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Conventional filtration system for seawater pretreatment at the Beni Saf desalination plant using conventional sand filters: a comparison with Filtralite pure and clay filters

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ABSTRACT

In the desalination of seawater, the conventional physical pretreatment of the flowing of seawater through sand, anthracite, and cartridge filters is mainly used to eliminate solid elements, such as algae and organic matter. The substitution of conventional sand filters with new ones, such as Filtralite pure and raw clay filters, constitutes the main purpose of the present investigation. The sand filters used in the conventional filtration system for seawater pretreatment at the Beni Saf desalination plant were compared with Filtralite pure and clay filters, and the Filtralite filters were characterized. The filtering material (i.e., Filtralite pure) was analyzed by means of X-ray diffraction and scanning electron microscopy before and after the filtration of seawater. The quantification of the main constituent elements present after the filtration was carried out by energy-dispersive X-ray analysis. A physicochemical study of the filtered water by Filtralite was then conducted to determine the elimination efficiency of salts and heavy metals. Subsequently, the performances of the conventional sand, the Filtralite pure, and the original raw clay (from Mzila, Mostaganem) filters were compared with each other. The results showed that both the new Filtralite pure and clay media gave the best prefiltration compared with the conventional filter sand.

Keywords: Desalination; Seawater pretreatment; Filtralite/clay filters; Physicochemical characterization

1. Introduction

Seawater pollution, accidental or voluntary, by industrial compounds (e.g., hydrocarbons, phenols, dyes) or agricultural chemicals (e.g., pesticides, fertilizers), constitutes a source of environmental degradation and is currently of particular interest internationally [11]. In general, aromatics and toxic heavy metals are nowadays regarded as carcinogenic and dangerous micropollutants, although in the form of traces. Wastewater from the textile industry is also loaded with many organic micropollutants, in particular certain detergents and dyes. Conventional seawater pretreatment processes have their limits; the combined chemical processes of coagulation, flocculation, and settling do unfortunately not allow sufficient reduction of these compounds.

Water covers almost two-thirds of the Earth's surface, and most of it is found in the oceans and seas. However, seawater is salty and unsuitable for direct consumption [1]. Because of the great abundance of saltwater, desalinating seawater and brackish water attract a great deal of attention.

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The difficulty of providing clean water is a serious issue and a source of many human diseases [10]. Nowadays, in order to overcome the scarcity of drinking water, seawater desalination seems to be the most reliable industrial means of producing freshwater that can cover the needs of most countries [12]. Reverse osmosis (RO) of seawater is a fully mature technology at an industrial scale and has been installed in all coastal areas around the world with limited natural hydrological resources [2].

However, the clogging (i.e., fouling) of the membranes remains the major constraint in this technology, leading to a decrease in productivity and a reduction in the membranes' lifetime [3]. Thus, to solve this problem, the pretreatment of seawater or brackish water is necessary and represents a key stage in the desalination process. Current processes make it possible to provide good water quality at the inlet of RO membranes. However, the desalination streams sometimes dysfunctional at the level of the pretreatment processes because of the appearance of voids in the sand filters. This leads to severe clogging of the pretreatment membranes (sand filters, microfiltration membranes, or ultrafiltration and nanofiltration membranes), which reduces their performance [3].

The reduction of micropollutants by adsorption on activated carbon or sand has for a long time remained the most used method [19,26]. Nowadays, a new family of microporous solids are used, commonly known as Filtralite, with controlled porosity similar to that of clays. Filtralite is manufactured in Norway, and the abbreviations used for Filtralite are the following: N = normal density, M = medium density, H = high density, and C = crushed. Each material has its own particle density and grain-size distribution [4].

Filtralite, an expanded aluminum silicate with high porosity, is produced by the combustion of clay at around 1,200°C, followed by padding and sieving. The material has a porous and crushing structure [4]. A large surface is exposed, the density of dry particles is between 500 and 1,600 kg/m^3, the aggregates do not release harmful substances, and the solubility in acid is minimal despite the material's low density and high porosity [5].

Filtralite has a high resistance to abrasion and impact, which makes it a good filtration medium in fillings. Furthermore, it has proved to be as efficient as anthracite. Filtralite has excellent properties for use in pretreatment filters in desalination plants, both in filters for the filtration of coagulated water and in biological processes. Filtralite has a low silt density index and reduces the risk of biological fouling of RO membranes [6].

In a study at Luleå kommun, Sweden, in a water treatment plant located west of Luleå between Storheden and Luleå (Lule River), two different media (sand and anthracite) and Filtralite were compared in terms of turbidity, color, and heavy metals, such as aluminum, iron, and manganese. It was found that Filtralite was more effective in terms of reduction of turbidity and color, while the particles of Filtralite were better dispersed in the filter medium. In contrast, the particles of sand and anthracite were more likely to remain stuck [5].

Filtralite pure can be used as a filtering medium in conventional deep filters with a granular bed and in biological filters [9]. It can also be used as a single-layer filter [23] or as an upper layer in a multilayer filter medium. Besides, it can be applied to both open and closed filters for the treatment of groundwater, surface water, seawater, and effluents [5].

The present work focuses on the application of the new filtering medium (i.e., Filtralite pure) to seawater pretreatment at the Beni Saf desalination plant (on the Mediterranean Sea coast, Algeria) to improve the treatment's efficiency and thus reduce the clogging percentage of the RO membranes and the osmotic pressure. Three filter-based media, namely conventional sand, new Filtralite pure, and raw clay originating from Mzila (Mostaganem), were studied and compared.

2. Materials and methods

2.1. Water treatment process at the Beni Saf plant

The water treatment process at the Beni Saf plant consists of a collection system and the pumping of seawater through a single round plug connected to a seawater pump tank by a pipe with a diameter of 2.4 m, submerged at 1,400 m from the coast at a depth of 18 m. The pretreatment of the seawater is performed by sand/anthracite filtration and microfiltration using polypropylene cartridge filters. It is then followed by demineralization using RO. Finally, brine and by-products are removed through an outlet pipe of 1.8 m in diameter at a depth of 8 m below sea level, discharging 2 m above the bottom through a single diffuser (1 m in diameter at an inclination of 45°) (Fig. 1). The total terrestrial and submerged length of the duct is 1,400 m [7]. The features of the Beni Saf seawater station are summarized in Table 1.

2.2. Seawater sampling sites

In order to clearly see the effect of contact time on the adsorption of heavy metals and salts on the three adsorbents studied (i.e., Filtralite, clay, and sand), we used different time intervals (2, 4, and 24 h) and solutions of 250 mL seawater withdrawn from Phase 1 before feeding the sand filter to the desalination plant (100 g of adsorbate in batch mode, at a temperature of 20°C, under a stirring speed of 300 rpm).

Various analyses are used in this study, which can be classified into two groups: (1) those that make it possible to characterize the physicochemical properties of the solid phase of the filters and (2) methods that make it possible to determine the properties of the liquid phase of the filtered seawater. The Beni Saf Water Company (BWC) seawater desalination plant has several sampling sites (Fig. 2): at seawater intake, before feeding the sand filter (Phase 1), before anthracite filtration (Phase 2), before cartridge filtration, before RO, and at the treated water tank.

2.3. Preparation of the Filtralite pure and clay samples

The Filtralite used in this study consists of two layers, a so-called "mono-multi" solution. The two layers of Filtralite pure are of different sizes and densities, as shown in Table 2. The specifications of the Filtralite are given in Table 3.

Table 1
Features of the Beni Saf Seawater Desalination Plant [14]

Desalted water production capacity	200,000 m^3/d
Number of modules	10 units of 20,000 m^3/d
Desalination technology	Reverse osmosis
Power consumption	≤4.15 kW/m^3
Type of seawater intake and discharge	Underwater outfall DN 2,400 mm/1,800 mm
Pretreatments	Prefiltration, sand and anthracite filters, cartridge filters
Chemical pretreatments	Sodium hypochlorite, ferric chloride, sulfuric acid, sodium metabisulfite, dispersant
Energy recovery system	Isobaric chambers (ERI) 95%
Product post-treatment	Calcium carbonate and sodium hypochlorite

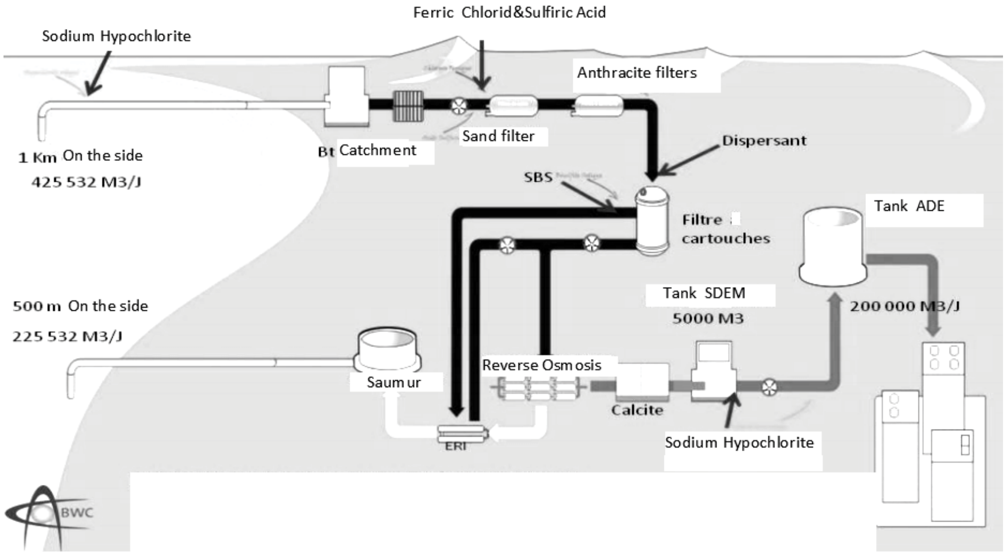

Fig. 1. The Beni Saf seawater treatment process plant.

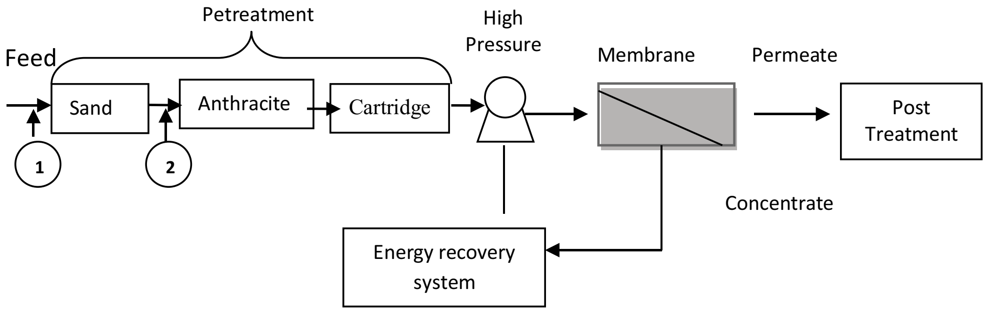

Fig. 2. Seawater desalination plant and sampling sites of the Beni Saf water.

Table 2
Two-layer media design recommended for use with Filtralite® Pure™ 1.5–2.5 mm

Type of filter medium	Grain size (mm)	Height of layer (mm)
Filtralite pure MC 1.5–2.5 mm	1.4–2.5	500–900
Filtralite pure MC 0.8–1.6 mm	0.8–1.2	400–800

2.3.1. Physicochemical characterization of the filters

2.3.1.1. X-ray diffraction analysis

The X-ray diffraction (XRD) analysis was performed using the Phillips X'PERT diffractometer in 2θ-θ mode with Cu Kα radiation X (α = 1.541837 A) operating at 45 kV and 40 mA. The XRD plots were recorded in a temperature range of 10°C–90°C with a step width of 0.02 s^{-1}.

Table 3
Specifications of Filtralite pure [8]

Trade name	Filtralite® MC 1.5–2.5 mm	Filtralite pure MC 0.8–1.6 mm
Density	Apparent density, after compression: 600 kg/m^3	Apparent density, after compression: 650 kg/m^3
Material type	Expanded clay	Expanded clay
Aspect	Crushed particles, porous surface	Crushed particles, porous surface
Made by	Leca Rælingen (Group Saint-Gobain), Norway	Leca Rælingen (Group Saint-Gobain), Norway
Granulometry	1.4–2.5 mm	0.8–1.2 mm
Density of particles	1,300 kg/m^3	1,400 kg/m^3
Solubility in acid	<7%	<7%
Fraction of emptiness	~55%	~55%

The samples (i.e., powder) were placed on a silicon substrate. A structural analysis was performed using Rietveld refinement with Material Analysis Using Diffraction (MAUD) software[1]. The calculated XRD diagrams were generated using the Mercury Software by the Cambridge Crystallographic Data Centre[2]. The crystallographic information files were downloaded from the Crystallographic Open Database (COD)[3]. The XRD analyses were carried out at the University of Moscovici (Japan).

2.3.1.2. Elemental analysis by X-ray spectrometry

Semiquantitative energy-dispersive X-ray (EDX) analyses of the Filtralite sample for the determination of the elemental composition were also performed. The analyses were carried out at the Oran University of Science and Technology – MB (Algeria).

2.3.1.3. Scanning electron microscopy

A scanning electron microscopy (SEM) allows the morphological characterization of the phases at a micrometer scale. The microscope used was JEOL JSM-5000 equipped with a field emission gun. The samples were deposited on a pellet containing silver lacquer metalized with gold or carbon. The acceleration voltage was variable between 0.5 and 30 kV depending on the quality of the image obtained; the magnification was up to 150,000x, and the resolution was from 1.6 to 20 kV. The observations were made with secondary electron detection. The SEM makes it possible to observe the texture of the three samples (Filtralite, sand, and clay) and to characterize the mineralogical assemblies. The SEM analyses were carried out at the University of Moscovici (Japan).

2.3.2. Properties of the liquid phase of filtered seawater

Turbidity was determined by a 2100N turbidimeter according to the HACH method. The electrical conductivity of water was measured by a HACH Model 44600 conductivity meter, equipped with a probe consisting of two electrodes covered with black platinum. The concentration of the various heavy metals contained in water was determined by atomic absorption spectrophotometry, according to Beer–Lambert's law.

3. Results and discussion

The chemical compositions of the studied raw clay and Filtralite pure filters are given in Table 4.

As shown in Table 4, the chemical compositions of the studied absorbents are similar to each other and to certain other compounds, such as the silica used as an anticaking agent in the food industry. In addition, the clay has the same composition as Filtralite pure. The percentage of AL_2O_3 is high, indicating that the analyzed clay and Filtralite samples are aluminous silicates [15,16].

3.1. Physicochemical characterization of the filters

The results of the physicochemical characterization of the studied filters are displayed in Figs. 3–5.

Examination of the XRD patterns of the sand sample before and after filtration (Fig. 3) shows the presence of peaks for quartz (Q), anorthite (A), and muscovite (M). The elevated baseline in the regions of $2\theta = 18°–28°$ and $2\theta = 36°$ is due to the amorphous phases. Besides, the appearance of new lines, especially at $2\theta = 40°$ and $2\theta = 43°$, are indicative of the presence of quartz. It should be noted that the identification of the filters was made by comparison with five montmorillonite reference minerals, according to the HANAWALT[4] method.

After the diffraction, the energy spectrum of the diffracted beam was obtained as a function of the diffraction angle 2θ. In this spectrum (Fig. 5), the angular values can be converted to the basal space d(Å) by applying the Bragg law and using the wavelength $K\alpha$ of the anode used to produce the incident X-ray.

Table 4
Chemical composition of Filtralite and raw clay (Mzila)

Compound percentage (%)	SiO_2	Na_2O	Al_2O_3	CaO	MgO	K_2O	Fe_2O_3
Filtralite	66	2	18	2	–	4	7
Raw clay (Mzila)	69	2	15	5	3	2	4

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[1] http://maud.radiographema.Eu/

[2] https://www.ccdc.cam.ac.uk/Community/csd-community/freemercury/

[3] http://www.crystallography.net/cod/

[4] Powder diffraction files (JCPDS), inorganic phases, International Centre for Diffraction Data, USA (1987).

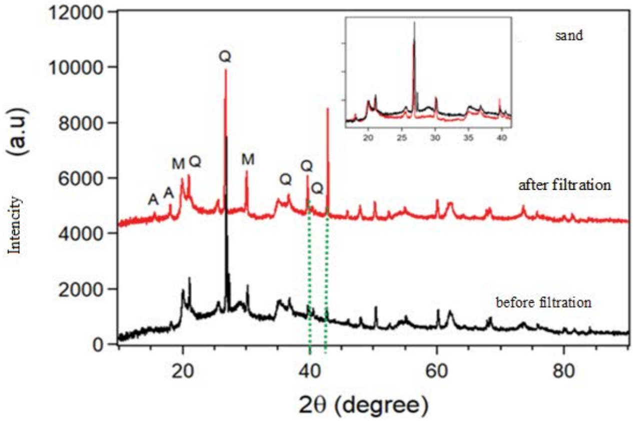


Fig. 3. XRD patterns of sand before and after filtration.

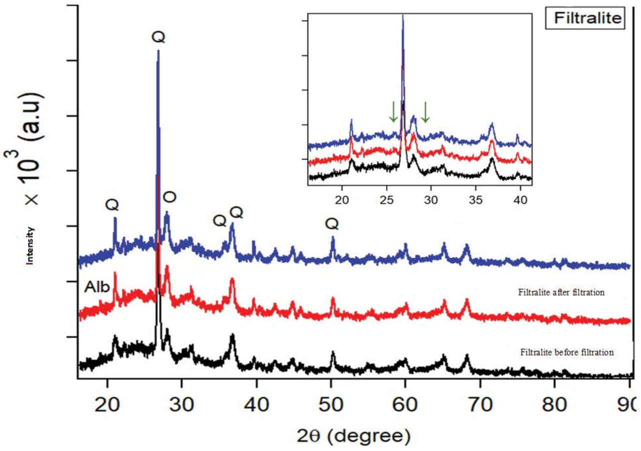


Fig. 4. XRD patterns of Filtralite. The mineralogical composition of Filtralite before and after filtration compared with reference materials. D = dolomite; S = smectite; Q = quartz; C = calcite; M = montmorillonite; B = bentonite.

Preliminary examination of the Filtralite XRD pattern before and after filtration revealed the presence of the following minerals: montmorillonite, quartz, dolomite, amorphous silica aluminum, amorphous silica, orthoclase, albite, calcite, hematite, and anorthite. The measured lattice distances *d* can be determined according to their values attributed to different species of minerals.

As a first step, the qualitative interpretation of the XRD diagrams makes it possible to identify these different mineral species by comparison with the data available in the literature. According to the XRD results, the major crystalline phases contained in the Filtralite are composed of the following minerals: montmorillonite and quartz. The crystalline impurities consist essentially of calcite, dolomite, hematite, and anorthite. Examination of the diffractogram of a Filtralite sample before and after filtration shows the presence of a peak for montmorillonite, in particular at d = 4.47 Å and 2θ = 19.84 Å; some peaks were identified as impurities. Also, note the presence of quartz at d = 3.35 Å and 2θ = 26.53 Å; calcite at d = 2.99 Å and 2θ = 22.10 Å exists in very small quantities in the sample.

The results of the clay filter submerged for 24 h in seawater before and after filtration (Fig. 6) show that the filtration of seawater by clay caused changes in the structure of the studied samples. The disappearance of the peaks is due to the partial decomposition of the interfoliar space. Moreover, certain lines characteristic of the crystalline phases are absent, particularly those of montmorillonite, located at 2θ = 12°, with d = 3.44 and d = 3.19; further, the dolomite line at d = 2.8 has disappeared.

3.1.1. Intermediate distances after filtration of the three studied filters (2θ°)

The XRD diffractograms of the three filters before and after treatment make it possible to follow the evolution of the interfoliar distance. According to the results shown in Tables 5–7, intercalations are obtained. After filtration

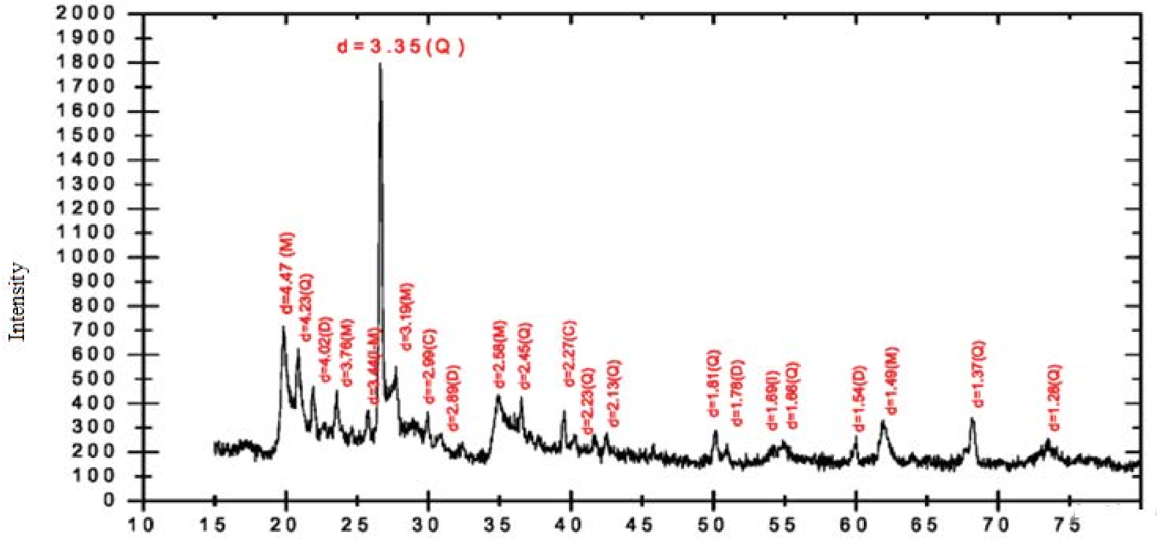


Fig. 5. XRD patterns of the reference montmorillonite materials [13,17].

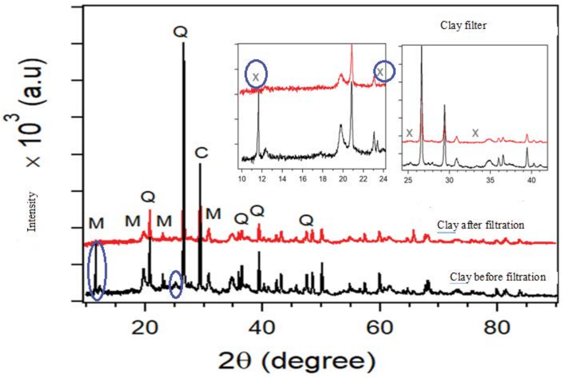


Fig. 6. XRD patterns of clay before and after filtration (analyses carried out at the University of Moscovici, Japan).

of the seawater, the intercalations are more important for the two clay and sand filters. The lattice distance of quartz shifts drastically from 17.86 to 47.07, and for sand and clay from 24.42 to 38.05. In contrast, for the Filtralite filter, only a small difference is noticed as the reticular distance changes slightly from 9.71 to 9.68. This change is due to the intercalation of the layers of the filters (sand and clay) with the seawater. Likewise, the other components show a small difference for the Filtralite filter and a remarkable difference for the sand and clay filters.

3.1.2. Elemental analysis by X-ray spectrometry

Semiquantitative EDX analyses of the Filtralite sample were performed to determine the elemental composition. The analyses were carried out at the University of Science and Technology, Algeria. The chemical elements contained in the material are shown in Fig. 7. The elemental composition of Filtralite pure after filtration by seawater is illustrated by the spectrum in Fig. 5, showing the presence of different elements. The atomic percentages of these elements are listed in Table 8, and semiquantitative analysis by EDX provides strong evidence for the presence of oxygen. The copper and carbon elements come from the support grid of the sample.

The results of the EDX analyses of Filtralite pure after filtration show that oxygen has the highest percentage of about 57.90%, followed by carbon with 21.89% and silicon with 11%. Most of the elements (87%) are due to the presence of quartz in the studied sample.

3.1.3. Scanning electron microscope analysis

The SEM analysis was carried out at the University of Moscovici, Japan. The image under the SEM show spores in the spherical and heterogeneously sized Filtralite grains. Large irregularly shaped cavities are observed, which might indicate a highly porous irregular structure favorable for a good diffusion of molecules. This confirms the heterogeneous composition of our Filtralite (Fig. 8).

The images obtained by SEM of the two sand and clay samples before filtration are shown in Fig. 9. The sand and clay particles are in the form of fine aggregates, with large cavities in the clay sample.

3.2. Properties of the liquid phase filtered seawater

The conductivity and turbidity of the studied filters were measured at the National Polytechnic School

Table 5
XRD crystalline phase sand filter composition before and after filtration

Crystalline phase	Quartz	Amorphous silica	Muscovite	Anorthite	Other[a]
Before filtration	17.86 ± 0.4	77.65 ± 1.66	3.86 ± 0.05	0.37 ± 0.07	0.24
After filtration	47.07 ± 0.66	41.38 ± 3.52	10.7 ± 0.08	0.83 ± 0.11	0.02

[a]Other: calcite, albite, and orthoclase.

Table 6
XRD crystalline phase composition of Filtralite before and after filtration

Crystalline phase	Quartz	Amorphous silica Al	Orthoclase	Albite	Other[a]
Before filtration	9.71 ± 0.4	52.87 ± 5.9	3. 35 ± 0.18	4.03 ± 0.16	1.6
After filtration	9.68 ± 0.3	52.3 ± 8.5	3.72 ± 4.48	4.48 ± 0.28	1.69

[a]Other: hematite, anorthite.

Table 7
Green clay filter XRD crystalline phase composition before and after filtration

Crystalline phase	Quartz	Muscovite	Albite	Calcite	Other[a]
Before filtration	24.42 ± 0.32	55.56 ± 1.8	2.40 ± 0.3	16.3 ± 0.29	1.32
After filtration	38.05 ± 1.09	38.04 ± 0.37	0.8 ± 0.37	23.8 ± 0.3	0.03

[a]Other: anorthite, dolomite, etc.

of Oran, Algeria. The analysis of the obtained results (Fig. 10a) shows that the two clay and Filtralite pure filters have similar conductivity values, yielding a concentration of about 10.80 ppm. The evolution of turbidity over time is presented in Fig. 10b. The analysis of the results shows that the concentration of turbidity in the seawater of the BWC station varies according to the treatment used. The turbidity is high for the sand filter, whereas it is about 20 NTU for both the clay and the Filtralite filter.

The chloride content was successively measured after 2, 4, and 24 h. The analysis of the obtained results reveals a decrease in the concentration of the chloride anion in the filtrate of the three filters after 24 h of treatment (Fig. 11).

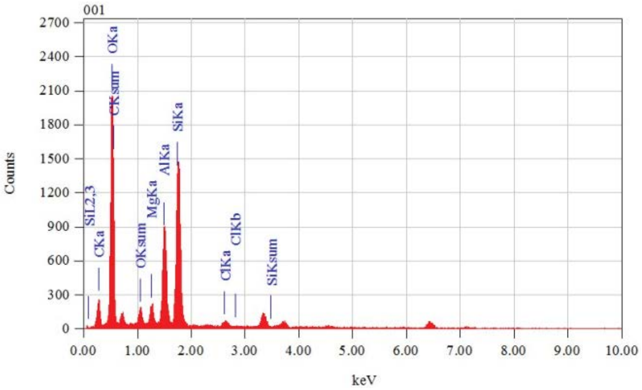
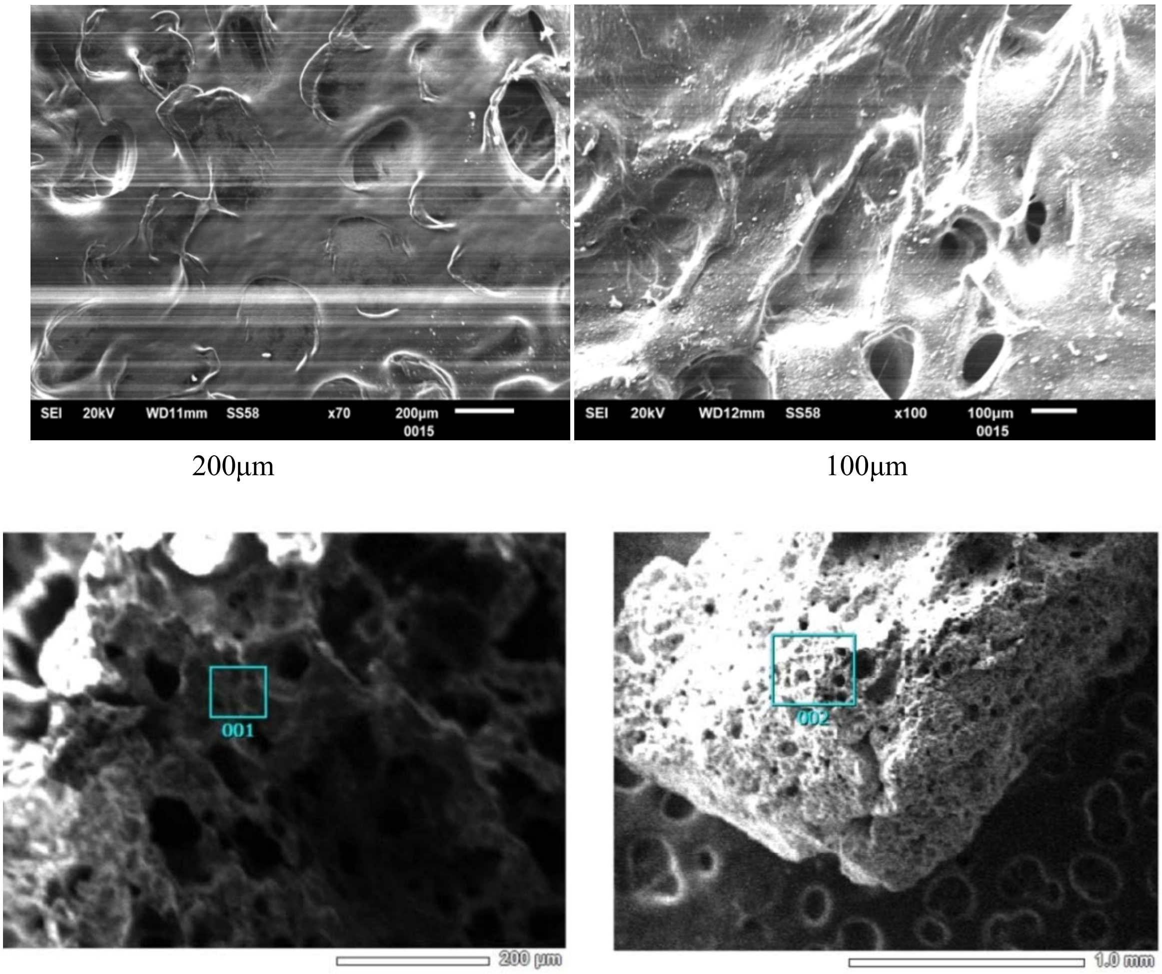


Fig. 7. EDX spectrum of Filtralite after filtration.

Table 8
Elemental composition of Filtralite pure

Element	Mass %	Atom %
C	21.89	29.51
O	57.90	58.60
Mg	1.78	1.18
Al	6.04	3.62
Si	11.87	6.84
Cl	0.52	0.24
Total	100	100



200µm

100µm

200µ

1mm

Fig. 8. SEM image of Filtralite after treatment: (a) 200 µm, (b) 100 µm, (c) 200 µm, and (d) 1 mm.

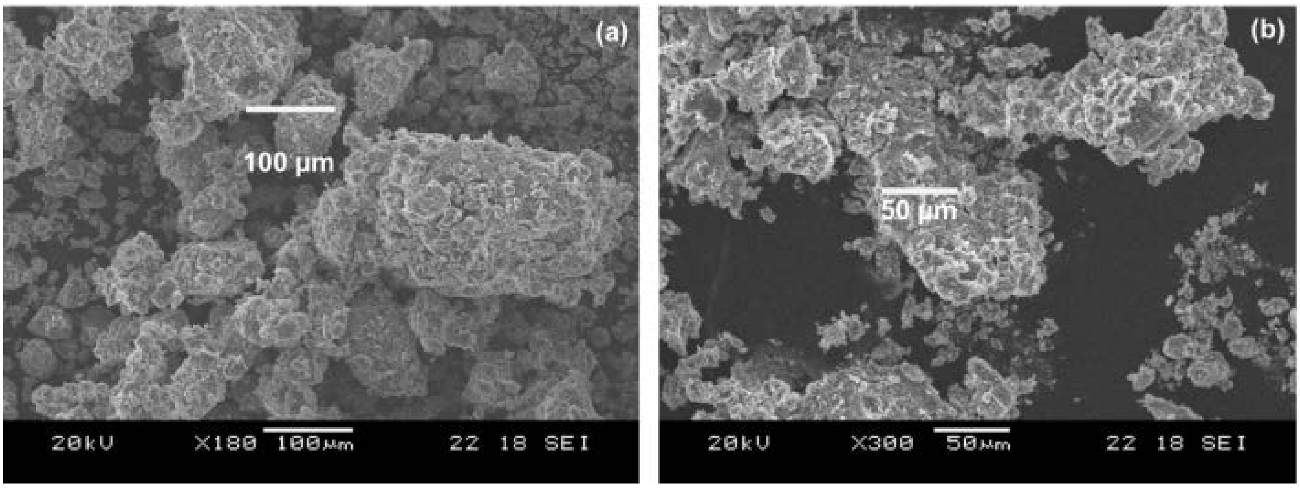


Fig. 9. SEM image of: (a) sand filter and (b) clay filter from Mostaganem before use.

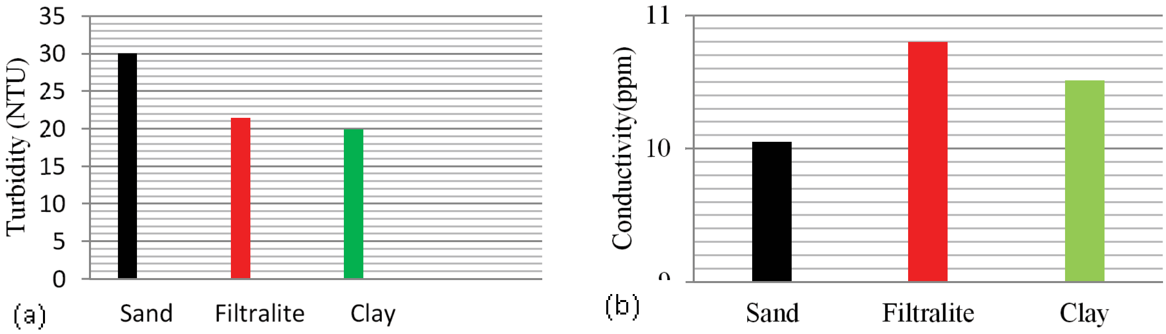


Fig. 10. Conductivity (a) and turbidity (b) values for the filters studied during 24 h.

The Filtralite filter has adsorbed [20,21] a large amount of chloride anions over a period of 2 h, whereas the sand filter required at least 4 h to achieve a good adsorption.

3.3. Efficiency of the studied filters

The elemental composition of the Filtralite after filtration by seawater is illustrated by the spectrum in Fig. 9, showing the presence of different elements. The analysis was carried out at the University of Moscovici, Japan. The atomic percentages of these elements are listed in Table 9, and the semiquantitative analysis by EDX highlighted a strong presence of oxygen. The copper and the carbon come from the support grid of the sample.

Fig. 12 shows that the Filtralite filter is more effective than the sand filter, whereas raw clay is as effective as the sand filter. This can be explained by the chemical composition [24,25], which is quite similar for the clay and Filtralite filters.

4. Conclusion

In this study, the substitution of conventional sand filters with new Filtralite pure filters and raw clay for the pretreatment of seawater in desalination has been investigated with the aim of reducing the clogging at the filters during the desalination process, thus improving the quality of the pretreated water. The filter materials, namely sand, Filtralite pure, and raw clay, were analyzed before and after filtration by SEM and EDX analyses. The analysis was confirmed by XRD to determine the properties and stability of the studied materials after filtration. Subsequently, the physicochemical characteristics of the water filtered by

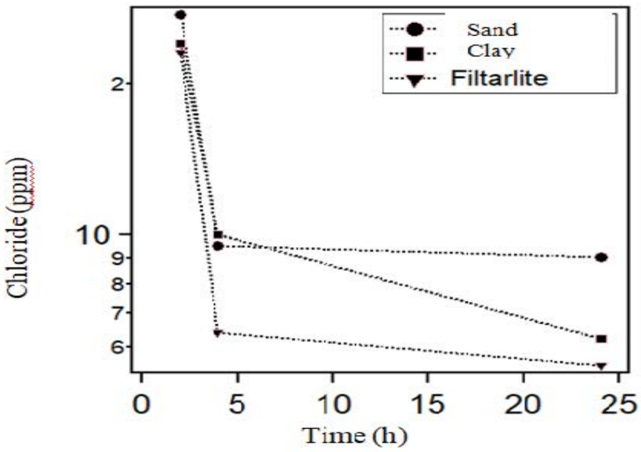


Fig. 11. Concentration profiles of the chloride anion in seawater after using the sand, clay, and Filtralite filters.

Table 9
Concentration of heavy metals in the seawater filtrates for the three filters studied after 24 h of treatment

Heavy metals (ppb)	Filter sand	Filter clay	Filtralite	Composition of seawater (ppb)
Al	0.091	0.057	0.053	0.350
Fe	0.091	0.010	0.005	0.056
Cu	0.128	0.082	0.068	0.100
Cr	0.066	0.060	0.040	0.250
Zn	0.134	0.080	0.082	0.480
Ni	0.126	0.085	0.073	0.470
Cd	0.0088	0.00568	0.0049	0.100
Ba	9.000	6.00	5.000	17.00
Se	0.160	0.114	0.080	0.200
Co	0.141	0.099	0.091	0.300
Mn	0.026	0.010	0.009	0.100
Total (ppb)	09.075	06.60	5.550	19.406
Efficiency (%)	53.24	65.98	71.40	

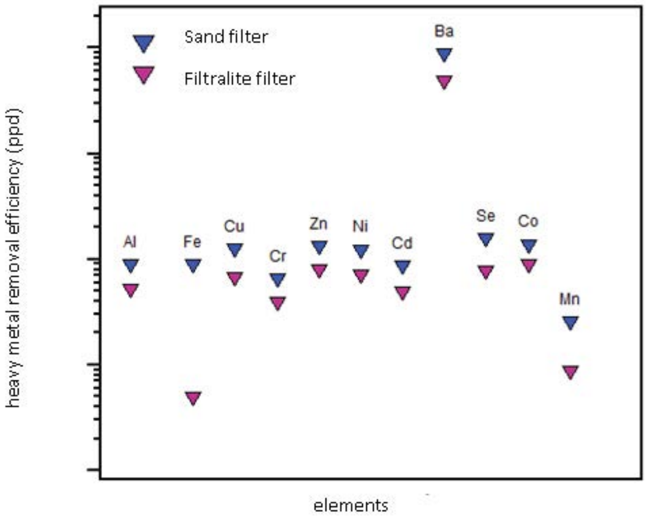


Fig. 12. Comparison between sand and Filtralite filters in the efficiency of heavy metal removal after 24 h of treatment.

the three filters were determined. The results revealed that the quality of the water filtered by Filtralite pure and raw clay, as compared with the quality of the water filtered by sand, was good in terms of most parameters, such as turbidity, conductivity, the reduction in the concentration of heavy metals, and the decrease in chloride concentration.

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