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Characterization of the reverse osmosis membrane fouled by Oum Errabia river water of Khenifra city, Morocco

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Abstract

The Khenifra desalination plant is designed to produce 36,290 m^3/d of drinking water by 2030. Since the start-up of this plant in 2013, several problems have been encountered in the reverse osmosis unit due to membrane fouling. Clogging is a major issue related to the interaction between feed water quality and the pre-treatment process. Membrane autopsy, monitoring of seasonal variations in raw water and surveillance of operating parameters are carried out. The results obtained show that feed water is subject to large seasonal variations in terms of temperature (10 - 25 °C), conductivity (1395 - 2500 µS.cm^{-1}) and Silt Density Index (SDI) (< 3) in 2017 using microfiltration, which influences the fouling of the membrane. Membrane autopsy by scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS) and X-ray Diffraction (XRD), shows the formation of large cracks on the surface of the membrane and that the fouling layer is mainly composed of: $CaCO_3$ (38.70 %), Al_2O_3 (17.42 %), $Ba(SO_4)_2$ (15.23 %), $MgCl_2$ (15.02 %) and SiO_2 (13.64%).

Keywords: *demineralization; reverse osmosis; membrane; permeability; water; fouling*

1. Introduction

Water represents the most crucial resource for the survival of all living beings on Earth. Approximately 94% of water is found in the oceans, while the remaining 6% is fresh water. About 72% of the total freshwater is found underground and 27% is in the form of glaciers [1]. In the context of the influence of climate on surface water quality, the importance of the time scale on the corresponding relationship should be noted. The dominant factors of the temporal scale , such as temperature, precipitation and agricultural activities, vary according to the seasons, and given their role on the process of convergence of flows and inputs of contaminants into water bodies, the researchers suggested that it is imperative to take seasonal variations into account when studying the impact of land use on river water quality [2,3]. Reverse Osmosis (RO) is becoming increasingly accepted worldwide in water treatment and desalination applications. It is a pressurized process in which a semi-permeable membrane rejects the dissolved constituents present in the feed water. This release is due to size exclusion, filler exclusion and physicochemical interactions between the solute, the solvent and the membrane [4–7]. The efficiency of the process depends on the operational parameters, the properties of the membrane as well as the properties of the feed water [8]. However, the effectiveness of this technique is limited by the fouling of the membranes. This has an impact on the performance, resulting in increased energy consumption, cleaning frequency, chemical consumption, membrane changes, and thus the cost of water treatment [9–11]. Pretreatment of the feed water is necessary to extend the life of the membrane and prevent fouling. Generally, pretreatment consists of chemical coagulation, filtration, ultrafiltration or microfiltration, control of scaling and acidification for pH regulation [12–15]. Membrane fouling may be due to scaling, microbial growth, dissolved organic substances, or particles and colloidal materials that can form compact cakes [8,16]. The aim of this work is to study the impact of seasonal variations in feed water quality on the fouling of the reverse osmosis membranes of the desalination plant of the city of Khenifra in Morocco. Accordingly, the characterization of the feed water and the characterization of the membrane were investigated.

2. Materials and Methods

2.1. Presentation of the water treatment plant of Khenifra city

The water treatment plant of Khenifra city is located 5 km from the center of Khenifra and 300 m from Oum Errabia river. It is fed by the Tanfnit El Borj dam (Figure 1).

Fig. 1. Satellite photo of water treatment plant of Khenifra city.

The Khenifra city water treatment plant combines conventional treatment with reverse osmosis to produce a continuous flow rate of 420 L/s of treated water from raw water with a suspended solids load of up to 20 g/L.

The operation of the station can be schematized as shown in (Figure 2).

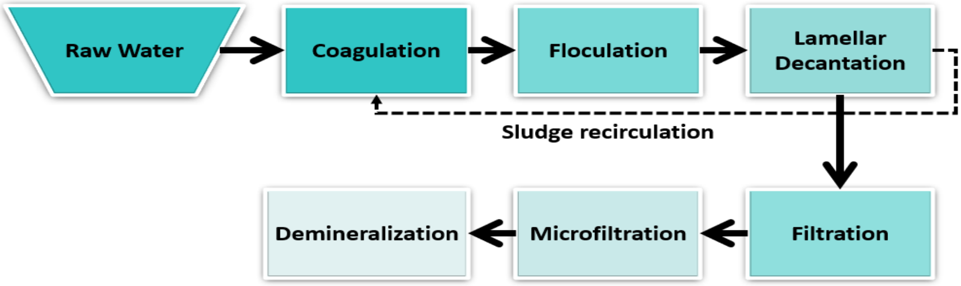

Fig. 2. Diagram of the water treatment plant.

2.2. Reverse Osmosis Membrane

2.2.1. Description of the reverse osmosis membrane

The reverse osmosis membrane used is a FilmTec ™ type called XLE440. It is part of the FILMTEC ™ FT30 membrane family. It consists of a thin-film composite membrane made of three layers: a polyester support web, a microporous polysulfone interlayer and an ultra-thin polyamide barrier layer on the upper surface (Figure 3). Each layer is adapted to specific requirements.

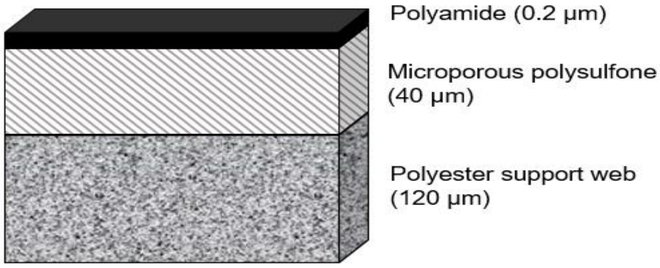

Fig. 3. Composition of the reverse osmosis membrane.

2.2.2. Transmembrane pressure

The transmembrane pressure (TMP) is the difference between the pressure on the supply side and the pressure on the permeate side [17]. It is expressed in bar or Pa:

$$TMP = \frac{P_F + P_R}{2} - P_E \qquad (1)$$

Where: P_F : Filter pressure; P_R : Return pressure; and PE : Effluent pressure, usually negligible.

2.2.3. Permeability

Hydraulic permeability (L_P) is a parameter that characterizes the ease with which water passes through the membrane. Permeability depends mainly on pore size, membrane thickness and the chemical properties of the membranes [18].

$$Lp = \frac{J_V}{\text{TMP}} \qquad (2)$$

$$J_V = \frac{Q_P}{TMP} \qquad (3)$$

Where: L_P: Permeability ($L.h^{-1}.m^{-2}.bar^{-1}$); J_V : Permeate volume flow (L.h-1 .m^{-2}), TMP: Transmembrane pressure (bar) and Qp: Permeate flow rate (L/s).

2.2.4. Characterization of reverse osmosis membrane

The scanning electron microscope used is a device type LEO1501. Before each analysis, the samples are fixed on a conductive adhesive tape, covered on the edges with silver lacquer and finally covered as a whole by two ultrafine layers

of Pt / Pd (2 × 2 nm) made by vacuum evaporation. The beam energies vary between 1 and 3 keV. It also allows chemical analysis using an EDS (Energy DipersiveX-ray Spectroscopy) detector. The x ray diffraction is carried out by a Siemesns D5000 diffractometer with a Cu-Kα radiation source (λ= 1.541838 Å). The samples are analyzed under 40 kV in 2θ range of 10 ° and 60 °.

3. Results and discussion

3.1. Water characterization

The demineralization plant of khenifra city is fed from the waters of the oum erbiaa river, which is the most important river in Morocco that feeds water to the large width for several months a year, the quality of the water supplied to the plant undergoes significant seasonal variations in terms of temperature, conductivity and silt density index. Table 1 shows the average values of the water characteristics of the oum erbiaa river.

Table 1: Feed water characteristics at the inlet of the reverse osmosis demineralization plant.

Chemical Composition	Amount
pH	8.5
Alkalinity (°F)	17.6
Calcium (mg/L)	95
Magnésium (mg/L)	32.5
Sodium (mg/L)	466
Potassium (mg/L)	2.9
Manganese total (mg/L)	0
Aluminium (mg/L)	< 0.2
Ammonium (mg/L)	0
Iron (mg/L)	< 0.03
Barium (mg/L)	0
Bicarbonnate (mg/L)	214
Chloride (mg/L)	866
Sulfate (mg/L)	117
Nitrate (mg/L)	6.49
Fluoride (mg/L)	0
Silica (mg/L)	15
Total dissolved solids TDS (mg/L)	1800

3.1.1. Temperature

The temperature is subject to indicative seasonal changes [19,20]. Changes in feed water temperature will affect reverse osmosis performance. For example, an increase in feed water temperature of 4°C will result in an increase in permeate flow rate of approximately 10%. However, this is a normal phenomenon [21]. Figure 4 shows the variation of the feed water temperature at the Khenifra city treatment plant during 2017. According to the figure, the temperature varies from 10 °C in February and March to 25 °C in August.

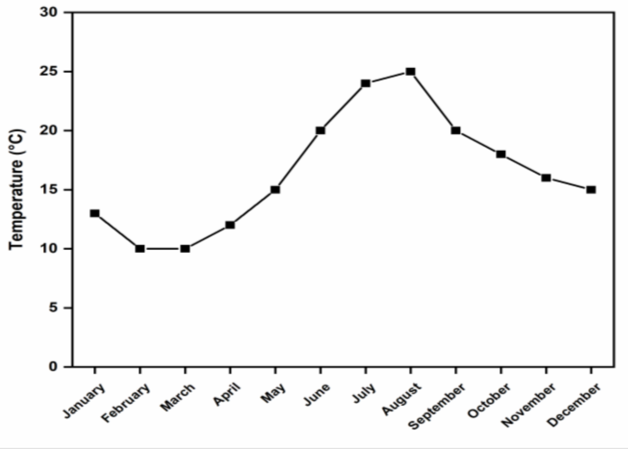

Fig. 4. Feed water temperature variations.

3.1.2. Conductivity

Figure 5 shows the variation in the conductivity of the plant's feed water during 2017. As shown in the figure, there are seasonal variations in conductivity during the year, ranging from 1395 µS.cm^{-1} in January to 2500 µS.cm^{-1} in summer (June to August). The increase of conductivity in summer is due to the evaporation of water, which leads to high salt concentration, resulting in the fouling of the membrane. While, the decrease of conductivity in winter is due to the precipitation, which leads to the dilution of the feed water, thus reducing the salt concentration (dilution) [10,21,22].

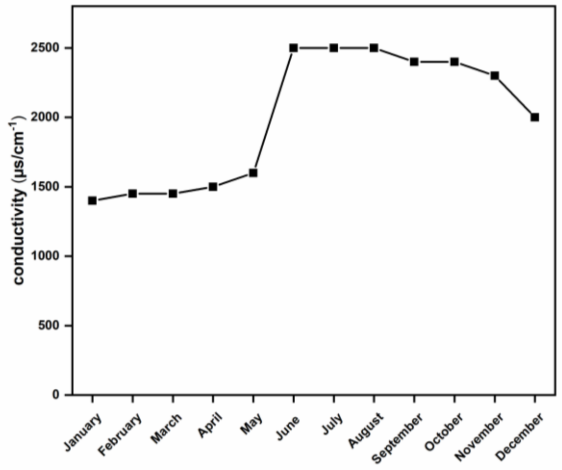

Fig. 5. Feed water conductivity variations.

3.1.3. Silt Density Index (SDI)

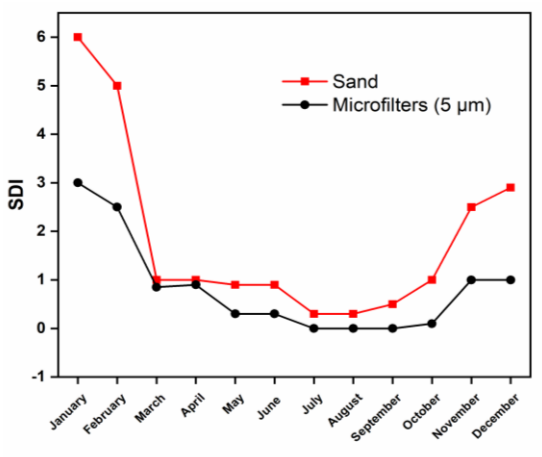

Fig. 6. SDI values at the inlet and outlet of the microfiltration.

Silt Density Index is a measure of colloids and suspended particles in water. Figure 6 shows the evolution of SDI of water filtered by sand and microfilters (5 µm) in 2017. From the figure it can be seen that the SDI values are below 3 for all months of 2017 using microfiltration, while the SDI values are above 3 during January and February 2017 using sand filters. The obtained results of SDI of microfiltered water were similar to those found by Boulahfa et al. in 2013 [21].

3.2. Characterization of reverse osmosis membrane

Figure 7 shows scanning electron microscope (SEM) images and corresponding EDS spectra of fouling membrane surfaces. The image of the surface of the reverse osmosis membrane obtained by SEM shows the formation of large surface cracks due to contact with chlorine. Membranes are very sensitive to disinfectants, especially oxidants [23,24]. There are also deposits in the form of clearly visible aggregates, which show a significant amount of colloidal fouling on the membrane. The EDS spectrum, shown in Figure 7, revealed the presence of calcium in large quantities, which is responsible for the formation of scale.

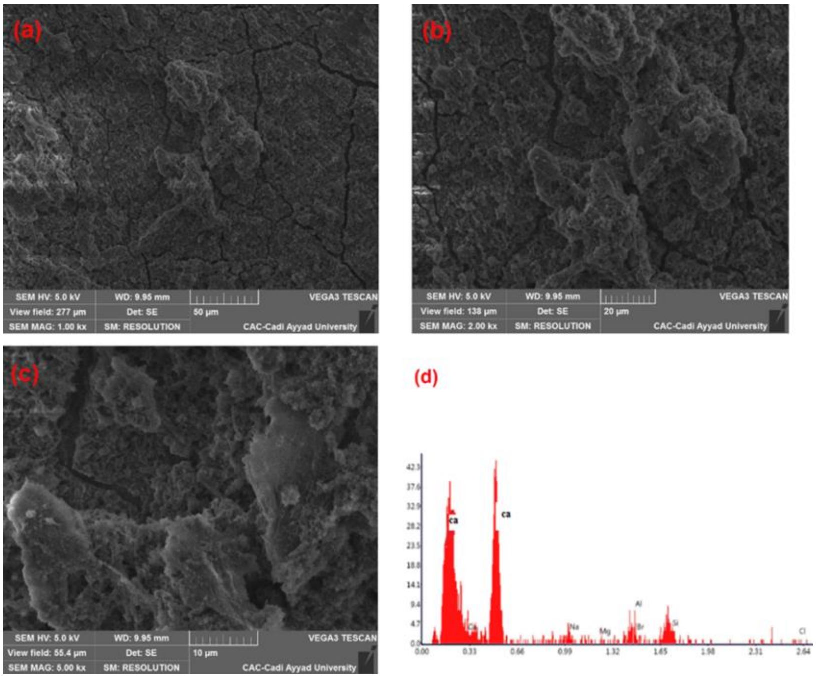

Fig. 7. (a) SEM images of a reverse osmosis membrane structure x 1000; (b) x 2000; (c) x 5000; (d) EDS spectrum result.

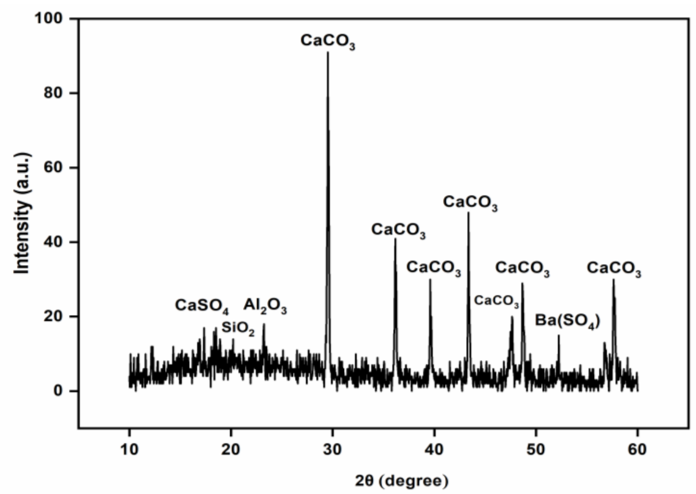

Fig. 8. XRD pattern of fouling matter.

Figure 8 shows the X-ray diffraction pattern of the fouling membrane. This analysis showed the presence of $CaCO_3$, Al_2O_3, $Ba(SO_4)_2$, $MgCl_2$ and SiO_2. Based on these results, the nature of the clogging material is essentially inorganic, and formed mostly by calcium carbonate (38.70%). Table 2 shows the values of the permeability of the reverse osmosis membrane before and after the washing period during 2017. According to table 2 the permeability value has been increased from 1 to 1.3 10^{-6} $m.s^{-1}.bar^{-1}$. an increase of the flow rate from 80 to 100 L/s has been observed.

Table 2 : Membrane permeability and debit values.

	Before cleaning	**After cleaning**
Permeability of FIMTEC Lp (10^{-6} $m.s^{-1}.bar^{-1}$)	1	1.3
Debit of permeate (L/s)	80	100

4. Conclusion

The quality of the feed water supplied to the Khenifra reverse osmosis desalination plant is subject to temporal variations. This change is due to the deviation of rainfall and seasonal temperature fluctuation leading to evaporation of water from the river. The feed water is subject to strong seasonal variations which leads to the precipitation of salts on the membrane surface inducing membrane scaling. The use of scale inhibitors must take into account the salinity of the feed water during the seasons and adjust its dosage according to the salinity. The use of chlorinated products in the treatment of surface water, may leave traces of chlorine in the water feeding the membrane and may damage the surface of the membrane. Indeed, for improving the functioning of the Khenifra Reverse Osmosis Plant and achieving high performance, pre-treatment of the feed water is highly recommended.

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