EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(7), 196–209
https://doi.org/10.12912/27197050/188378
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Received: 2024.04.27
Accepted: 2024.05.14
Published: 2024.06.01

Comparative Study of Two Types of Sand Used for Wastewater Treatment (Case of Algerian Sahara)

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ABSTRACT

Filtration is one of the oldest techniques and by far the most widely applied in water treatment operations. It is considered one of the most effective methods for purifying waste water. Sand filtration consists of passing water loaded with suspended and colloidal matter through a filtering material in order to clarify it. In Ouargla region, wastewater is evacuated in a closed system without any treatment, which presents a natural risk to public health and endangers the sustainability of agriculture and the environment. In this modest study, two sand samples of different grain size and shape were used as the filter bed. Several filters were constructed using two types of sand with the same dimensions and different characteristics. The filter was exposed to clogging during the operation, which is prejudicial to the filtration process. For this reason, our study aims to see the influence of the type of sand on this process and analyze the phenomenon of filter clogging: the causes of its appearance, its types and their location as well as the parameters governing it. The most important thing is to evaluate the quantity of organic matter deposited in the different layers of the filter, and see its distribution as a function of time over the whole the depth of the filters. This study shows that the sand filter is subjected to progressive clogging. This clogging is classified into three fragments: mechanical, physical and organic. The study showed that the finer the granulometry, the greater the accumulation of organic matter. From the third week onwards, the formation of a biological film has been observed, which allows for very thorough purification. In other words, a quantity of suspended matter settles as the biomass degrades the organic matter.

Keywords: Algeria, slow filtration, filter clogging, sand, treatment, wastewater.

INTRODUCTION

Safe drinking water remains a major global challenge, especially in rural areas where, according to UNICEF, 80% of those without access to improved water systems reside. While water, sanitation, and hygiene (WASH) – related diseases and deaths are common outcomes of unsafe water, there is also an economic burden associated with unsafe water. These burdens are most prominent in rural areas in less-developed nations (Dasika et al, 2023).

Providing clean water to people in developing countries is an urgent global water problem and a major challenge of the United Nations Sustainable Development Goals. The surface and shallow groundwater in developing countries around urban areas are often polluted by domestic wastewater containing these microbes and nutrients. Thus, slow sand filtration's function is to treat raw water in the form of diluted wastewater (Abdiyev et al, 2023).

Filtration is a physical process designed to clarify a liquid containing suspended solids by passing it through a porous medium (Legube, 2015). Slow sand filtration is the oldest method of water treatment. Studies with other observations have shown that slow sand filtration effectively eliminates coliform bacteria from wastewater and is an innovative and cost-effective treatment process that requires little maintenance (Desjardind, 1997).

The effectiveness of this process is recognized as a means of preventing water-borne epidemics and bacteriological studies have demonstrated its ability to eliminate pathogenic germs (Badia and Gandar, 2003).

Sand filters are natural environments that can be used as filter beds in wastewater treatment (Saad et al., 2009; Jianmin et al., 2003), by playing a dual role: retaining suspended matter and fixing the biomass that develops around the grains, which biodegrades organic, phosphorus and nitrogen pollution (Monroe et al., 2002; Kellil and Bensafia, 2003).

Slow sand filtration has always been one of the most important methods for treating drinking water and eradicating sanitation problems. Due to its effectiveness and low cost, slow sand filtration is still considered an effective and inexpensive way to provide safe drinking water in resource-limited developing countries. Slow sand filtration is recognized by the United States Environmental Protection Agency (USEPA) and WHO as an inexpensive and reliable means of providing safe drinking water (Slezak and Sims, 1984; Agrawal, 2021).

Algeria's vast desert region is home to enormous amounts of dune sand, most of which has a grain size of less than two millimeters. Dune sand is the only local material in the Algerian south that has long been marginalized. At present, great efforts are being made to make the most of dune sand and our work is part of this effort.

With dunes over 150 meters high and alluvial deposits, the Ouargla region is incredibly rich in dune sand deposits from the eastern ergs. The majority of these sands have qualities that fulfill biological filtration standards (Touil et al., 2008).

During operation, the sand filter is subject to variations in morphological characteristics; which hinder the filtration process. The objective of the present work is to determine the variation in porosity, the clogging effect, and the evolution of the organic matter content and COD as a function of time of use, these along the depth of the filter. As well as carrying out a comparative study between two pre-selected quarry sands from the Algerian northern Sahara, in order to set up the most efficient devices possible.

We will present all the stages of our experiment, which includes characterizing the sands used, setting up the filters and their operation, then we will present all the measurements of the parameters which help us to determine clogging through the filters, with an interpretation of the results obtained.

MATERIAL AND METHOD

Study area

The town of Ouargla is located in the Bas-Sahara, the most active part of the Algerian Sahara, the home to 2/3 of the country's palm groves and 2/3 of its inhabitants. Situated in the north-east of the Sahara, the Bas-Sahara owes its name to its lower topography, with an average altitude of -40 m below sea level, rather than its latitude. This gives it a special climate, with high temperatures and very dry air (Bensaad, 2013). The soil in the Ouargla basin is salty. This salinization is linked to the salinity of irrigation water and the high level of saline groundwater. Studies of the hydro-edaphic characteristics show the existence of several hydric, saline and mechanical constraints. Irrigation water management and the rise in the groundwater due to faulty drainage have led to waterlogging, the formation of gypsum crusts and salinization of the soil (Rezagui et al., 2016). The sands used as filters come from two localities, Hassi Messaoud (HMD) and Sidi Mahdi (SM) in the wilaya of Ouargla (Fig. 1). The town of Hassi Messaoud (HMD) is located 86 km south-east of Ouargla, and the sand in this area has a larger diameter than other sand.The Sidi Mehdi (SM) station is located in the Oued-Righ region. It is located in the Sidi-Mehdi palm grove, 7 km from the main town of Touggourt. It covers a total area of 52 hectares, 26 of which are used for phoeniciculture (Fig. 1).

Study methodology

The size and homogeneity of sand particles essentially influence the efficiency of water purification with an slow sand filtration (Huisman and Wood, 1974). The homogeneity of the particles is determined by the homogeneity coefficient. The homogeneity

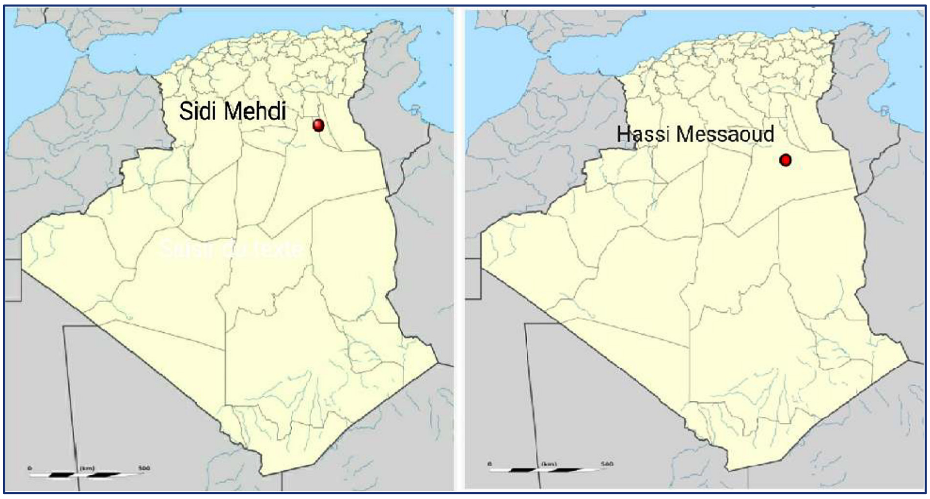

Figure 1. Map showing the location of the study sites (Google Maps, 2023)

coefficient of sand is defined as the ratio: coarseness at which 60% (by weight) of the sand sample passes through the sieve divided by the coarseness at which 10% of the same sample (by weight) passes through the sieve, i.e., $UF_{60/10} = d_{60}/d_{10}$. A uniformity factor UF means that all particles are the same size. As the uniformity of the sand particles increases, the filtration efficiency increases. If the sand particles vary greatly in size, the smaller sand particles will fill the gaps between the larger particles, resulting in filter clogging (Lesikar). The most effective sand particle size for slow filtration is 0.15–0.35 mm and a uniformity factor of less than two (Logan et al., 2001). While according to (Castany, 1982), Sand that meets the requirements for slow filtration is that which has a UF between 0.7 and 3. For the sand samples, we took a random sample, using visual analysis to select sites that were more or less representative. Samples were taken from two horizons, the first at the surface and the second at a depth of 50 cm at each point. The sand samples were placed in clean bottles, labelled and transported to the analysis laboratory. The thickness of the sand layer has a significant influence on the degree of removal of contaminants from the water composition by the method of SSF. It is generally assumed that the thicker the sand layer, the greater the retention of fine and colloidal particles and viruses and the better the discoloration of water. According to (Williams, 1987), a sand layer 200 mm thick removes 99.5% of fecal bacteria. The minimum thickness of the sand layer to remove turbidity and coliform bacteria is 300 mm, while 600 mm sand thickness is sufficient to remove all viruses (Ellis and Wood, 1985). The filters used were PVC columns with an external diameter of 80 mm, an internal diameter of 76 mm and a height of 65 to 80 cm. The filtration (pilot) column is open at the top and completely closed at the bottom, except for a part in the form of a hole connected to a small pipe (about 1.5 cm) used to drain off the filtered water (Fig. 2).

We started by placing fabric and a layer of gravel at the bottom of the pilots to prevent the immigration of sand particles. Next, we placed a sampling tube, a set of PVC cylinders with an internal diameter of 2.8 cm and a heightof 3 cm. Twenty cylinders joined together to form a tube 60 cm long (see Figure 4). To make it easier to take samples, this tube had to be placed axially inside the column before the sand was filled in. The method is based on an undisturbed soil sample, i.e. one whose structure has not been modified. For this reason, the sampling tube is used. We then filled our pilots with successive layers of sand in quantities measured and prepared previously, to form a 60 cm layer. A few blows were made with a suitable tool (hand hammer) to homogenize the column and achieve a thickness of 60 cm. Our system can operate 10 filtration columns simultaneously. The filters are numbered 1 to 5 from Hassi Messaoud and 1 to 5 from Sidi Mehdi. Each filter operates independently of the others for a specified period of time. The filters must work under the same conditions. The columns must be stable and vertical for proper operation. To ensure the stability and vertical placement of the pilots, to promote vertical flow and to operate under the same conditions from the start to the end of the experiment, the filters are supported on a rectangular metal support, called a clamping bracket.

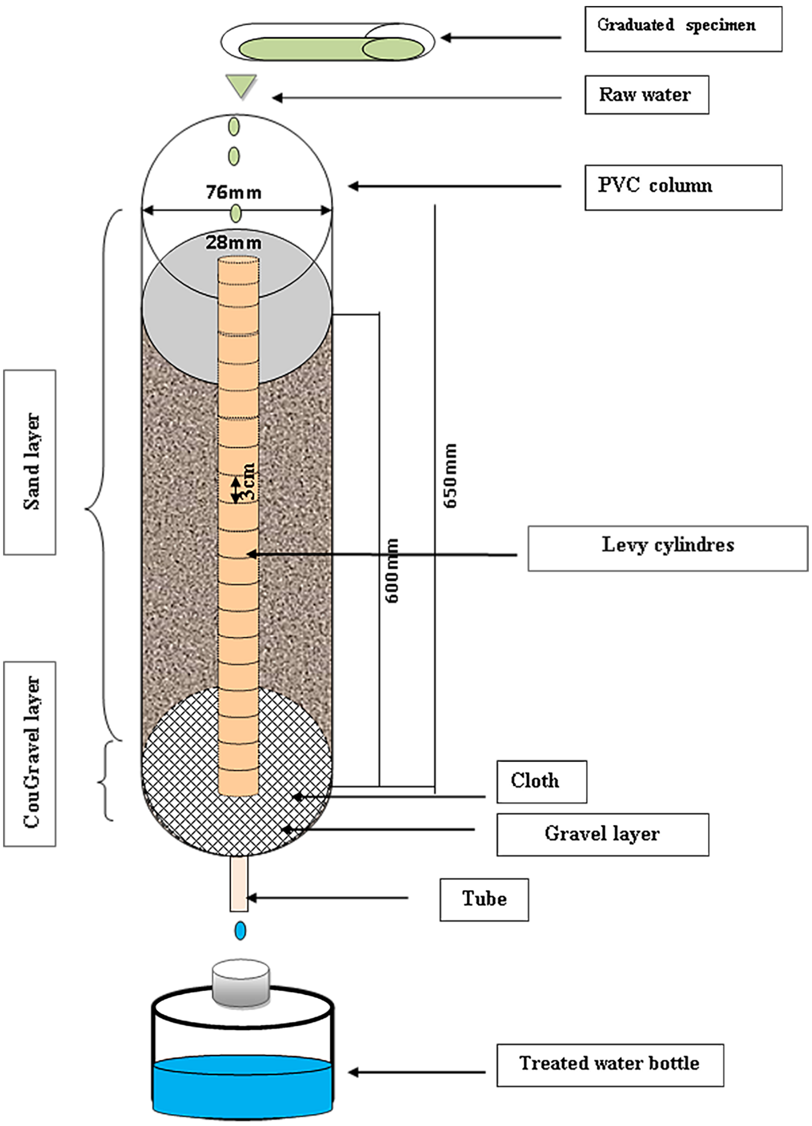

Figure 2. Schematic of the filtre drive

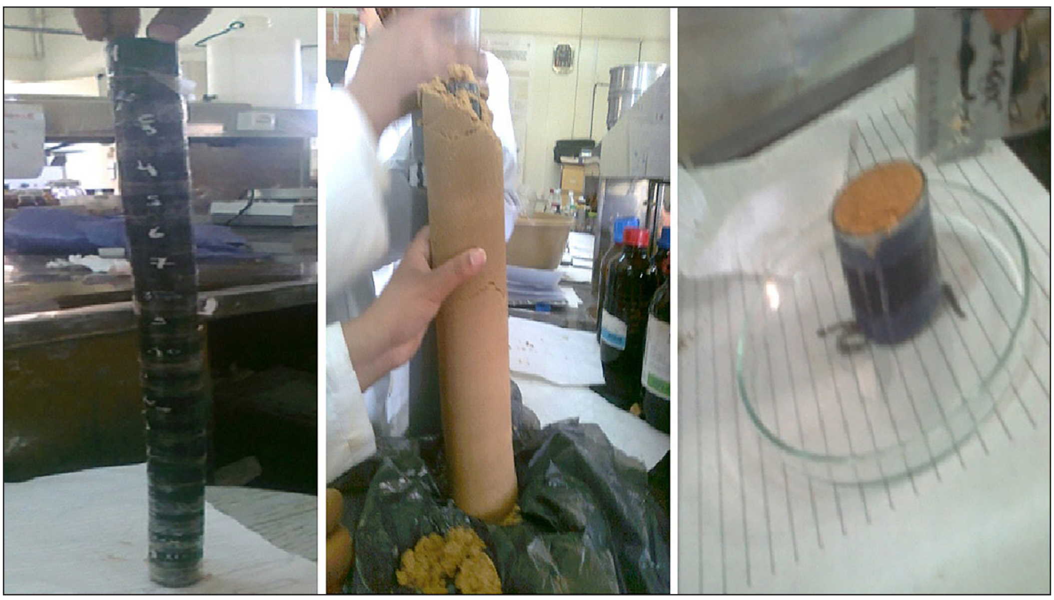

Figure 3. Taking sand samples

Figure 4. Filter clogging

RESULTS AND DISCUSSION

Characterization of sands

Based on the results, we have plotted the particle size curves (Fig. 5), the findings of which can be illustrated:

- The sand at Hassi Messaoud is a mixture of coarse sand and silt.
- The sand used at Sidi Mehdi is fine sand with some coarse sand and silt.
- Hassi Messaoud's sand (UF = 2,667), which is distinguished by a UF > 2.5, has a varied granulometry, while Sidi Mehdi's sand (UF = 1,731) has a uniform granulometry (UF < 2.5). These values indicate that our sands meet the requirements of slow filtration since UF is between 0.7 and 3 according to Castany, 1982.
- The apparent density values 1.70 g/cm^3 of HMD sand and 1.65 g/cm^3 of SM sand indicate that these soils belong to the class of sandy soils determined by the following interval: $1.4 < Da\ (g/cm^3) < 1.7\ g/cm^3$ (Musy and Soutter, 1991).
- The HMD sand has a true density of 2.61 g/cm^3 and 2.85 g/cm^3 for the SM sand. These values at both stations indicate loose, porous soils (Musy and Soutter, 1991).
- Hassi Messaoud sand has a porosity equal to 34.86%, and 43.10% for Sidi Mehdi sand.
- pH values above 7 are associated with a basic property, so the sands studied are alkaline sands (Nur, 1996).
- Salinity measurements mean that the sand from Sidi Mehdi (2.45 ms/cm) is saltier than the sand from Hassi Messaoud (0.43 ms/cm) (Aubert, 1978; Rodier, 2005).
- Furthermore, the total limestone values are equal to 0.51% at the Hassi Messaoud station and 4.03% at Sidi Mehdi, thus the values at the two stations are less than 5%, which indicates that the sands are not very calcareous (Clement and Pieltain, 1998).
- The rate of organic matter in the Sidi Mehdi sand is equal to 0.158%, whereas the other sands have a rate of 0.211%. The organic matter content is lower (poor) in both sands (Morand, 2001). These sands are desert and this quantity of organic matter may be due to the existence of plant debris at the Sidi Mahdi stationand the possible presence of hydrocarbons at the Hassi Messaoud station.
- According to (Clement and Pieltain, 1998), these two sands are suitable for use in slow filtration: the best sand for biological filtration is that with a low total limestone content.

Filter porosity and clogging

The flow of wastewater through the filter over a period of time causes a variation in porosity. This variation is a function of the depth of the filter for each period of operation (Fig. 6) The curves above show that all the porosity values are lower than those of the natural soil. Porosity decreases over time, starting to fall after 1ère week of operation. This decrease in porosity is due to the accumulation of organic matter in the pores and the colonization of the pore space by biomass. The values at the surface are lower than those in the deeper layers, which is due to the retention of suspended matter at the surface. Porosity increases with depth (Fig. 6) and at a certain height begins to decrease due to the formation of algae. Settlement is also greater in the last layers than in the first, essentially due to the dual action of water and the weight of the soil over time. The decrease in porosity

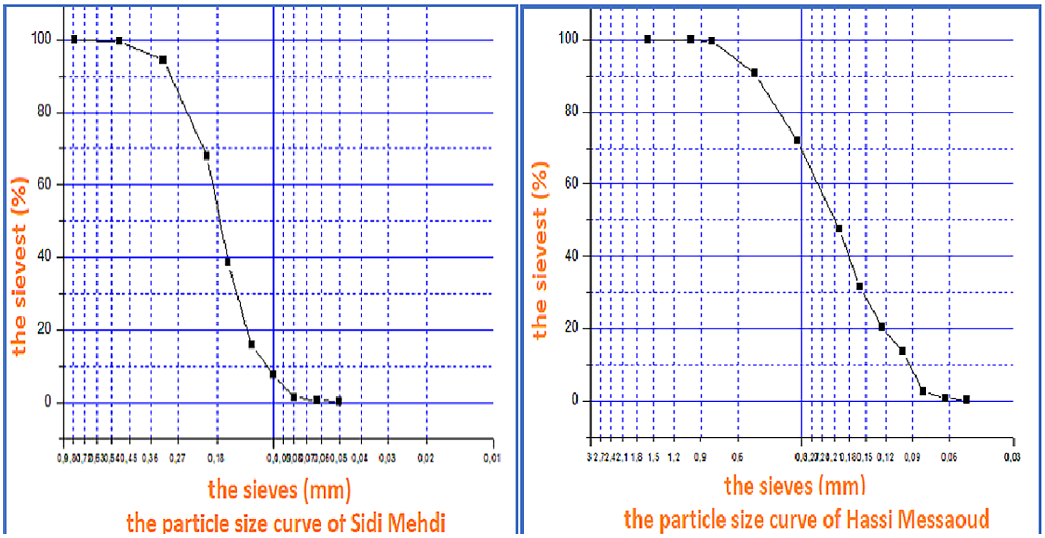

Figure 5. The granulometric curve for Sidi Mehdi and Hassi Messoud

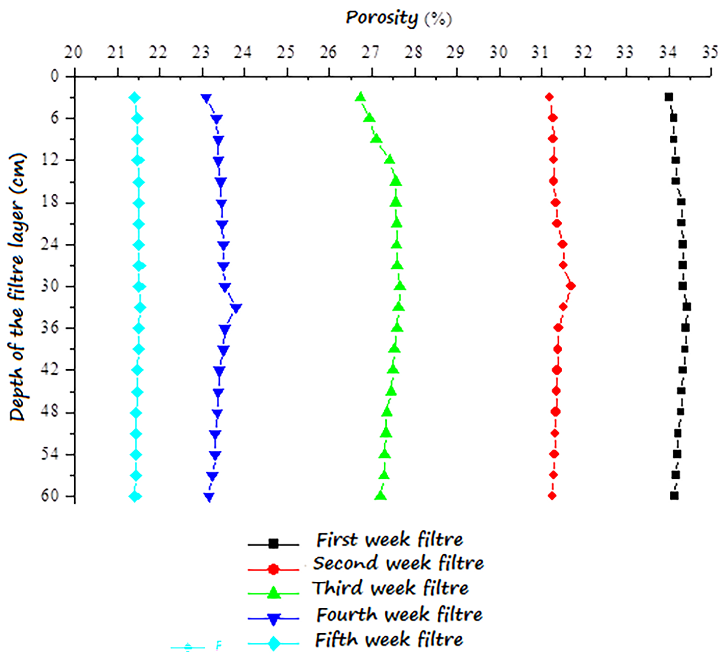

Figure 6. The evolution of the porosity of HMD sand as a function of depth

called clogging. The clogging values of the first layer are higher than those of the last layer. The relationship between porosity and clogging is therefore inverse (Fig. 7). The correlation coefficient between the average porosity rate and the clogging rate for Hassi Messaoud sand is equal to (-0.9953392) (Fig. 8). For Sidi Mehdi sand, the curves showing the evolution of porosity and clogging as a function of operating time take on a more or less linear appearance from the first week (Fig. 9 and Fig. 10), with a negative slope for porosity and a positive one for clogging. The clogging curves increase over the operating time (Fig. 10), due to the continuous accumulation of suspended matter at the surface and its retention by the pores and the colonization of the pore space by biomass, which causes the clogging phenomenon**.** The correlation coefficient (Fig. 11) between the average porosity rate and the clogging rate for the Sidi Mehdi sand is equal to (-0.995281156). This can be seen by the appearance of a layer of water over a period of time. This prolonged stagnation of liquids on the infiltration surface is a sign of a clogging phase:

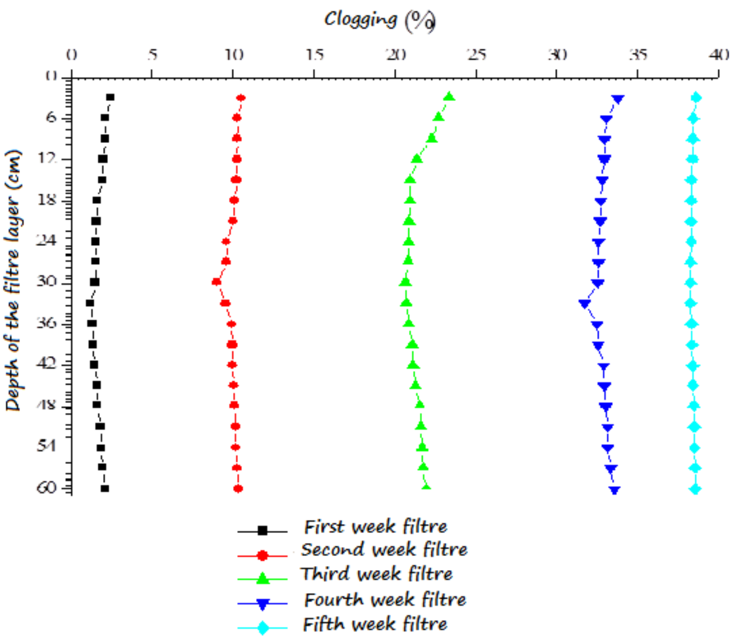

Figure 7. Clogging changes of HMD filters as a function of depth

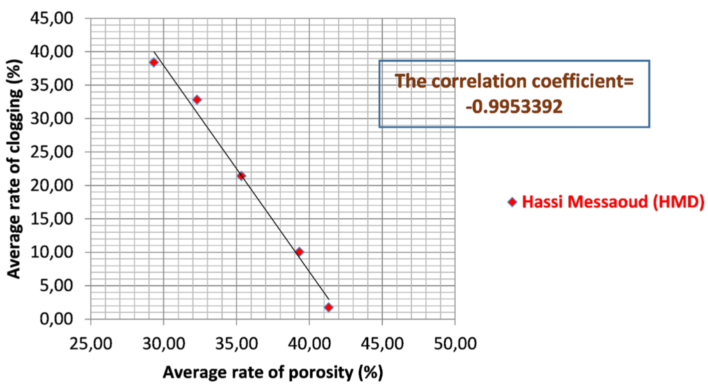

Figure 8. Relationship between average porosity rate and average clogging rate of Hassi Messaoud sand

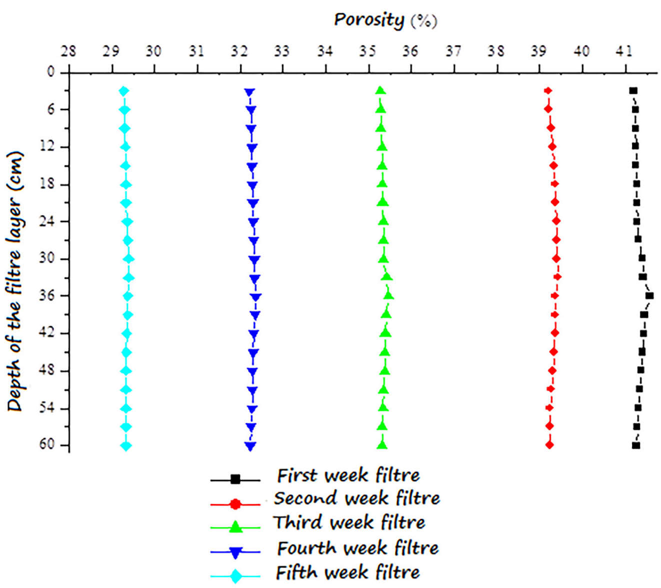

Figure 9. The porosity changes of SM sand as a function of depth

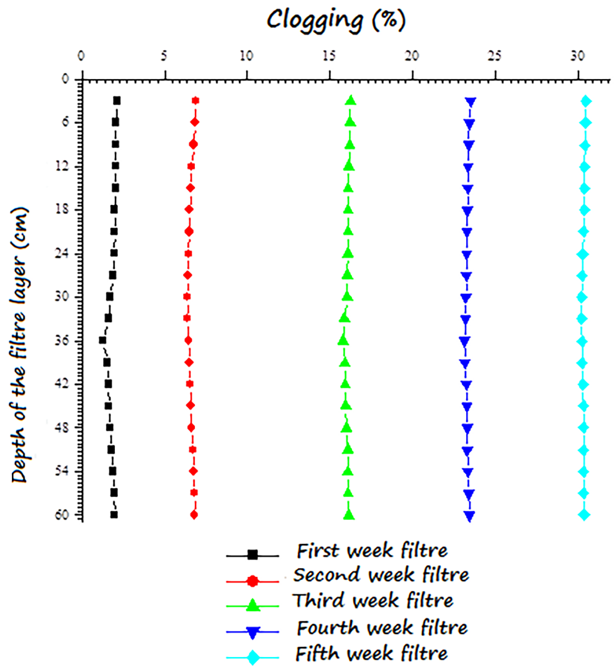

Figure 10. Clogging changes of SM filters as a function of depth

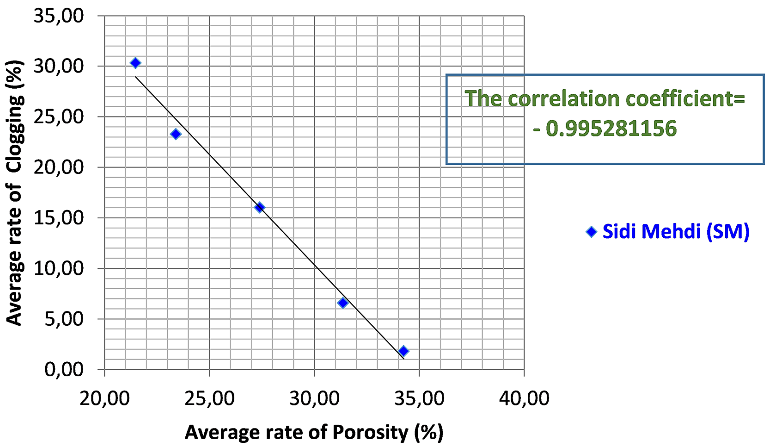

Figure 11. Relationship between average porosity rate and average clogging rate of Sidi Mehdi sand

- A start-up phase: the volume of air is replaced by the effluent discharged.
- A slow-down phase: organic deposits and bacterial biomass accumulate in the filter.
- A rest period is necessary to ensure that the deposits are digested by the micro-organisms and thebiomass regresses.

The Hassi Messaoud filters remain more or less porous than the Sidi Mehdi filters, because of their fine granulometry. During the course of the study, the reduction in porosity was reflected in the stagnation of water on the surface of the filter from 3th weeks**.** We have also noticed that the difference between the porosity of the second filter and that of the third is considerable (5%) for the sand from Hassi Messaoud and 4% for Sidi Mehdi. This may be linked to the formation of the biological film in the first layer during this period (Clement and Pieltain, 1998). This phenomenon can be classified into three types: mechanical, physical and organic clogging (Jedidi, 1991; Rodgers, 2004). It can be seen that mechanical clogging in the Hassi Messaoud filter is greater than in the Sidi Mehdi filter. This type of clogging is therefore due to the flow and settlement of the filter, under the effect of its own weight. The sand's granulometry, the solid skeletons of the filter layer's reorganization and rearrangement, and the passage of tiny particles from the top to the bottom of the filter as a result of gravity and water flow are all responsible for the decrease. The variation in mechanical clogging increases with depth, as the compacting effect of the grains and the pressure of the water reach maximum values at the bottom of the filter and the passage of the water transports the fine particles from the top to the bottom of the filter. Physical clogging is due to the accumulation of suspended matter on the sand grains; in the sieving mechanism (the filter acts like a sieve) (Degremont, 1989; Degremont, 2005). Suspended matter retained in the surface layer by the sieving mechanism; when the dimensions of the suspended particles are greater than those of the pores in the filtering mass. The variation in physical clogging decreases with depth and reaching maximum values at the surface of the filter. The adsorption of dissolved matter, especially organic matter, and the development of microorganisms and algae, particularly on the filter's surface, result in a third type of clogging known as biochemical (organic) clogging, which also explains the distinction between he deep and surface layers. this was very visible from the 3th week by the stagnation of the water on the surface of the filters (Jedidi, 1991; Rodgers, 2004).

Organic matter content

After the filters have been operated, the organic matter (OM) content is measured for each layer using the Anne method. Measurements were taken every 7 days (Fig. 12). The organic matter composition of the filter layer varies with depth, and this variation can be understood by looking at the following pictures, where the depth is shown as curves (Fig. 13):

- All values are higher than those for natural soil (before operation).
- The curves increase with running time. So, as filtration time increases, the level of organic matter also increases from the first week of filtration.
- The finer the grain size, the greater the accumulation of OM. Sidi Mehdi sand has a higher OM content than Hassi Messaoud sand, thanks to its fine grain size.
- The correlation coefficient between the average rate of clogging and that of organic matter for the sand of HassiMessaoud (Fig. 14) is equal to: 0.9862282.
- The correlation coefficient between the average rate of clogging and that of organic matter for the sand of Sidi Mehdi (Fig. 15) is equal to: (0.98567558).
- The presence of high levels of organic matter favours the cementation of grains and thus leads to clogging fairly quickly. It should also be noted that the presence of a small amount of organic matter can help accelerate filter maturation, i.e. promote rapid biomass formation.
- It is also evident for both sands that the levels' organic matter content differs from one to another, with the topmost layer retaining a higher proportion and the lowest layer having a lower amount. (Laurent, 1999), in the first and second weeks, but in the other periods it starts to increase after a certain height. This remarkable increase can be explained by the formation of algae, which were noticed by the appearance of the green color on the surface of the filters from the third filter and even micro-organisms. This is due to the fact that an area with enough aeration provides a conducive setting for the emergence of aerobic biological activity.

Chemical oxygen demand COD

COD is measured several times with a 1/10 soil extract, in accordance with AFNOR standards. By oxidation of the reducing substances contained in the water; by an excess of potassium dichromate (NFT 90–101). COD values are shown in Figures 16 and 17:

- For the 5th week pilots, the analysis results show a high COD load at surface level.
- The sand from Sidi Mehdi has a higher COD than that from Hassi Messaoud, thanks to its fine granulometry.
- The curves increase with the time the filter material is in operation, and after several hours the filter matures. In the upper layers of the sand, an accumulation of organic and mineral particles forms, in which an intense biological life (biomass) reigns. This biological association covers the grains of sand; this is the formation of the membrane or biological film that enables advanced purification. In other words, some of the suspended matter settles as the organic matter is broken down by the biomass.
- The general shape of the curves makes it possible to divide the evolution of COD into three periods, a phase characterized by descending and ascending curves, and then descending phase. The increase in the second phase is due to the formation of biomass, in other words the growth and metabolism of the bacterial

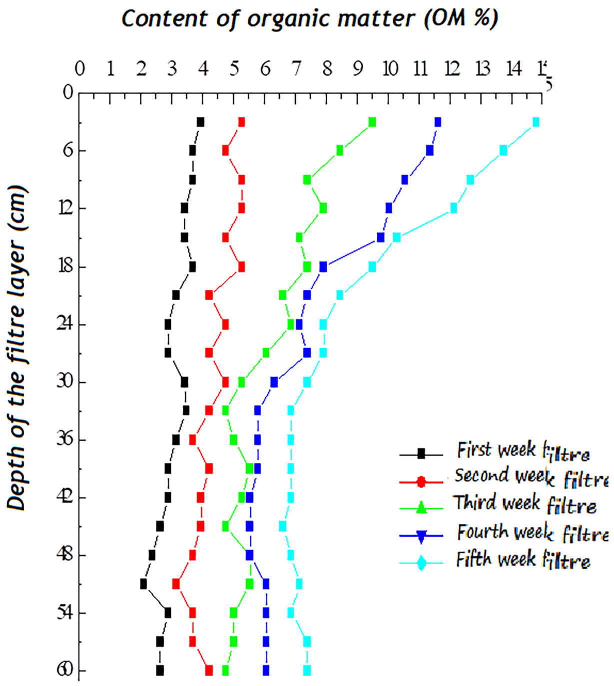

Figure 12. Evolution of the M.O. of HMD sand as a function of depth

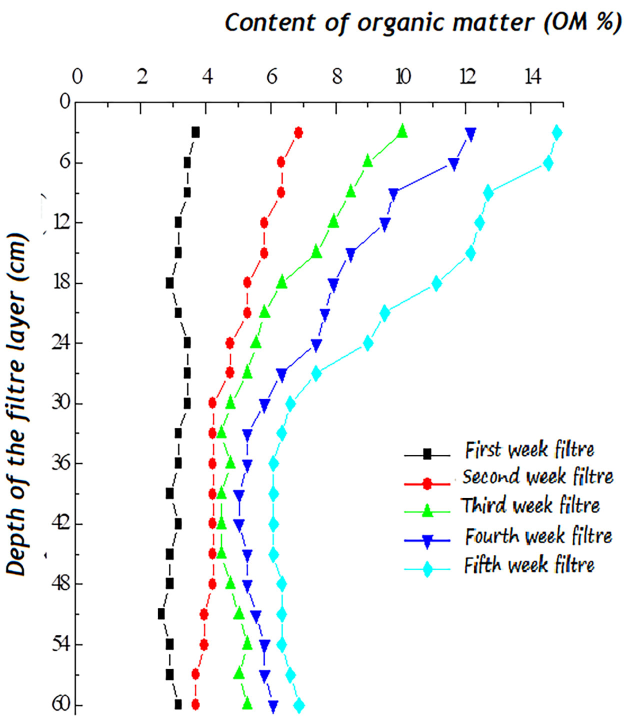

Figure 13. Evolution of the M.O. of SM sand as a function of depth

population that will ensure the degradation of certain pollutants (Laurent, 1999) and destroy the organic matter that exists in the wastewater that can be retained by the grains of sand, which subsequently causes the phenomenon of biomass proliferation (Ouali, 1996).

Removal efficiency of slow sand filtration

Slow sand filtration is proven to achieve excellent removals of pathogenic bacteria, protozoa, viruses, suspended solids, and turbidity. However, removal efficiency is highly dependent on physical and

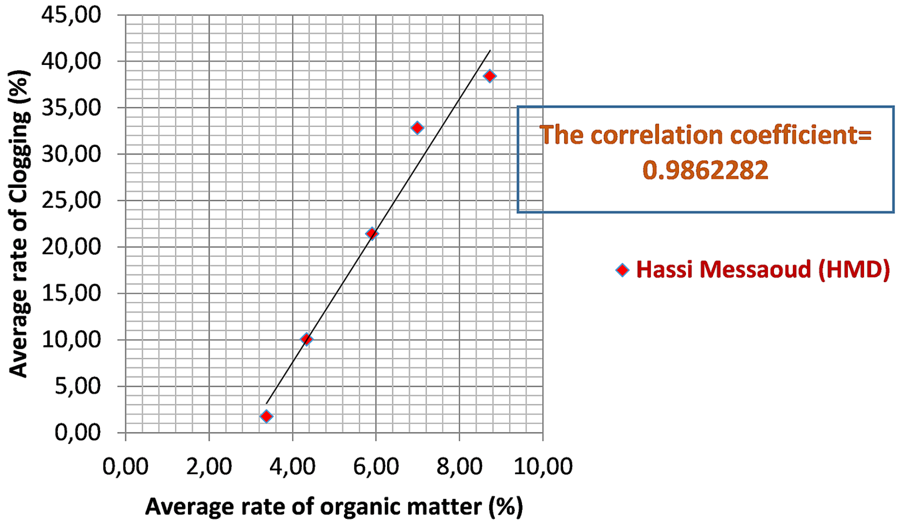

Figure 14. Relationship between average rate of organic matter and average rate of clogging of HassiMessaoud sand

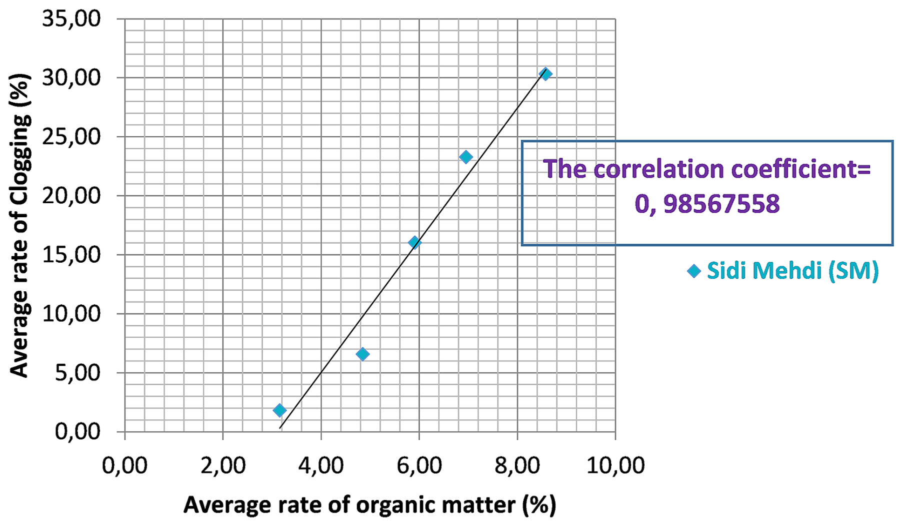

Figure 15. Relationship between average rate of organic matter and average rate of clogging of SidiMehdi sand

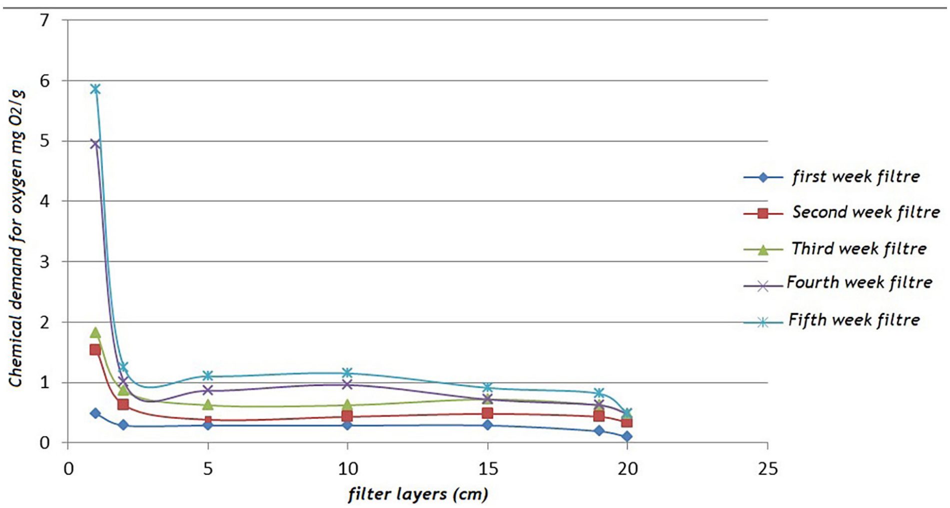

Figure 16. Changes in COD of HMD sand as a function of depth

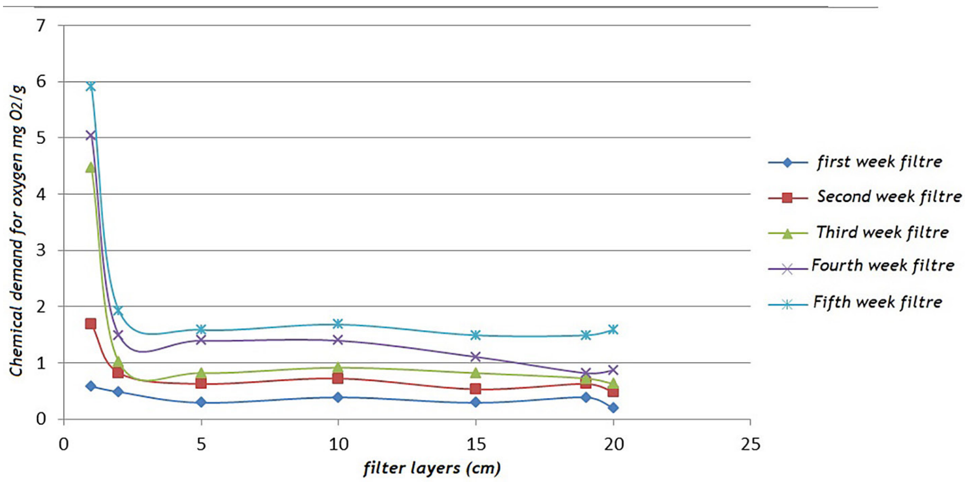

Figure 17. Changes in COD of SM sand as a function of depth

operational characteristics of the filter including the media size, bed depth, filtration rate, biological maturity of the filter, and cleaning practices. Cleaning must be performed at the end of a filter run to avoid clogging. Typically, filter run times range from 30 to 60 days, but could reach more than 100 days (Ellis, 1985). The traditional method of cleaning slow sand filters involves draining the water level from just below to above the surface of the sand and removing the top 1 or 2 cm of biofilm. The biofilm is where the highest concentration of biomass exists, hence the region where most biological treatment is achieved. Thus, pathogen removal may be compromised for a couple of days after cleaning until biofilm maturity is reestablished. In some cases, however, cleaning may have no effect on treatment efficiency. Fox et al. (1984) found that bacteria removal was unaffected by scraping. Pointer and Slade (1977) found that scraping had little effect on the removal efficiency of viruses.

CONCLUSIONS

This study concerns the testing of a number of sands for wastewater treatment. We used dune sands from the wilaya of Ouargla, from two stations, Hassi Messaoud and Sidi Mahdi. The study focused on the evaluation of sand from the northern Algerian Sahara for slow filtration. This work was carried out using filtration pilots, which are PVC columns filled with sand samples in well-calculated and well-measured quantities from the quarries mentioned above, and which are fed by periodic injection (every hour) with synthetic wastewater. The efficiency of this process is assessed using measurements relating to parameters such porosity, clogging, organic matter and COD. The sand filter undergoes three types of clogging during its operation: mechanical clogging due to the flow of water, physical clogging caused by the retention of suspended matter and organic and biological clogging due to the accumulation of organic matter and the formation of micro-organisms. This clogging is the main cause of filter breakdown. Given the widespread availability of sand substrate in our Saharan regions, promoting the reuse of wastewater following treatment is imperative for the sustainable and reasonable management of water resources in a deficient environment (low rainfall). This study has led us to conclude that sand from the Hassi Messaoud and Sidi Mehdi regions is suitable for use as a filter medium for wastewater treatment. It also comes out from this study that the use of sands of dune makes it possible to solve the problem of the water used without recourse to very expensive techniques, which require very important means of management. However, to justify the choice of this technique, it is necessary to carry out an experimentation to reduce the errors of scale and to take into account the other parameters of pollution that was not studied in this work (suspended matters SM, Biological oxygen demand BOD_5, phosphorated pollution and bacteriological quality).

Acknowledgements

The authors are grateful to the University Center of Maghnia in the state of Tlemcen and the University Kasdi Merbah Ouargla for supporting this work through the research plan entitled Comparative study between two types of sand used for slow filtration.

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