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Improving sand filtration of municipal wastewater pre-treatment by optimization using local Algerian media

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ABSTRACT

The main purpose of this study was to improve sand filtration process by using local media and optimizing to obtain the best operating parameters. Sand from the Algerian desert was utilized. The treatment effectiveness on domestic effluent was assessed by monitoring pollution parameters such as turbidity, chemical oxygen demand (COD) and biological oxygen demand (BOD). The results of showed that the sand had a homogenous structure with a large presence of angular and blunted grains and a low percentage in round grains. This characteristic improves the filtration efficiency. The results showed also that the abatement rates of pollution indicators such as turbidity, COD and BOD were high for all experiments, between 60% and 90%. The sand filter designed in this study demonstrated a great performance for the treatment of domestic wastewater.

Keywords: Wastewater treatment; Sustainable process; Algerian sand; Turbidity abatement; Sand filtration

1. Introduction

Access to fresh water represents a major issue for upcoming years. It is therefore necessary to find alternative solutions for overcoming this shortage in water. Today, the preservation of water resources and the environment is a big challenge, which depends on the ability to treat wastewater before being reused or released into the natural environment. In order to have good water quality that meets the standards of rejection or reuse, the wastewater must pass through a series of purification treatment using different techniques in water treatment plants.

Algeria, one of North African countries suffering from water shortages, for example, has adopted a strategy to integrate simple and economical techniques to achieve the government's action plan 2030 regarding the reuse of treated water for irrigation. One billion m^3 of treated wastewater will be reused to nearly double the area of irrigated land, from 1.2 million ha to 2.2 million ha. Research has been conducted in this field using various wastewater treatments methods [1,2]. Among these techniques, sand filtration was one of the oldest methods with a proven effectiveness since the 19th century in removal of suspended solids [3–5]. At a flow rate of 0.1–0.2 m^3/h, it was an effective wastewater treatment technology. It was also efficient in removing total coliforms such as Giardia, Cryptosporidium, Salmonella, Escherichia coli, (TC) and fecal coliform such as fecal streptococci, as well as bacteriophage, MS2 virus from water/wastewater [6,7].

Today, this method is still well suited in most global purification stations, since it has a good quality of treatment, a simple operation and has a relatively limited maintenance. Many researchers have carried out studies [8–12]

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to perfect its functioning and improve its purification efficiency. This process has been widely used in Algeria, especially due to the ready availability of the raw material sand from the vast southern desert.

The current investigation was part of a wastewater treatment team project, from the Solar Equipment Development Unit (UDES), located in Bou-Ismail, Algeria. This project focused on design of a micro-wastewater treatment plant using sustainable processes with renewable energies or processes utilizing minimum energy consumption like solar photocatalysis [13–15] and solar wastewater treatment SOWAT [16]. In this context, a new sand filter for wastewater treatment was developed. To improve the filtration process as a primary or final treatment in the micro-plant, several filter materials from the Algerian desert were assessed to obtain a better quality of treated wastewater.

2. Materials and methods

2.1. Experimental set-up

The experimental set-up was designed and carried out in a wastewater treatment laboratory of Development Unit of Solar Equipment (UDES), located in Tipaza, Algeria. The filter was Plexiglas parallelepiped 20 cm long, 20 cm wide, and 50 cm high. The device was transparent allowing for the observation of the incident phenomena. The set-up contained a perforated plate, which served as a sand filter support. The sand filter consisted of bottom to top, four essential layers, a draining layer of gravel, then a layer of coarse sand, a filter layer of fine sand and a top layer of gravel G, as described in Fig. 1. The sand filter was gravity fed using a 12 L capacity tank placed above. The filtrate (filtered water) was collected in a tank using a valve at the end of the filter. The water from the feed passed through a perforated tube to ensure a good distribution of the wastewater at the inlet of the filter.

2.2. Filter materials

In southern Algeria, there is a large sand potential, the majority of this sand meets the characteristic standards of sand filtration. The different types of sand used in this study as a filter media are presented in Fig. 2.

The first sand (noted sand 1) came from Ouargla dunes and was formed by the sand wind at a height of 300 m, more precisely from the great desert. This type of sand was very fine. The second-sand (sand 2) came from the wilaya of Oued Souf, commune of Djamaa. This sample was underground sand extracted from sand mines located in the Tigdidine region at a depth of 100 m. This type of sand was generally destined for construction. Sands 3 and 4 were extracted from Ouargla from the region of "Neggar". They were like sand 2, deep sands extracted from two different sandpits. They were also intended for construction.

Several designs of sand filters were carried out during this study, by varying the height of the sand, the type of sand or the addition of other filtering materials. Table 1 groups all designed filters.

2.3. Sand characterization

Sand characterization was achieved by granulometric analysis by sieving and morphoscopic by observing the insoluble fraction. The particle size was measured by a laser micro-particle size analyzer of the "Mastersizer 2000 from the firm Malvern". The particles to be measured were diluted in a 0.6–1 L beaker and then circulated in a cell traversed by a parallel laser beam to measure the size of the particle. Microscopic analysis was carried out using a binocular magnifying glass, under intense illumination produced by a lamp, whose light was converged into a punctual light beam. This allowed for to observation of the shape and appearance of the surface the sand particles.

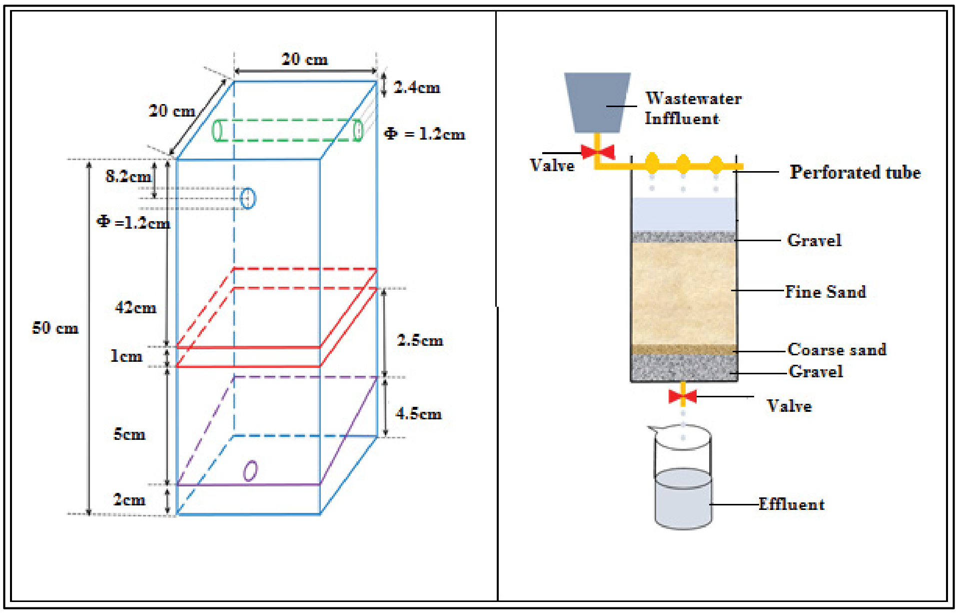

Fig. 1. Experimental set-up.

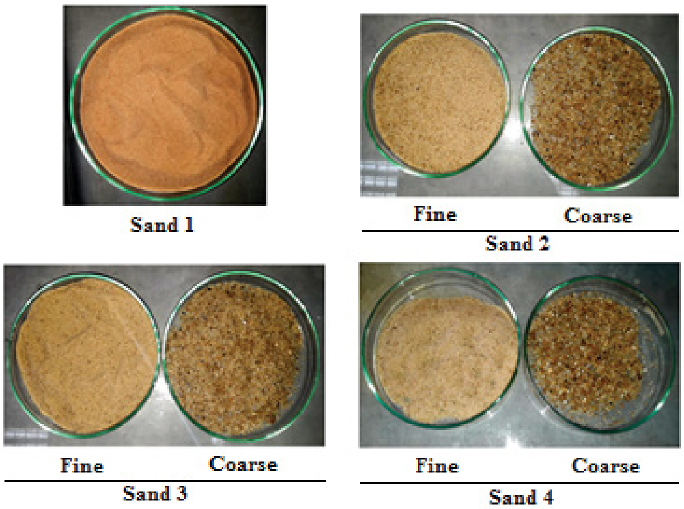

Fig. 2. Media used in sand filter design. Sands 1 to 4 (i.e., S1 to S4).

Table 1
Filter design parameters

	Filter materials	Height (cm)
Filter name and code	Top layer: gravel	1
	Middle layer: fine sand	Variable
	Bottom layer: gravel + coarse sand	5 + 2
Filter 1/F1	Sand 3	5
Filter 2/F2	Sand 3	10
Filter 3/F3	Sand 3	15
Filter 4/F4	Sand 3	20
Filter 5/F5	Sand 3	25
Filter 6/F6	Sand 1	10
Filter 7/F7	Sand 2	10
Filter 8/F8	Sand 4	10

Table 2
Physical–chemical characteristics of the real effluent

Wastewater	E1
Turbidity (NTU)	177 ± 26
COD (mg/L)	209 ± 21
BOD (mg/L)	161 ± 26
pH	7 ± 0.01
Conductivity (µs/cm^2)	1,179 ± 36

2.4. Wastewater characterization

The effluent used for the filtration system was municipal wastewater (noted E1) taken from the waste point of the city of Fouka, Bou Ismail, Tipaza. The effluent was characterized before and after treatment by measuring different pollution parameters. The turbidity measurement was carried out by a Turbidimeter HI88703 "HANNA Instrument" while the conductivity and the pH are measured by the Multiparameter "Consort C3010". As well, chemical oxygen demand (COD) and biological oxygen demand (BOD) measurements are given by using the photometer-System AL200 and Velp Scientifica™ BOD Sensor respectively. Results of physical–chemical characteristics of the real effluent are summarized in Table 2.

3. Results and discussion

3.1. Sand characterization

The grain size distribution of filter media was one of the most important operating variables, which ensured effluent quality [17,18]. Particle size analysis consisted of isolating various particle sizes or size increments and then measuring the abundance of each size [19]. To have the particle size distribution of the sands, S1, S2 and S3 were analysed by a laser granulometer "Mastersizer 2000 (Malvern)". However, due to the existence of large particles in the sand S4 the particle sizing was accomplished by sieving method. Likewise, particle suspensions of different sands were prepared with distilled water as a dispersant agent. The percentage of volume corresponding to each observed population was obtained using the software provided with the equipment (Mastersizer 2000 (Malvern)).

The results from the analysis of S1, S2 and S3 were relative volume distribution of particles in the size range 0.02 to 2,000 microns While the result of particle size distribution of the sand S4 by sieving was expressed as a percent retained by weight on each sieve size. Since the particles studied most likely had the same density, it can be assumed that the density percentage was equivalent to the mass percentage.

The particle distribution curves obtained by plotting cumulative percent passing vs. particle size based on the data calculated are presented in Fig. 3. Sand S1 showed a heterogeneous mixture of grain sizes distribution with two particle size categories: the dominant size fraction (10%) represented by medium sand about 350 µm, and the least frequent fraction (6.5%) represented by very coarse sand 1,300 µm. Sand S3 also showed a non-uniformity in size

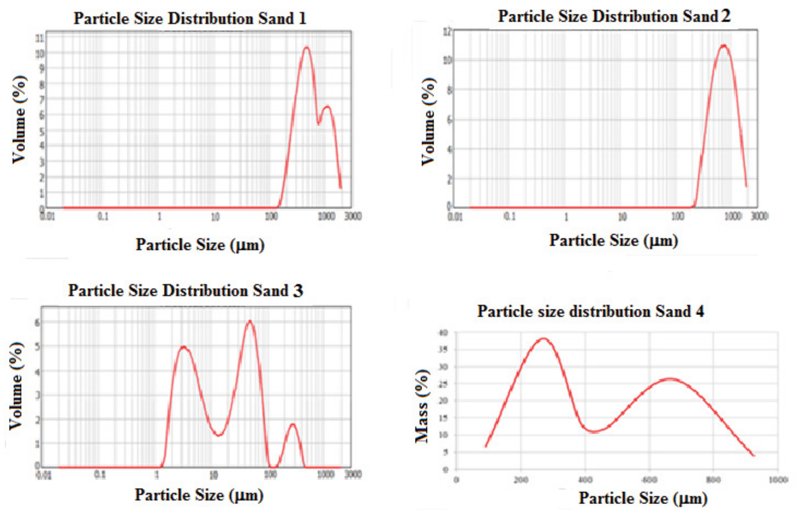

Fig. 3. Particle sizes distribution curves for sands S1 to S4.

distribution. Three size categories were observed, two dominant grain sizes with a proportion of 6% and 5%: fine sand with 40 µm diameter, and very fine sand 3.5 µm diameter respectively, and the least frequent grain size 1.8% a medium sand, which was around 280 µm in diameter. The results showed that the dominant grain sizes were fine and very fine sands.

Similar results were obtained for S4 which showed a discontinuous particle size distribution. There were two categories of size: the medium sand approximately 267 µm diameter was the most frequent with a proportion of 38%, and coarse sand 675 µm diameter, the least frequent at 26%. However, the results of the distribution of S2 sand showed that it was a homogeneous uniform coarse sand with a dominant grain size of 650 µm for a fraction of 11%.

Several authors have proposed some recommendation on the design criteria for an effective slow sand filter. Two critical parameters were the grain size distribution and the hydraulic loading rate. According to this recommendation, the filter media should be fine, that is, d_{10} (0.15–0.35 mm)/Cu < 3 and the rate should be low enough, that is, 0.04–0.40 m/h to ensure its removal efficiency. The grain size of the sand was a very important parameter in this process. Other researchers [17,18] have confirmed that grain size distribution of media was one of the most important operating variables ensure the effluent quality. The capture of polluting particles intercepted between the grains of sand was proportional to the specific surface which itself was inversely proportional to the size of the grains of sand. Therefore, the greater the specific surface, the smaller is the grain diameter, the more effective is the retention of pollutants. This is what was also observed in the current investigation.

Filtration efficiency in slow sand is determined by the effective size (d_{10}) of the grains in filter media. The d_{10} represents the grain size which is 10% finer by weight. A low d_{10} value represents finer grains and vice versa [20]. Filter efficiency increases as grain size of the medium lowers [21]. For example, total suspended solids (TSS) removal was highly correlated with turbidity and better achieved when finer media (i.e., with smaller d) was used [22,23]. However, more frequent cleaning of filter medium was required at lower grain size [24]. Table 3 summarizes various sand effective diameters and the specific surface, which was the ratio between the surface of the grain and its volume. According to the d_{10} values, the sand S3 was the finest. Even the appearance of S1 sand indicated that it was the finest compared to other types, its effective diameter was larger than S3 and S4 sand.

The results showed that the span value of S3 sand was high, indicating it was heterogeneous. This could be due to the variety of grain sizes with an average granular size d_{50} of 20 µm corresponding to a strong presence of small grains. All types of sand (S1, S2 and S4) were homogeneous compared to sand S3. According to the recommended values of grain size distribution on the design criteria of slow sand filtration, fine media was preferably chosen but it did not necessarily need to be uniform.

The heterogeneity and the small size of the particles in sand 3 can affect the efficiency of the filtration; this hypothesis remains to be verified during the filtration tests. The recommended effective grain size was 150–350 µm for a slow sand filter, with a preferred uniformity coefficient of less than 2 or 3 [24,25]. Hence the different types of sand used in this study met the terms of standards. The estimated empty bed contact time was 3–10 h [26].

Morphoscopic analysis based on the counting method, consisted of sorting by sieving the main particle size fractions of the sand, then in classifying the grains by observation with a binocular microscope. This classification took into account two criteria, surface appearance and the shape of the grains. The surface appearance of the different types of sand by the binocular magnifier helped, not only to discover the morphology of the grains, but also to observe the overall appearance of the filter materials.

Fig. 4 shows that the sand S1 presented a heterogeneity in the size and the shape of particles, confirming the particle size results. There were two categories: the largest proportion presented small grains, large grains were less important and most of the particles were blunted. The

Table 3
Particle size parameters values

	Sand 1	Sand 2	Sand 3	Sand 4
d_{10} (μm)	273.05	375.533	2.588	100
d_{50} (μm)	538.37	722.336	20.208	300
d_{90} (μm)	1,330.04	1,359.521	79.783	600
Span	1.96	1.362	3.820	1
Specific surface (μm^2/g)	0.0187	0.0142	1.2844	0.0191
Uniformity	0.58	0.42	1.92	–

surface had a shiny appearance with a considerable presence of silica and an absence of any kind of impurity.

While sand S2 was characterized by the existence of coarse particles and homogeneous, the size compared to S1 and the majority had a blunt shape, with the existence of small grains. There was also an abundance of silica. The surface appearance was also shiny and looked pure. Likewise, sand S3 was heterogeneous and presented three categories of granular size: large particles were the least frequent with a blunt form, medium particles were most frequent with a mixture of blunt and angular form, and small particles were moderately frequent with an angular shape. The presence of silica was also important in the sand S3 and the surface of the grains was shiny and free of impurities. Furthermore, whereas, the sand S4 had two categories of grain size: the medium particles in were a significant proportion and the large particles were less in proportion. Most of the grains had a blunt shape and an abundance of silica was observed. The appearance of the surface was very shiny and pure. This type of sand was homogeneous compared to the previous three sands.

The percentages reported for all types of grain for each sand are summarized in Table 4. There was an abundance

Table 4
Morphoscopic analysis results of sands S1 to S4

Shape sand type	Percentage of sand grains %		
	Angular	Blunt	Round
Sand 1	73	25	2
Sand 2	48	48	4
Sand 3	35	59	6
Sand 4	12	58	30

of angular grains and an average proportion of blunt grains with a negligible presence of the round shape in sand 1. While the analysis showed an equal average distribution of blunt and angular grains in sand 2, the presence of round grains was negligible. The morphological structure of the grains of sand 3 was characterized by a large proportion of blunt grains, and a less significant proportion of the angular grains, and the presence of the grains with round shape remained negligible.

However, sand 4 had a considerable proportion of round grains, and the most important proportion was blunt grains with a less significant presence of angular grains. A considerable presence of angular and blunt grains in all types of sand was observed. This can explain the high retention capacity of great quantities of MES, hence the reduction of turbidity during the filtration tests. However, the considerable presence of round grains in sand 4 may influence its ability to retain.

3.2. Parameters affecting sand filtration

Taking into account the results of the sand characterization, the sand 3 was chosen to carry out the study of the optimization of the filter height. Having the finest diameter,

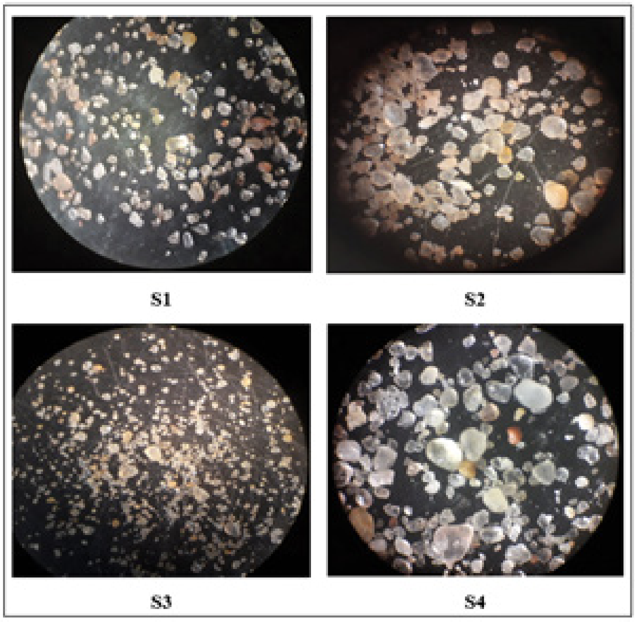

Fig. 4. Morphoscopic images of different sands.

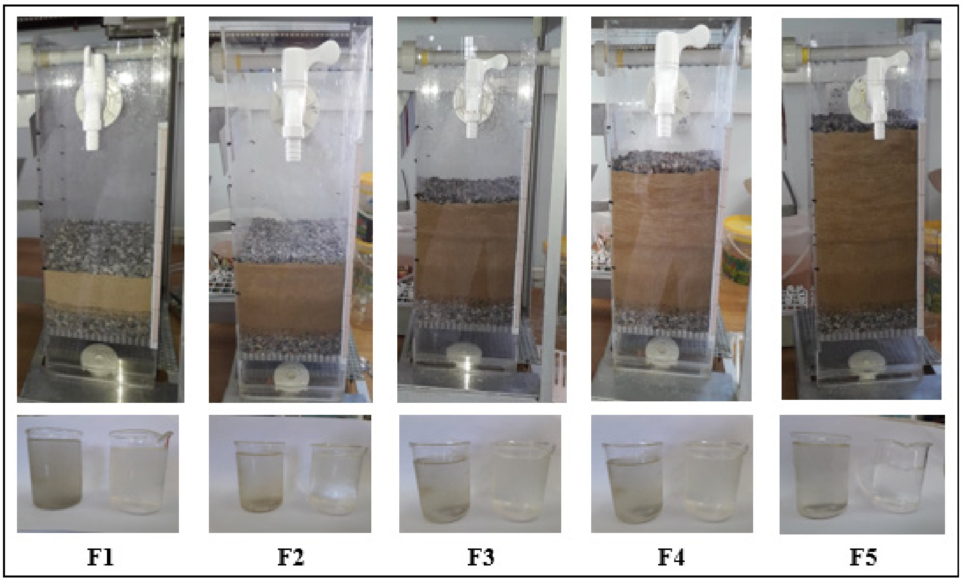

Fig. 5. Sand filter for different height followed by the image of real effluent before and after filtration test.

the largest specific surface and the largest conformity coefficient, sand 3 can be best suited for filtration. A series of filtration tests were carried out by varying the height of the sand 3 from 5 to 25 cm with a step of 5 cm. Fig. 5 presents the different sand filters designed as well as water samples before and after filtration of Fouka wastewater.

According to Fig. 5, it appears that the height of the filter influences the quality of the filtered water. This could be verified by measuring the turbidity of the water. The difference in the height of the sand was generally identified by a difference in the flow rate. The recommended filtration speed for a slow sand filter was 0.1–0.4 m/h and the recommended effective grain size was 0.15–0.35 mm [17,25]. A filtration speed between 0.1 and 0.2 m/h was suitable. Faster filtration can cause early clogging. However, a filtration speed of 0.3 m/h could be accepted for short periods in the filtration units. Table 5 groups parameters of the different designed sand filters. The filtration speed was the same 0.33 m/h for heights 5 and 10. By increasing the height of the bed, there was a small decrease in flow, 0.27, 0.21 and 0.18 m/h for the heights 15, 20 and 25 cm, respectively. These results were in agreement with the literature.

Results of the various pollution indicator parameters before and after filtration test for all experiments relating to the optimization of the filter height are presented in Fig. 6. A great turbidity reduction rate was observed for the different sand heights with a value greater than 70%. For a minimum height of 5 cm, the turbidity removal rate reached 77%, thus indicating that the filter made it possible to remove a good quantity of MES contained in the wastewater. This abatement rate increased depending on the sand height up to 97% and 98% for 20 and 25 cm heights respectively.

The sand bed can also remove organic matter in some cases. For a height of 5cm, an average COD reduction rate of 46% was obtained. By increasing the height of the bed, an increase in the elimination rate was observed. It was around 65% for heights ranging from 10 to 25 cm. The best filtration efficiency was reached at a height of 20 cm based on the results of the turbidity. However, a height of 15 cm can be considered as an optimal height, due to economic reasons, to reduce the cost of the process since the two rates at 15 and 20 cm were close and exceeded 90%. On the other hand, a height 15 cm corresponded to the best reduction efficiency of COD and BOD. The water after filtration was colorless and odorless, which confirmed the elimination of the pollutants responsible for the green color and the bad smell of this wastewater before filtration.

Table 5
Filter design parameters of different heights

Filter code	F1	F2	F3	F4	F5
Filter height (cm)	5	10	15	20	25
Filtration rate (m^3/h)	0.011	0.012	0.009	0.007	0.006
Filtration speed (m/h)	0.33	0.33	0.27	0.21	0.18

3.3. *Effect of nature of sand*

Effectiveness of a sand filter depended on the nature of the filter material, as well as the size and shape of the grains. This study allowed to visualize this influence on the filtration efficiency of wastewater. Filters F2, F6, F7 and F8 design parameters are grouped in Table 6. Thus, for different types of sand, a volume of 3L of municipal wastewater (E1) was filtered under the same operating conditions.

The filtration rate was almost the same for F7 (sand 2) and F8 (sand 4), 0.017 and 0.018 m^3/h, respectively. For the filter F2 (sand 3) and F6 (sand 1) sand the flow rate was a little lower in the order of 0.012 m^3/h. The filtration speed between 0.2 and 0.4 m/h, presented a slow filtration.

Fig. 7 illustrates an excellent removal of suspended solids visually by the change of color, which was confirmed by the measurement of the different pollution parameters.

For a height of 10 cm, the results obtained (Table 7) showed high turbidity removal efficiencies exceeding 90% for the three types of sand S1, sand S2 and S4. Also, the sand S3 presented a good elimination of suspended matter with a decrease of the turbidity value from 55 to 8 NTU.

Chemical oxygen demand (COD) values also decreased after filtration with all four sand types. For sands S1 and S3 the COD removal efficiencies were close, 69% and 64%. Similarly for the S2 and S4 sands, the efficiencies were 71% and 75% respectively.

It can be considered that sand bed F7 (S2) gave the best performances of turbidity and COD removal using a sand height of 10 cm. These high efficiencies may be due to the good granulometry of the sand S2 which was the most homogeneous and well classified. The F2 (S3) filter had turbidity and COD removal efficiencies of 85% and 64%, respectively. These values were high but still low compared to the other filters F6 (S1) and F7 (S2) and F8 (S4). This may have been due to the particle size structure of S3, which had a high degree of heterogeneity and a low sand grain size. These two criteria can really influence the filtration efficiency and thus confirms the hypothesis posed previously in the granulometric analysis.

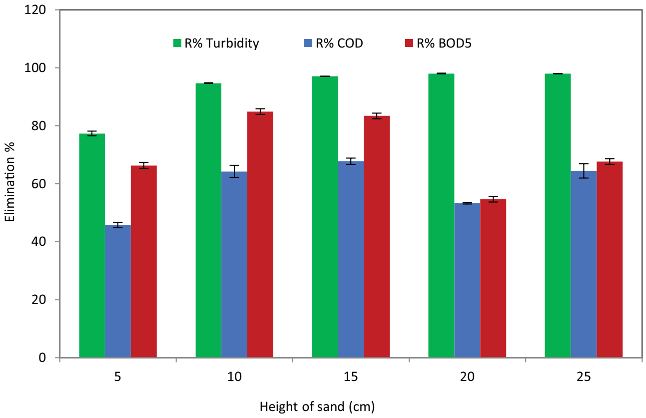

Fig. 6. Abattement or removal rates of COD, BOD and turbidity for different sand heights.

Table 6
Design parameters of F2, F6, F7 and F8 filters

Filter code	F6	F7	F2	F8
Sand type	Sand 1	Sand 2	Sand 3	Sand 4
Filter height (cm)	10	10	10	10
Filtration rate (m^3/h)	0.011	0.017	0.012	0.018
Filtration speed (m/h)	0.31	0.48	0.33	0.52

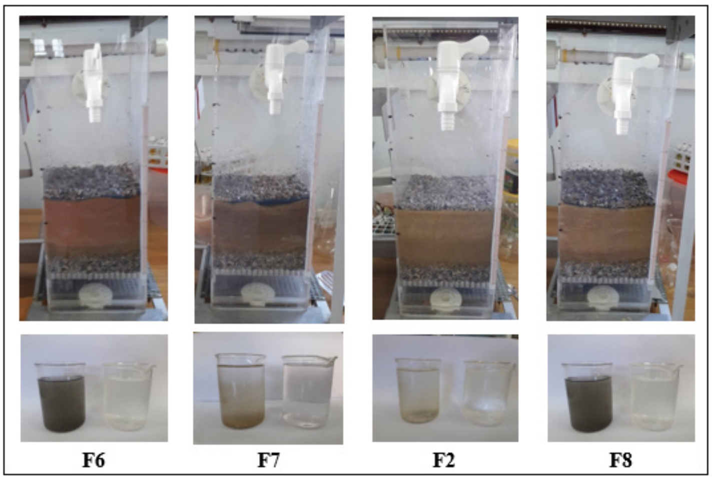

Fig. 7. F2, F6, F7 and F8 filters design followed by wastewater before and after filtration test.

Table 7
Evaluation of the abatement efficiencies for different types of sand at a height of 10 cm

		F6	F7	F2	F8
Turbidity (NTU)	Initial	263.33 ± 4.71	150.00 ± 0.00	55.00 ± 4.08	263.33 ± 4.71
	Final	9.07 ± 0.40	9.47 ± 0.41	8.23 ± 0.39	10.00 ± 0.00
COD (mg/L)	Initial	545.33 ± 1.25	251.33 ± 1.70	216.33 ± 0.94	566.00 ± 0.00
	Final	170.00 ± 2.83	62.33 ± 2.05	77.33 ± 4.71	163.67 ± 1.70
pH	Initial	6.81 ± 0.03	7.22 ± 0.03	7.04 ± 0.00	6.57 ± 0.06
	Final	7.85 ± 0.04	7.69 ± 0.06	7.48 ± 0.03	7.26 ± 0.01
K (μs/cm)	Initial	1,217.33 ± 4.03	1,279.67 ± 0.47	1,202.33 ± 2.05	1,230.67 ± 1.89
	Final	6,613.33 ± 9.43	2,253.33 ± 4.71	4,500 ± 0.00	1,754 ± 1.63

4. Conclusions

This study focused on pretreatment of municipal wastewater from the "Fouka" region in Algeria, by the sand filtration process using several filter materials. The particle size analysis showed different physical aspects of each type of sand and determined their average particle size. The morphoscopic analysis indicated a strong presence of angular and blunt grains and a low percentage in round grains which can improve the filtration efficiency. Hence, the sands of Algerian dunes can be considered as a good filtering material in order to alleviate the problem of wastewater, without resorting to expensive techniques. Sand filtration experiments showed that the abatement or reduction rates of pollution indicators such as turbidity, COD and BOD_5 were high for all experiments, around 90%, 60% and 80%, respectively.

In the light of the results, sand filtration proved effective for domestic effluents. The cleaning efficiency depended on the nature of the filter material and the load of the effluent. It can be concluded that the sand filter designed in this study had an excellent performance for the treatment of wastewater. It is recommended studies be conducted in the future to further improve the efficiency.

References

[1] M.A. Oturan, J.-J. Aaron, Advanced oxidation processes in water/wastewater treatment: principles and applications. A review, Crit. Rev. Env. Sci. Technol., 44 (2014) 2577–2641.

[2] P.R. Gogate, A.B. Pandit, A review of imperative technologies for wastewater treatment II: hybrid methods, Adv. Environ. Res., 8 (2004) 553–597.

[3] M. Achak, L. Mandi, N. Ouazzani, Removal of organic pollutants and nutrients from olive mill wastewater by a sand filter, J. Environ. Manage., 90 (2009) 2771–2779.

[4] A. Bendida, A. El-Bari Tidjani, A. Badri, M.A. Kendouci, M. Nabou, Treatment of domestic wastewater from the town of Bechar by a sand filter (sand of Beni Abbes Bechar Algeria), Energy Procedia, 36 (2013) 825–833.

[5] Y.W. Kang, K.M. Mancl, O.H. Tuovinen, Treatment of turkey processing wastewater with sand filtration, Bioresour. Technol., 98 (2007) 1460–1466.

[6] S. Verma, A. Daverey, A. Sharma, Slow sand filtration for water and wastewater treatment – a review, Environ. Technol. Rev., 6 (2017) 47–58.

[7] K. Langenbach, P. Kuschk, H. Horn, M. Kästner, Modeling of slow sand filtration for disinfection of secondary clarifier effluent, Water Res., 44 (2010) 159–166.

[8] A. Maazouzi, A. Ketteb, A. Badri, Etude de procédés de filtration sur sable de la région de Béchar en pré traitement de l'eau potable, Desalination, 206 (2007) 358–368.

[9] I. Papineau, Influence des variations de qualité d'eau brute et du vieillissement des matériaux filtrants sur la performance de la filtration granulaire, Doctoral Thesis, École Polytechnique de Montréal, Canada, 2013.

[10] A. Bezziou, R. Mekkaoui, Essai de traitement biologique des eaux usées en utilisant des filtres bicouches, Doctoral Thesis, Université Kasdi Merbah Ouergla, Algérie, 2013.

[11] M. Kone diallo, Infiltration-percolation sur sable et sur fibre de coco, filtres plantes et épuration d'eaux usées domestiques à dominance agroalimentaire sous climat tropical sec: cas des eaux résiduaires urbaines de Ouagadougou, Burkina Faso, Doctoral Thesis, Université de Ouagadougou, Burkina Faso, 2011.

[12] F.H. de Souza, B.S. Pizzolatti, J.M. Schöntag, M. Luiz Sens, Study of slow sand filtration with backwash and the influence of the filter media on the filter recovery and cleaning, Environ. Technol., 37 (2016) 1802–1810.

[13] O. Benhabiles, N. Chekir, D. Tassalit, Solar photocatalytic degradation of methylene blue in a fixed bed reactor, Desal. Water Treat., 60 (2017) 285–290.

[14] N. Chekir, O. Benhabiles, D. Tassalit, N.A. Laoufi, F. Bentahar, Photocatalytic degradation of methylene blue in aqueous suspensions using TiO_2 and ZnO, Desal. Water Treat., 57 (2016) 6141–6147.

[15] B. Boutra, M. Trari, Solar photodegradation of a textile azo dye using synthesized ZnO/bentonite, Water Sci. Technol., 75 (2017) 1211–1220.

[16] S. Igoud, F. Souahi, C.E. Chitour, Solar wastewater treatment (SOWAT) and reuse for agricultural irrigation, Irrig. Drain., 66 (2017) 750–757.

[17] L. Huisman, W.E. Wood, Slow Sand Filtration, World Health Organization, Geneva, 1974.

[18] L. Rolland, P. Molle, A. Liénard, F. Bouteldja, A. Grasmick, Influence of the physical and mechanical characteristics of sands on the hydraulic and biological behaviors of sand filters, Desalination, 248 (2009) 998–1007.

[19] M. Raviv, H. Lieth, A. Bar-Tal, Soilless Culture: Theory and Practice, 1st ed., Elsevier BV.

[20] M. Assassi, F. Madjene, S. Harchouche, H. Boulfiza, Photocatalytic treatment of Crystal Violet in aqueous solution: Box–Behnken optimization and degradation mechanism, Environ. Prog. Sustainable Energy, 40 (2021) e13702.

[21] N.G. Pizzi, Water Treatment: Principles and Practices of Water Supply Operations, 3rd ed., American Water Works Association, Denver, 1995.

[22] K.J. Ives, Deep bed filtration: theory and practice, Filter Sep., 17 (1980) 157–166.

[23] T.H.Y. Tebbutt, An investigation into tertiary treatment by rapid filtration, Water Res., 5 (1971) 81–82, IN1, 83–92.

[24] D.J. Pitts, D.Z. Haman, A.G. Smajstrla, Causes and Prevention of Emitter Plugging in Micro-Irrigation System, Bulletin 258, Florida Cooperative Extension Service, Institute of Food and Agriculture Science, University of Florida, Gainesville (FL), 1990.

[25] G.E. Visscher, R.L. Robison, G.I. Argentieri, Tissue response to biodegradable injectable microcapsules, J. Biomat. Appl., 2 (1987) 118–131.

[26] L.A. Amy, P.J. Talling, V.O. Edmonds, E.J. Sumner, A. Lesueur, An experimental investigation of sand–mud suspension settling behaviour: implications for bimodal mud contents of submarine flow deposits, Sedimentology, 53 (2006) 1411–1434.