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Performances of nanofiltration and reverse osmosis in textile industry waste water treatment

Emna Ellouze[a], Sami Souissi[a], Amel Jrad[b], Raja Ben Amar[a,*], Abdelhamid Ben Salah[a]

[a]*Faculté des Sciences de Sfax, Laboratoire Sciences des Matériaux et Environnement, Route de Soukra Km 4, BP 763, 3000, Sfax, Tunisie*
Tel. 216 4 276 400; Fax: 216 4 274 437; email: raja.rekik@fss.rnu.tn
[b]*Centre International de l'Environnement de Tunis (CITET), Bd du Leader Yassar Arafet, Tunis*

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ABSTRACT

In this paper experimental results obtained from the treatment by different membrane based processes, namely, microfiltration (MF), nanofiltration (NF) and reverse osmosis (RO) of Sitex industry waste water pretreated by biological activated sludge are presented and compared. The results obtained from direct NF performed at different transmembrane pressures (8 < TMP < 14 bar) and at a temperature (T = 25 °C) show that the permeate flux decreased from initial value of 19 to 9 l/h · m^2 for a volume reduction factor (VRF) of 4 and that the osmotic pressure π = 4 bar. A high quality of treated effluent in term of colour removal and desalination was obtained for a VRF of 2: salinity retention rate (R) 57% and decolourization almost 100% at pressure of 12 bar. While, the permeate flux obtained using the combination MF/RO at a different pressures 10 < TMP < 24 bar decreased from initial value of 35 to 20l/h · m^2 for a VRF of 7 indicating an important fouling. The optimum salinity and colour retention rate were 86% and 100%, respectively obtained at a VRF of 2.

Keywords: Textile industry waste water; Direct nanofiltration; Reverse osmosis; Salinity; Decolouration; Retention rate

1. Introduction

Mediterranean countries located on south coasts are characterized by semi arid climate. Since the two last decades, the combination of climate and demographical evolutions results in a decrease of water availability both for drinking water supply and irrigation management. Moreover, the industrial development has brought an increasing demand for water and waste water treatment.

In the field of textile, dyeing industry consumes a great amount of water used as solvent. The treatment of 1 Kg of cotton requires about 150 l of water and 40 g reactive dye [1] resulting in a large volume of strongly coloured effluents. The degree of fixation of a dye on a fibre varies depending on the type of fibre to be dyed and the dying parameters. Reactive dyes have poor fixation rates and hence may be hard to remove from wastewaters because of their low biodegradability and their low level of absorption into activated sludge [2].

During the dyeing steps of textile materials, the generated effluent resulted from at least 9 baths consisting in dyeing, finishing, coating, bleaching and washing bathes [2]. Several Steps used salt and high temperature (up to 90 °C) resulting in a final effluent of high temperature between 35 and 40 °C and high salt content (salinity between 4 and 10 g/l).

Thus, the large volumes of effluent often produced are heavily loaded with pollutants, turbidity and highly

*Corresponding author.

concentrated in salts. A significant improvement in effluent quality is required before discharged into the environment.

From an environmental point of view, Tunisia is considered one of the leader developing country in the field of water treatment and reuse to minimise losses of water. Tunisian legislations and regulations impose high limit pollution values for discharge into a municipal wastewater treatment plants or into the environment: For example, regarding discharge into the environment, the COD limit value is about 100 mg/l against 1000 mg/l concerning discharge into a municipal wastewater treatment plant. It can be seen that the norms applied to discharge into a municipal treatment plant are less strict than those applied to discharge into the environment. Besides, up to 65% of wastewater is recycled [3].

Since the last decay, the textile sector knows a great expansion in Tunisia. The region of the Sahel in the east of the country has the greatest concentration of textile companies. The textile waste effluents correspond to the total volume collected from the different baths necessary in the dyeing industry like bleaching and finishing treatment and dyeing auxiliaries. The average daily water consumption for some Company located at Ksar Helal, is estimated of about 2500 $m^3 \cdot d^{-1}$.

Textile effluents are one of the wastewaters that are very difficult to treat satisfactorily to reach the discharge norms. Studies regarding the treatment processes were carried out by different investigators [4,5,6]. According to the literature, several processes are used to eliminate organic load, suspended matter, color and salt such as combinations of biological, physical and chemical processes [7,8].

Recently, membrane technology like ultrafiltration, nanofiltration (NF) and reverse osmosis (RO) have been used in the field of textile waste water treatment in order to remove COD, color and salts and also to reuse the treated water and to recycle valuable components from the waste streams [1,9,10,11].

The aim of this work is to present a comparison between NF and RO performances on the textile waste water treatment after biological pretreatment. The effect of some experimental parameters on the permeation and separation of some components have been discussed.

2. Materials and methods

2.1. Materials

The Sitex textile factory utilizes different reactive dyes and chemical substances such as detergents, salts and auxiliaries (e.g. surfactants, emulsifiers). Generally, the waste water is coming from the washing baths in the dyeing step. Actually, a conventional activated sludge process is used. Under these biological conditions, the pretreated effluent characteristics are given by the Table 1.

2.2. Filtration rigs

The NF and RO experimental units were classical filtration set-up (Fig. 1). The experiments were performed with DK spiral wound membranes (RO and NF). Table 2 gives the main characteristics of these membranes provided by the manufacturer (Osmonics).

2.3. Conduction of experiments

At the first time, experiments were carried out under total recirculation mode in order to optimise the operating parameters: both the concentrate and permeate were recycled into the feed tank to keep the feed concentration approximately constant. During each experiment,

Table 1
Characteristics of the pretreated effluent from Sitex company which utilise sulphur dyeing processes and cotton fibres

Parameters	Unity	Raw effluent
pH	–	8.50
Suspended Ssolids (SS)		
Temperature (T)	°C	17
Turbidity	NTU	54
Conductivity	mS/cm	9
Salinity	g/l	7.5
Color (λ = 350 nm)	–	0.31
COD	mg/l	200
HCO_3^-	mg/l	3588
Cl^-	mg/l	1210
NO_3^-		60.3
SO_4^{2-}	mg/l	1260
Ca^{2+}		33.5
Mg^{2+}	mg/l	16.1
Na^+	mg/l	2800
K^+	mg/l	123

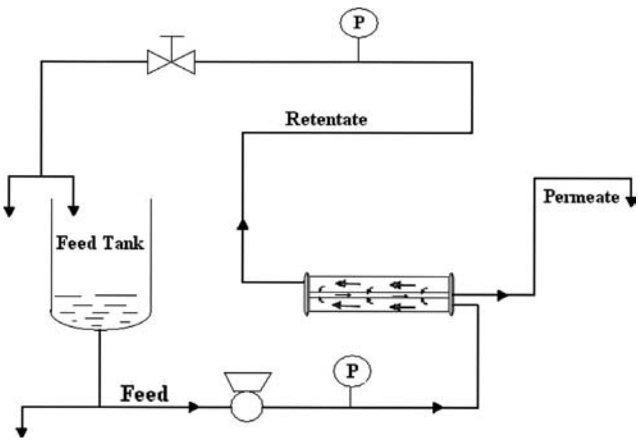

Fig. 1. Experimental unit for nanofiltration and reverse osmosis.

Table 2
Mains characteristics of the Osmonics membranes used

	NF membrane
Membrane area	2.5 m^2
MWCO	200 Da
Salt rejection	98% (2 g/l $MgSO_4$ at 6.9 bar, 25 °C, pH = 7.5)
Operating pH	3–9
Water permeability	4 l/h · m² · bar
	RO membrane
Membrane area	2.5 m^2
Salt rejection	99.4% (2 g/l NaCl at 15.5 bar, 25 °C, pH = 7.5)
Operating pH	4–11
Water permeability	3 l/h · m² · bar

the following parameters were determined: temperature (T) and transmembrane pressures (TMP) defined as: TMP = (Pi + Pe)/2 – Pp. When Pi is the inlet pressure; Pe is the exit pressure and Pp is the permeate pressure, usually $Pp = P_{atm}$.

At the second time, the permeate was not returned to the feed tank, resulting in increasing feed concentration. The volume reduction factor (VRF) is then determined: VRF = Vi/Vr where Vi and Vr are respectively, the initial and the retentate volumes.

After each run, the membrane was cleaned according to the recommendations of the manufacturer. The membrane permeability was checked by using pure distilled water at room temperature.

During each experiment, permeate volumes were collected and analyzed. The retention rate (RR) were then determined using the following equation: R (%) = 100 (1 – Cp/Cf)), where Cp and Cf are respectively, the permeate and the feed concentrations.

2.4. Analysis

Physical-chemical parameters of raw effluent and of permeate were determined: turbidity (turbidimeter, HACH RATIO 2100A); conductivity (conductimeter, Tacussel model 123); pH (pH-meter, Metrohm 744); color (direct reading spectrophotometer at 620 nm: Perkin Elmer Lamba 20 UV/VIS Spectrophotometer); anions (ionic chromatography : Metrosep anion dual 2 colum : 4.6 × 75 mm, with a particle diameter of 6 μm); Na^+ and K^+ (atomic emission spectroscopy : Genway PFP 7 spectrometer).

3. Results and discussions

3.1. Performances of the nanofiltration

The initial water flux (pure distilled water) of the membrane should be obtained after each regeneration and allowed to determine the membrane permeability (Lp) according to Darcy's law: Lp = Jw/TMP.

Where TMP is the transmembrane pressure (bar); μ: the dynamic viscosity (Pa.s); Jw: water permeability (l/h·m²); Lp: membrane permeability ((l/h · m² · bar). In this case, the measurement of NF membrane permeability gives a value of 4 l/h · m² · bar (Fig. 2).

A significant influence of TMP on permeate flux was observed when the NF of effluent was performed. A classical J versus TMP filtration curve show that the permeate flux increase with TMP from 19 l/h·m² at 8 bar to 33 l/h · m² at 14 bars. In comparison with water permeate flux, it is possible to deduce the contribution of osmotic pressure (average value along the membrane: $\Delta\pi$ = 3.7 bar in this case) which acts as an opposite force to the applied pressure (TMP). On the other hand, in experiments performed at variable concentration, the optimal VRF values are determined for the applied range of TMP (Fig. 3): VRF = 3.87 at TMP = 8 bar and VRF = 2

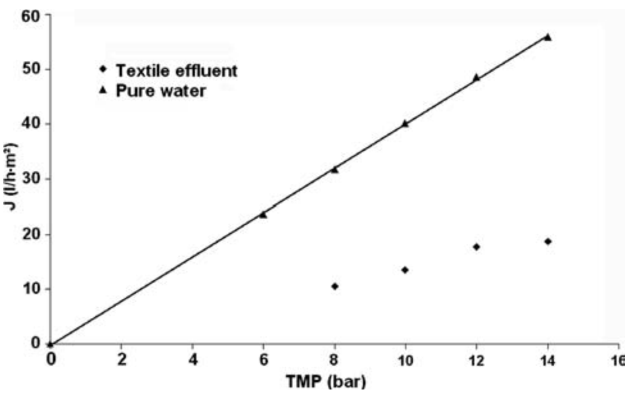

Fig. 2. Influence of TMP on the permeate flux.

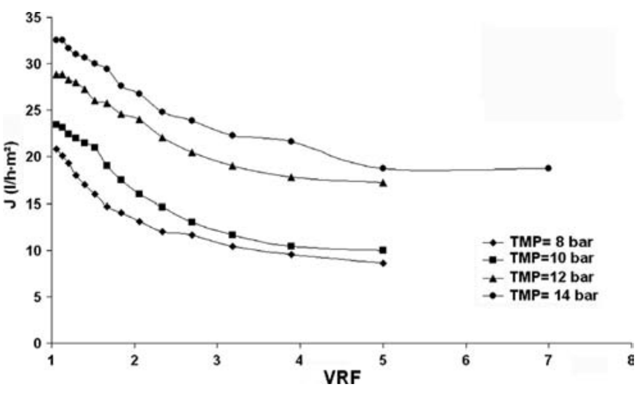

Fig. 3. Variation of permeate flux with VRF at different pressure (T = 25 °C).

at TMP = 10; 12 and 14 bar. The performances in term of permeate flux was higher at 14 bars but the higher retention rate of different anions and cations and also of COD was obtained at 12 bar. The abatement of color is constant and was of 100% for the different TMP values (Table 3).

3.2. *Effect of temperature*

Fig. 4 represents the variation of permeate flux with temperature. The flux was found to increase with temperature throughout the temperature interval investigated (25–35 °C). This behavior is due to the decrease in the viscosity which leads to the increase of the mass transfer coefficient. As the higher flux is obtained at 35 °C (38 l/h·m²) and no influence of temperature on salts retention was observed (Table 4), it was concluded that experiments could be performed at 35 °C.

Table 3
Effect of TMP on permeate quality at the optimum value of VRF (T = 25 °C)

Parameters	TMP = 8 bar	TMP = 10 bar	TMP = 12 bar	TMP = 14 bar
VRF	3.2	2	2	2
R Color (%)	100	100	100	100
R Salinity (%)	50	50	65	61
R COD (%)	63	68	83	62
J (l/h·m²)	10.5	9.5	18	18.7
R HCO^-(%)	31.4	53.4	71.1	71.8
R Cl^-(%)	11.2	23.7	32.3	19.8
RNO^-(%)	58.2	60	61.9	40
RSO_4^{2-} (%)	98.6	99.2	99	99
R Ca^{2-} (%)	90.4	99	96.8	95.5
R Mg^{2+} (%)	90.6	94.8	97	97.5
RNa^+ (%)	41.7	66	62.5	64.5
RK^+ (%)	38.3	70.4	63.7	65.8

3.3. *Performances of reverse osmosis*

Microfiltration (MF) was used in this case as a preatreatment of RO to avoid membrane fouling. The effluent preatreatment undertaken with a 0.1 mm multitubular ceramic membrane at 2 bars and 5.6 m/s allows a color retention of 50% and over 95% SS removal. The MF performances in term of permeate flux were 145l/h·m² obtained at a VRF of 7.

Fig. 5 shows the variation of flux with VRF for TMP of 10, 16 and 24 bar. The variation of pressure is due to the increase of the osmotic pressure with salt concentration when VRF increases. It was observed that higher flux was obtained when the TMP increases. The permeate flux varies between 35 l/h · m² for VRF = 1 and 20 l/h · m² for VRF = 7.

Figs. 6a and b show that the best anions and cations retention were obtained for 2–3 VRF range which corresponds to a 10–16 bar TMP range. The divalent anions and cations were highly rejected whatever is the VRF.

A retention rate improvement was observed using MF/RO treatment mostly for monovalent ions, color and COD removal at a similar TMP pressure (10–12 bar) and permeate flux (18–20 l/h·m²) comparing to the direct NF (Table 5).

Table 4
Performances at different temperatures

Parameters	T = 25 °C	T = 30 °C	T = 35 °C
R Salinity (%)	51.5	53	53
R Color (%)	100	100	100
J (l/h·m²)	30	33.5	37.5

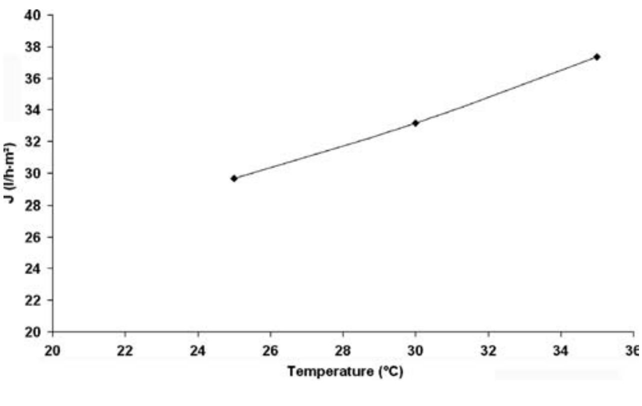

Fig. 4. Effect of Temperature on the permeate flux (PTM = 12 bar).

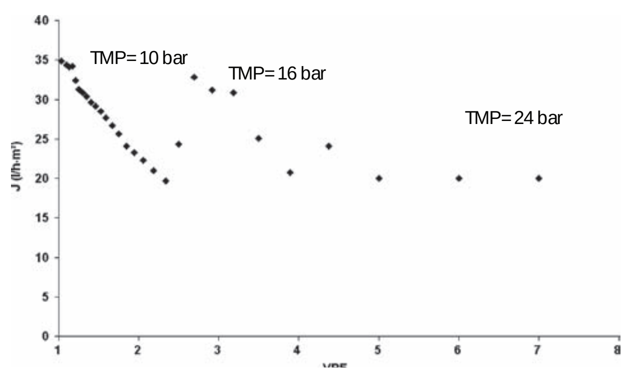

Fig. 5. Variation of permeate flux with VRF for MF/RO treatment (T = 25 °C).

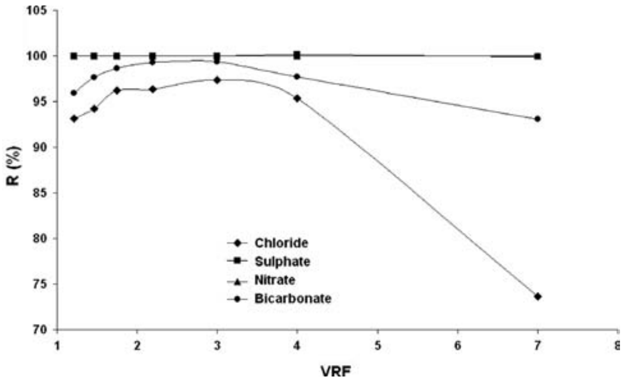

Fig. 6a. Evolution of the retention rate of different anions with VRF after MF/RO treatment.

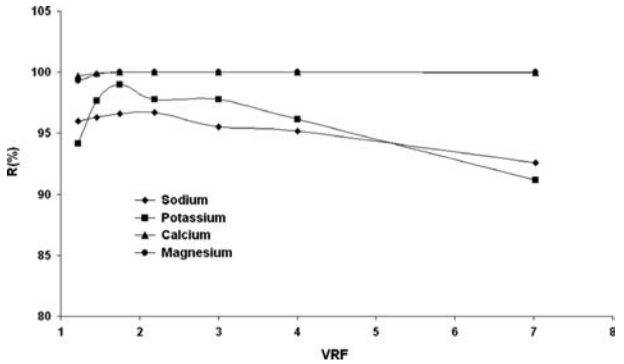

Fig. 6b. Evolution of the retention rate of different cations with VRF after MF/RO treatment.

Table 5
Permeate flux characteristics for the different treatments used

Parameters	MF alone	MF/RO	Direct NF
VRF	4	2–3	2
R color (%)	50	100	100
Turbidity (NTU)	0.6	0	0
R Salinity (%)	32. 5	86.4	59
R COD (%)	40	96	83
J ($l/h \cdot m^2$)	145	20	18
R HCO_3^-(%)	35	99.29	71.76
RCl^- (%)	19.75	96.36	42.64
RNO_3^-(%)	40	100	36.65
RSO_3^{2-} (%)	50.79	100	99
R Ca^{2+} (%)	19	100	95.52
R Mg^{2+} (%)	8.71	100	97.45
RNa^+ (%)	28.57	96.66	64.5
RK^+ (%)	30.81	97.75	65.77

4. Conclusion

In the present study, membrane processes were proposed for the textile effluent from Sitex Company. Basing on permeate flux performances, the best NF operating conditions were: 12 bar TMP and 35°C for operating temperature. With regard to the quality of the obtained permeate color and salinity removal were respectively, 100% and 59%.

To yield higher permeate fluxes and to improve the treated effluent quality, RO was used as a postreatment of the MF. This combination show better permeate quality in term of salinity removal than that obtained with direct NF (more than 85%). The performances in term of permeate flux is similar than that of direct NF obtained at a similar TMP of 10–12 bar and VRF: 2–3 range .

Hence, considering these results, membrane processes with a suitable selection of membranes cut-off and pre-treatment step could be used to preserve environment since the treated water could be recycled into the industrial process.

Acknowledgments

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