causes variations in the physical and chemical properties of the filter media. The objective of this study was to investigate and characterize the physical and chemical properties of dune sand filters after a certain period of operation. Lab-scale studies were performed using four dune sand filter columns for treating wastewater. The column was split into ten layers; each of which was through physical and chemical analyses after a certain operational period. It was observed that 34%–51% of the organic matter in the column was found in the top layer. The flow of wastewater caused a deposition of limestone and fine particles onto the filter. There was a noticeably low pH in the upper layers of the columns due to the high amounts of organic matter. Lastly, the virgin sands were more saturated in salts than the used sand after operation.

Keywords: Wastewater treatment; Biological sand filter; Organic matter accumulation; Dune sand

1. Introduction

Domestic wastewater treatment and reuse is becoming an important field of research in the global context of increasing water scarcity and inadequate sanitation [1]. Among the available processes for wastewater treatment, the use of septic pits followed by sand filtration appears to be the most relevant in the southern region of Algeria due to the smaller urban agglomerations.

The use of the sand dunes as a biological filter is a promising technique for wastewater treatment in Algeria, and the characteristics of most sands in the region of Ouargla appear to be favorable according to the standards of biological filtration [2,3].

Accumulation of biomass and deposition of suspended solids on the surface of a sand filter can lead to clogging of the filter media. Biological and physical clogging results from the excessive formation of biomass due to the degradation of pollutants and retention of inert suspended fine particles [4,5]. Furthermore, physical/mechanical clogging may result from the migration of fine-grained materials into coarse-grained materials [6].

The objective of this work was to characterize the physical and chemical properties of the filter media of dune sand filters. To accomplish this, lab-scale filter columns containing dune sand were used to treat wastewater. Sand was taken from four different locations, and four corresponding pilot filter columns were made.

The columns were operated for a period of twelve weeks, after which a comparative study of the dune sand in each column was conducted. The accumulation of biomass and the deposition of suspended solid material at the surface of a sand filter were investigated by chemical and physical analyses of the sand filter. The variations in limestone yield, sand column pH, and electrical conductivity (EC) in the different column layers were also investigated.

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2. Materials and methods

Laboratory sand columns were operated for a period of 12 weeks to treat wastewater [2]. The experiment was performed in polyvinyl chloride laboratory columns, 800 mm in height, with 76 mm inner diameter. 600 mm of sand were placed in each sand filter column (Fig. 3). Over the course of operation, the filters were fed with synthetic wastewater [3]. The composition of the synthetic wastewater was: glucose, yeast, dried milk, urea, NH_4Cl, $NaHCO_3$, $MgSO_4.7H_2O$, $CaCl_2.6H_2O$, and K_2HPO_4 [4,7], supplied at a flow rate of 520 mL/d [3]. The characteristics of the synthetic wastewater are given in Table 1.

The dune sands were taken from four locations (Fig. 1) in southern Algeria: Tebesbest (T), Benaceur (B), Hassi Messaoud (H), and N'Goussa (N). The physiochemical characteristics of the spent (T, B, H, and N) and virgin (Tv, Bv, Hv, and Nv) sand samples from each of these locations were compared.

2.1. The physical characteristics of virgin sands

The physical characteristics of virgin dune sand from the four locations are shown in Fig. 2 and Table 2.

2.2. The chemical characteristics of virgin sands

Based on the physical characteristics of the virgin sands (Table 2), the Bv and Nv sand was classified as having a very tight particle size distribution (Cu ≤ 2), and the rest of the virgin sands samples (Tv and Hv) as having tight particle size distributions (2 ≤ Cu ≤ 5) [8]. The chemical characteristics of virgin dune sand from the four locations are shown in Table 3.

These sands are, therefore, favorable for use as the filter media. Several other studies have also indicated the favorable use of these sands as filter media [2].

Table 1
Characteristics of the wastewater

Characteristics		Wastewater standards
BOD_5 as mg O_2/L	480 ± 20	100–500
DOC as mg O_2/L	878.4 ± 10	300–1,000
EC as μS/cm	970	900–1,300
pH	6.66 ± 0.5	7.5–8.5

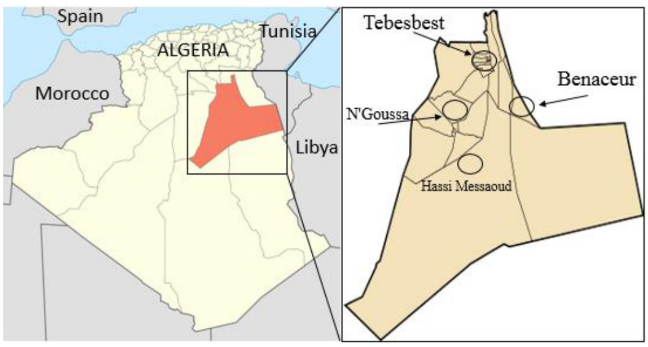

Fig. 1. Map of the dune sands locations: Tebesbest, Benaceur, Hassi Messaoud, and N'Goussa.

2.3. Sampling

After the 12-week operational period, the filters were allowed to be drained by gravity. In order to have good curves of evolution of the characteristics of the filters, the columns were then dismantled and divided into 10 layers, each measuring 60 mm [9], and numbered from 1 to 10 from the top to the bottom Fig. 3. The sand samples were dried in an oven at 105°C for 24 h.

2.4. Laboratory analyses

Samples of each layer were subjected to the following chemical and physical analyses.

Measuring the rate of organic matter by the Anne method: oxidation method directly measures organic carbon via excess potassium bichromate in sulphuric acid; the excess of potassium bichromate ions is back-titrated against a ferrous solution using diphenylamine as redox indicator [10].

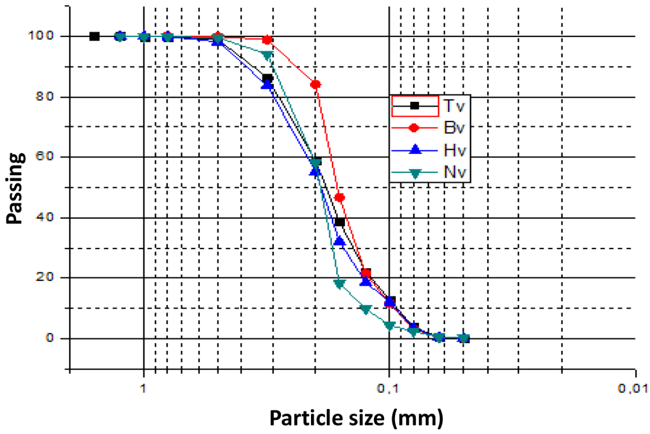

Fig. 2. Particle size distribution of virgin sands.

Table 2
Physical characteristics of virgin dune sand

Parameters	Tv	Bv	Hv	Nv
D10 (mm)	0.09	0.10	0.10	0.12
D60 (mm)	0.20	0.17	0.22	0.21
D30 (mm)	0.14	0.13	0.15	0.17
Uniformity coefficient Cu	2.18	1.81	2.32	1.75
Real density g/cm^3	2.88	2.79	3.07	2.96
Apparent density g/m^3	1.54	1.58	1.62	1.53
Porosity *n* (%)	46.56	43.44	47.23	48.46

Table 3
Chemical characteristics of virgin dune sand

Parameters	Tv	Bv	Hv	Nv
Organic matter	0.37	0.16	0.42	0.40
$CaCO_3$	4.32	2.79	0.32	0.27
pH	8.39	8.76	8.22	8.35
EC	2.68	0.46	0.35	3.52

Measuring the rate of limestone by using the BERNARD calcimeter: calcimeter is a device used to determine the calcium carbonate ($CaCO_3$); the apparatus works on the principle that a soil sample placed in contact with hydrochloric acid (HCl) causes carbon dioxide (CO_2) emission.

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2 \text{ [10,11]} \quad (1)$$

Particle size analysis by sieving: the operation was based on the separation of particles by size, usually by sieving. Samples of sand were filtered through a series of sieves of decreasing diameters from the top to the bottom using the AFNOR standards [12].

The pH and EC measurement was made by a pH meter and EC meter, respectively, in soil extract (mixing soil with added water, ratio soil/water was 1/5) [10].

Chemical oxygen demand (COD) was determined according to the AFNOR standard (NFT 90-101). Under hot, acidic conditions, potassium dichromate oxidizes practically all organic substances. The analyses are carried out with an excess of potassium dichromate, whereby a part of the dichromate is reduced to the chromium(III) ion; the excess of potassium dichromate ions is back-titrated against a ferrous solution using ferroin as redox indicator [13,14].

Biological oxygen demand (BOD_5) was determined by the manometric method. The amount of a defined quantity of dissolved oxygen consumed is measured in a closed, calibrated vessel by determining the difference between incubation. The O_2 is determined volumetrically or electrometrically [13,14].

3. Results and discussion

The removal yields of COD during the period of operation were between 72.09% and 94% (from 48 to 230 mg O_2/L, column T), 63.70% and 91% (from 76.8 to 249 mg O_2/L, column B), 64.74% and 93% (from 52 to 240 mg O_2/L, column H), and 63.30% and 90% (from 60 to 244 mg O_2/L, column N).

BOD_5 removal yields were between 80% and 92% (from 40 to 90 mg O_2/L column T), 76.08% and 94% (from 30 to 110 mg O_2/L column B), 83.69% and 96% (from 20 to 75 mg O_2/L column H), and 60% and 90% (from 40 to 180 mg O_2/L column N); a decrease of the COD and DOB removal yields was observed in the last week of operation, which can be explained by water stagnation in the surface and filter clogging.

The BOD_5 represents the activity of aerobic microorganisms on filters surface; the BOD_5 results showed a significant degradation of the organic matter.

3.1. Organic matter content

The organic matter content was measured for each layer and for each type of sand (used and virgin).

The organic matter content obtained for the virgin sands was 0.37% (Tv), 0.16% (Bv), 0.42% (Hv), and 0.40% (Nv); all sands were poor in organic matter, as has previously been reported [2].

The distribution of organic matter in the four types of sands can be divided into two intervals. The first interval corresponds to the surface layer (layer 1) as shown in Fig. 4 and Table 4, which was characterized by a significant increase in the amount of organic matter (from 1.87% to 2.12%). This is

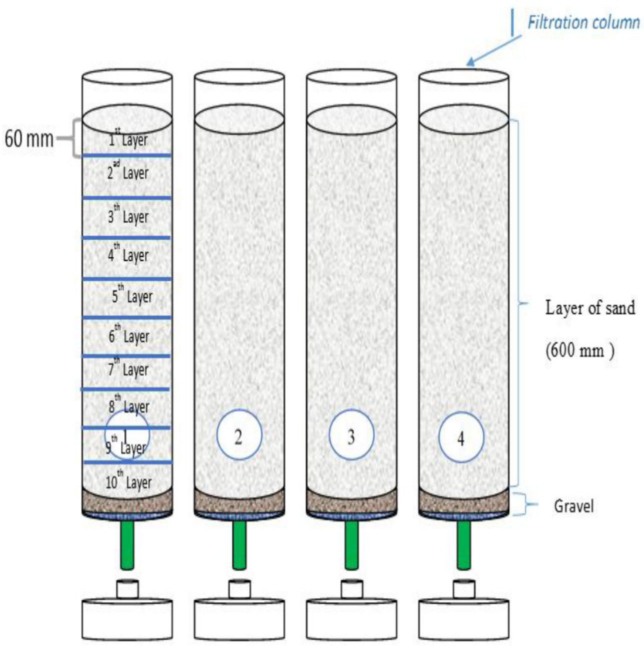

Fig. 3. Schematic of the filtration columns used.

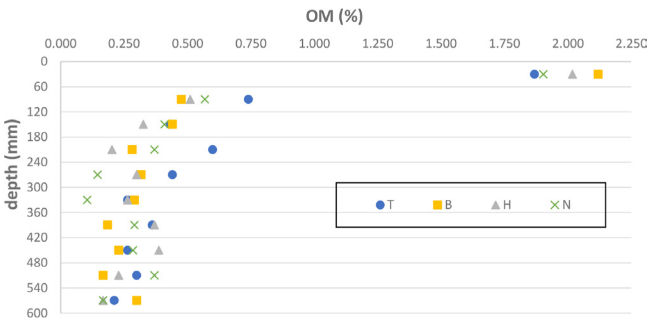

Fig. 4. Vertical distribution of organic matter after the operation (%).

Table 4
Vertical distribution of organic matter after operation (%)

Organic matter (%)				
Layer	T	B	H	N
1	1.87	2.12	2.02	1.90
2	0.74	0.48	0.51	0.57
3	0.43	0.44	0.33	0.41
4	0.60	0.28	0.20	0.37
5	0.44	0.32	0.30	0.15
6	0.26	0.29	0.26	0.11
7	0.36	0.19	0.37	0.29
8	0.26	0.23	0.39	0.29
9	0.30	0.17	0.23	0.37
10	0.21	0.30	0.17	0.17

because the first layer was the site of deposition of organic matter and because microbial activity including algal growth occurred on the surface of the filters [4,15]. The second interval corresponds to the deeper layers (layers 2–10). The organic matter content varied from 0.21% to 0.74% (layers 2–10) in column T, gradually decreasing with depth, but remaining significantly higher as compared with the virgin sand (Tv) in deeper layers (2–5). This is likely due to the deposition of organic matter, which was transported by the flow of wastewater. The organic matter content in column B varied from 0.17% to 0.47% in the underlying layers (layers 2–10). A small increase in organic matter compared with the virgin sand (Bv) was observed. This is most likely due to the fact that the sand obtained from the dune of Bv was fine (particles diameter ≤0.8 mm, and uniformity coefficient = 1.81). Columns H and N showed low organic matter content in layers 3–10 compared with the corresponding virgin sands. The main accumulation of organic matter was in the first and second layers. The organic matter content in the surface layer represented about 34%–51% of the total amount of organic material accumulated in the sand column. Accumulation and secretion of microorganisms as biofilms on the surface layer caused surface ponding on the filter.

3.2. Limestone content

$CaCO_3$, a mineral constituent of sand, has been previously shown to have a high absorption capacity for phosphorus [7]. This results from the Ca_2^+ ion, which forms from the dissolution of $CaCO_3$, and reacts with the PO_4^3 ion to form an insoluble compound. However, the presence of large quantities of the resulting calcium phosphate in the filter medium is unfavorable. The precipitation of this insoluble mineral can cause cementing in the sand grains and, consequently, lead to rapid clogging of the filter [16].

The limestone content in the virgin sands Tv and Bv was 4.32% and 2.79%, respectively. After the operation, the limestone content recorded in the surface layer of columns T and B had decreased by 2.76% and 1.06%, respectively. The limestone content in layers 2–10 was between 3.94% and 4.56% for column T, and between 2.19% and 2.87% for column B as shown in Fig. 5 and Table 5.

The virgin sand samples Hv and Nv showed low limestone amounts, 0.32% and 0.27%, respectively. After operation, the limestone content recorded in layers 1–10 of column H was between 0.03% and 0.47%. Limestone content was very low in the layers of column N, where the sand was found to be nearly decarbonized (0% $CaCO_3$ in the surface layers).

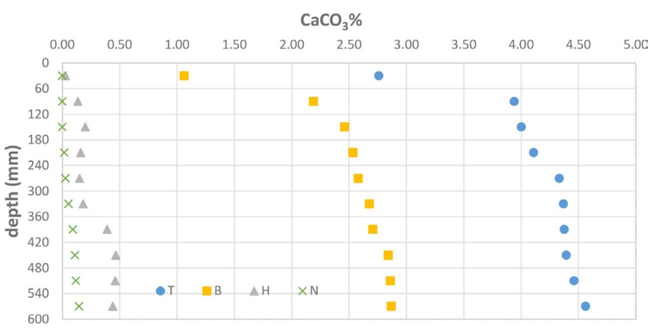

Fig. 5. Limestone yields after the operation ($CaCO_3$ [%]).

Two simultaneous processes can explain the development of limestone. One of these processes is biochemical, and the other is physical (Fig. 6). The first is the lixiviation of limestone, corresponding to the decarbonation of the sand by organic acids. The organic acids derive from the decomposition of organic matter due to the microbial biomass, which develops in the upper layers of the filter. The carbonate dissolution process is triggered according to the reaction:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca_2^+ + 2HCO_3^- \text{ [17]} \quad (2)$$

Table 5
Limestone content after operation ($CaCO_3$ [%])

Layer	T	B	H	N
1	2.76	1.06	0.03	0.00
2	3.94	2.19	0.14	0.00
3	4.00	2.46	0.20	0.00
4	4.11	2.53	0.16	0.02
5	4.33	2.58	0.15	0.03
6	4.37	2.68	0.18	0.05
7	4.38	2.71	0.39	0.09
8	4.40	2.84	0.47	0.11
9	4.46	2.86	0.46	0.12
10	4.56	2.87	0.44	0.15

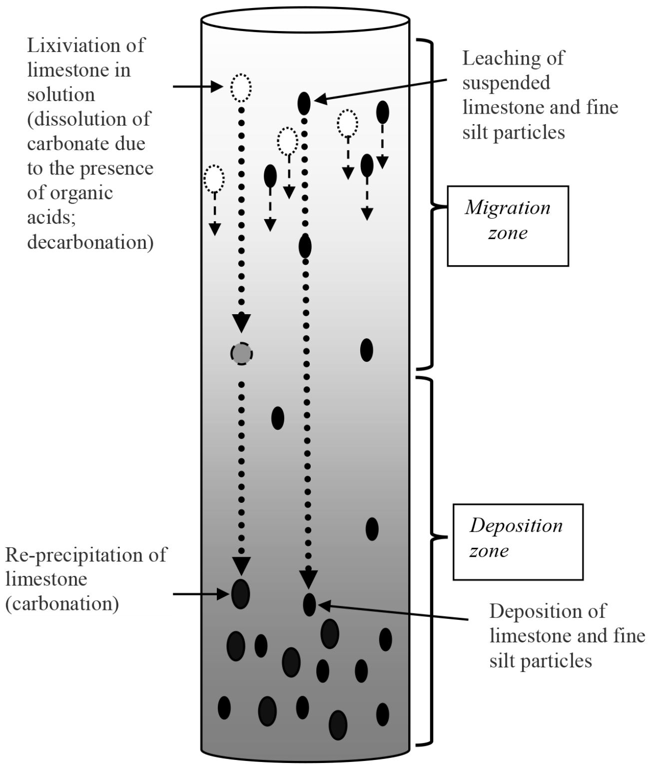

Fig. 6. Model of migration and deposition of limestone and fine silt in the dune sand filter.

The second is a physical process, in which limestone silt particles are leached through the filter sand column due to the wastewater flow (Fig. 6). As a result, all the columns showed an increasing gradient of limestone from the top to the bottom of the columns.

3.3. pH

The virgin sands were alkaline with a pH of 8.39 (Tv), 8.76 (Bv), 8.22 (Hv), and 8.35 (Nv). After the 12-week operational period, a small decrease in pH was observed.

For each column, the pH increased with depth. The pH values ranged between 7.72 and 8.12 (column T), 7.65 and 8.64 (column B), 7.26 and 8.23 (column H), and 6.70 and 8.75 (column N) as shown in Fig. 7 and Table 6.

3.4. Relation between organic matter and limestone and pH

Figs. 8 and 9 confirm that the change in pH is correlated with the amount of organic matter and limestone.

The pH was relatively low in the upper layers of the columns where the organic matter content was elevated mainly due to microbial processes; pollutant transfer and biodegradation kinetics rely on material characteristics such as: pH and organic matter [18]. pH displayed a positive correlation with the limestone rate (Fig. 9), which is attributed to the leaching and dissolution of limestone by the flow of wastewater, as well as through the natural presence of organic acids. At the bottom of each column, pH values were more alkaline, as there was an accumulation of limestone resulting from the leaching process from the upper layers of the columns (Fig. 6).

Fig. 7. The pH variation in the sand layers.

3.5. Electrical conductivity

The total salt content expressed by the EC of the diluted extracts (soil/water ratio of 1/5) showed negligible amounts of salts for all sands (EC < 2.5 ms/cm). However, Tv and Nv were slightly saline [12] as shown in Table 7 and Fig. 10. The virgin sands were more saline than the used sands.

The EC at 25°C varied from 0.85 to 2.35 ms/cm (column T), from 0.48 to 0.14 ms/cm (column B), from 0.08 to 0.18 ms/

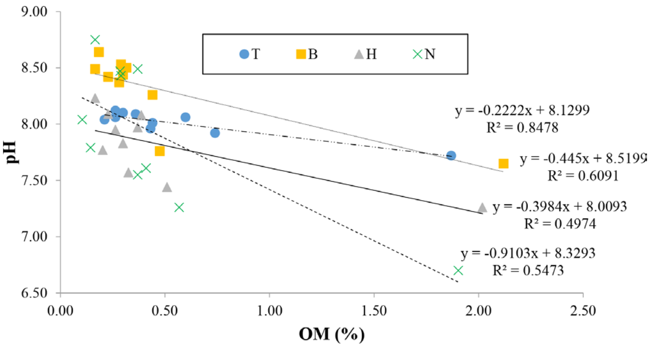

Fig. 8. The evolution of the pH in correlation with the organic matter.

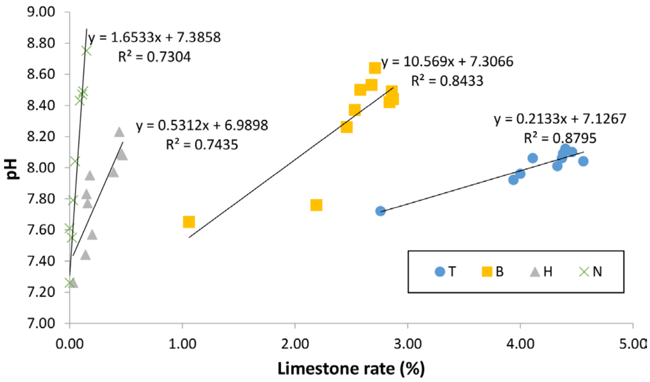

Fig. 9. The evolution of pH in correlation with limestone.

Table 6
pH of the sands after operation

Depth	T	B	H	N
1	7.72	7.65	7.26	6.7
2	7.92	7.76	7.44	7.26
3	7.96	8.26	7.57	7.61
4	8.06	8.37	7.77	7.55
5	8.01	8.50	7.83	7.79
6	8.06	8.53	7.95	8.04
7	8.09	8.64	7.97	8.43
8	8.12	8.42	8.08	8.47
9	8.10	8.49	8.09	8.49
10	8.04	8.44	8.23	8.75

Table 7
EC of the sands after operation

Depth	T	B	H	N
1	0.85	0.48	0.18	0.22
2	2.27	0.37	0.18	0.21
3	2.27	0.19	0.10	0.40
4	2.31	0.21	0.08	0.14
5	2.31	0.14	0.08	0.24
6	2.33	0.20	0.09	0.22
7	2.32	0.19	0.10	0.13
8	2.35	0.20	0.10	0.15
9	2.31	0.23	0.11	0.19
10	2.35	0.20	0.12	0.22

cm (column H), and from 0.13 to 0.40 ms/cm (column N). The EC decreased from top to bottom within a given filter, most likely due to salt leaching by the flow of water [3]. Salt flocculation plays a minor role, if any. Flocs are mainly formed by a combination of two groups of processes: those bringing particles together and those keeping them together [19]. Chemical clogging occurred in the filter column due to the deposition of dissolved salts into the pores. Furthermore, there was an alteration in the structure of the sand due to deflocculation [20].

3.6. Particle size analysis

The flow of wastewater through the filters for the 12-week operational period caused a vertical redistribution of the fine fraction (<0.050 mm), including the fine silt in the sand column. The fine fraction migrates by leaching from the upper layers to the bottom layers of the filters (Table 8), due to the intergranular macroporosity of the sand filter. The fine particles penetrated deep within the filter; thus, the leaching of fine particles caused clogging of the column filters in the lower portion. This can be observed in the operating model of the dune sand filter (Fig. 6). After the operation period, a particle size analysis was performed for each layer using the AFNOR standards. The results are shown in Table 8 and Fig. 11.

The purpose of the particle size analysis was to characterize the size of the mineral elements of the sand and to quantify the particle weight distribution.

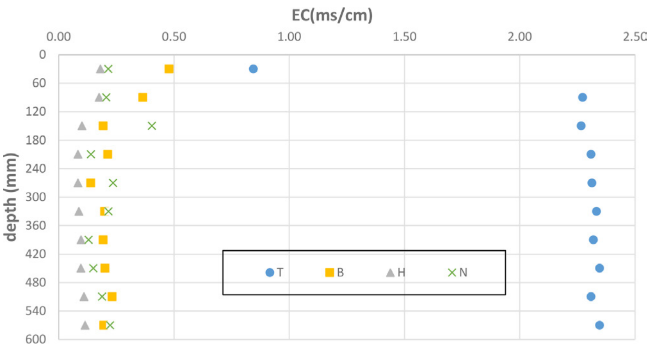

Fig. 10. The variation of the EC in the sands already used as a function of the depth of the layers.

Table 8
Fine silt (%) after operation

Layer	T	B	H	N
1	0.073	0.114	0.063	0.073
2	0.062	0.126	0.085	0.140
3	0.090	0.128	0.096	0.204
4	0.094	0.156	0.106	0.183
5	0.114	0.181	0.107	0.209
6	0.163	0.176	0.128	0.261
7	0.201	0.203	0.131	0.229
8	0.195	0.191	0.131	0.230
9	0.256	0.236	0.135	0.261
10	0.273	0.292	0.151	0.266

Fig. 11 shows the distribution of fine silt in correlation to the depth of each layer. The percentage of fine particles increased with depth; this is consistent with observations from previous studies. The finer particles tend to penetrate deeper into the sand bed as the wastewater carries fine materials grains into the depths of the filter [21].

4. Reusability

The quantity of organic matter was higher (between 1.87% and 2.12%) within the surface layer (layer 1). The sand in layer 1 was sealed and cemented by the organic matter; thus, it is unfavorable to reuse as filter media. However, sewage sludge and biosolids can be used as a supplement to fertilizers to reduce costs [22] and can be even used for producing methane gas as an energy source from the sludge [23]. The organic matter content for the other layers (from 0.15% to 0.74%), where the sands were poor in organic matter [2], appears to be acceptable for reuse as filter media.

After operation, the limestone contents for columns H and N were negligible (0%–0.47%) and were between 1.06% and 4.56% for columns T and B, showing that all the columns were acceptable for reuse as filter media, to improve the filtration process After the operation period, this work suggests removing and changes the first layer.

5. Conclusions

Wastewater flow and biological activity were the major factors involved in the modification of the characteristics of dune sand filters. In the surface layer, the organic matter content was between 1.87% and 2.12%, which can be explained by an accumulation of organic matter due to the flow of wastewater. In the other layers (depths of 60–600 mm), the organic matter content was between 0.15% and 0.74% and. After operation, the limestone content for columns H and N was negligible at 0.47%–0%, but was slightly higher for columns T and B, at 1.06%–4.56 %, respectively.

Fine particles and limestone were transported and deposited within the columns. For each column, the pH increased with depth (from 7.72 to 8.10 for T, from 7.65 to 8.64 for B, from 7.26 to 8.23 for H, and from 6.70 to 8.75 for N). The electric conductivity as a function of depth indicates that the salts were washed downward by the flow of the wastewater.

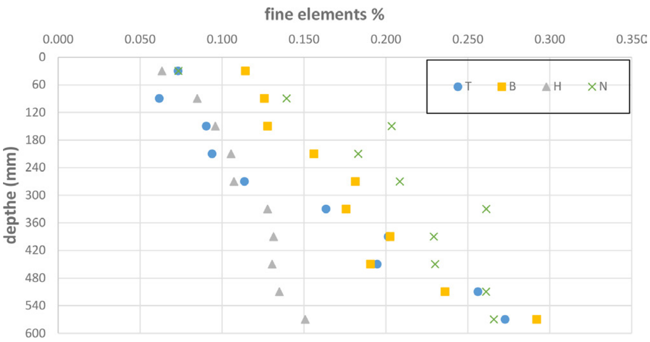

Fig. 11. The distribution of the fine particles in the sand columns.

References

[1] S. Finley, S. Barrington, D. Lyew, Reuse of domestic greywater for the irrigation of food crops, Water Air Soil Pollut., 199 (2009) 235–245.

[2] Y. Touil, S. Tahab, R. Issaadi, A. Amrane, Pilot plant for wastewater treatment involving septic pit and biological filtration on sand of dunes of the Algerian Sahara, Desal. Wat. Treat., 10 (2009) 148–152.

[3] G. Yamina, A. Abdeltif, T. Youcef, H.M. Mahfoud, G. Fatiha, B. lotfia, A comparative study of the addition effect of activated carbon obtained from date stones on the biological filtration efficiency using sand dune bed, Energy Procedia, 36 (2013) 1175–1183.

[4] M. Rodgers, J. Mulqueen, M.G. Healy, Surface clogging in an intermittent stratified sand filter, Soil Sci. Soc. Am. J., 68 (2004) 1827–1832.

[5] A. Sani, M. Scholz, A. Babatunde, Y. Wang, Impact of water quality parameters on the clogging of vertical-flow constructed wetlands treating urban wastewater, Water Air Soil Pollut., 224 (2013) 1488–1505.

[6] H. Kandra, D.M. Carthy, A. Deletic, Assessment of the impact of stormwater characteristics on clogging in stormwater filters, Water Resour. Manage., 29 (2015) 1031–1048.

[7] L. Gill, C. Doran, D. Misstear, B. Sheahan, The use of recycled glass as a filter media for on-site wastewater treatment, Desal. Wat. Treat., 4 (2009) 198–205.

[8] V. Robitaille, D. Tremblay, Mécanique des sols: Théorie et Pratique, Edition Modulo, 1997.

[9] Y. Touil, Y. Gherairi, R. Issaadi, A. Amrane, Biological filtration on sand of dunes – Filters fouling, Energy Procedia, 50 (2014) 471–478.

[10] G. Aubert, Méthodes d'analyse des sols, Edition centre régional de documentation pédagogique, Marseille, 1978.

[11] V. Gowariker, V.N. Krishnamurthy, S. Gowariker, M. Dhanorkar, K. Paranjape, The Fertilizer Encyclopedia, John Wiley & Sons, Canada, 2009.

[12] D. Baize, Guide des analyses en pédologie, Edition INRA, Paris, 2000.

[13] J. Rodier, Analyse de l'eau, Edition Dunod, Paris, 2009.

[14] W. Fresenius, K. Quentin, W. Schneider, Water Analysis: A Practical Guide to Physico-Chemical, Chemical and Microbiological Water Examination and Quality Assurance, Springer, Berlin Heidelberg, 1988.

[15] N. Djedidi, A. Hassen, Physical properties of soils and ability to clog sewage according to their degree of treatment, Cah. ORSTOM sér. Pédol., 1 (1991) 3–10.

[16] M. Clément, P. Françoise, Analyse chimique des sols, Edition Tec Doc Lavoisier, 2003.

[17] N. Durand, H.C. Monger, M.G. Canti, Calcium Carbonate Features, Chap. 9, Interpretation of Micromorphological Features of Soils and Regoliths, Elsevier Netherlands, 2010, pp. 149.

[18] M.B. Jaber, B. Anet, A. Amrane, C. Couriol, T. Lendormi, P. Cloirec, G. Cogny, R. Fillières, Impact of nutrients supply and pH changes on the elimination of hydrogen sulfide, dimethyl disulfide and ethanethiol by biofiltration, Chem. Eng. J., 258 (2014) 420–426.

[19] D. Eisma, Flocculation and de-flocculation of suspended matter in estuaries, Neth. J. Sea Res., 20 (1986) 183–199.

[20] S. Ettaleb, R. Elhaouti, M. Abbaz, S. Lhanafi, M. Ezzahery, R. Aba-aaki, N. Elalem, Comparison of the clogging phenomenon wastewater through two types of sand: one virgin and one used during treatment with infiltration, J. Mater. Environ. Sci., 5 (2014) 1906–1912.

[21] A. Alem, A. Elkawafi, A. Benamar, H. Wang, N. Ahfir, Transport and retention of clay particles in a saturated porous medium, International Conference Soils Non Saturated and Environment, Tlemcen, 2009.

[22] C.S. Gilbert, Recycling biosolids and lake-dredged materials to pasture-based animal agriculture: alternative nutrient sources for forage productivity and sustainability. A review, Agron. Sustain. Dev., 29 (2009) 143–160.

[23] T. Fitamo, A. Boldrin, K. Boe, I. Angelidaki, C. Scheutz, Co-digestion of food and garden waste with mixed sludge from wastewater treatment in continuously stirred tank reactors, Bioresour. Technol., 206 (2016) 245–254.