ELSEVIER

Desalination 222 (2008) 263–271

DESALINATION

www.elsevier.com/locate/desal

Treatment of textile plant effluent by ultrafiltration and/or nanofiltration for water reuse

Cheïma Fersi, Mahmoud Dhahbi*

Laboratoire Eau et Technologies Membranaires, CERTE, BP 273 Soliman 8020, Tunisia
Tel. +216(71)430044; Fax +216(71)430934; email: mahmoud.dhahbi@inrst.rnrt.tn

Received 20 December 2006; accepted 3 January 2007

Abstract

The textile wastewater treatment by membrane processes presents some limitations such as membrane fouling which causes a rapid flux decline. In fact, the membrane processes efficiency can be affected by membrane pore blocking or/and cake formation. In order to limit the effect of membrane fouling caused by plugging particles in textile effluent, a combination between two membrane processes was studied. The ultrafiltration (UF) was used as pretreatment for nanofiltration (NF) process. A comparison between direct NF and UF/ NF combination performances was carried out.

Experimental results showed that the second treatment improved the textile permeate quality by increasing the retention values of the majority of analyzed parameters. In fact, color retention was about 95%, conductivity and total dissolved salts retentions were about 80% and the bivalent ions retention values exceeded 95%. In the case of direct NF, permeate flux remained constant until a volume reduction factor (VRF) reaching 1.35. After coupling UF with NF process, a stable permeate flux was observed until a VRF equal to 2.77. This result showed that using UF process as pretreatment for NF process improved the efficiency of textile effluent treatment by increasing the membrane run-time.

Keywords: Ultrafiltration; Nanofiltration; Textile effluent; Volume reduction factor

1. Introduction

The textile industry covers a wide range of activities from preparation of the raw material to ennoblement treatment. These activities are all energy- and water-consuming as well as highly chemically polluting [1].

Untreated effluents from textile industries are usually highly colored and contain a considerable amount of contaminants and pollutants. Stringent environmental regulation for the control of textile effluents is enforced in several countries [2,3].

---

*Corresponding author.

Presented at the conference on Desalination and the Environment. Sponsored by the European Desalination Society and Center for Research and Technology Hellas (CERTH), Sani Resort, Halkidiki, Greece, April 22–25, 2007.

doi:10.1016/j.desal.0000.00.000

The main important pollutants in textile effluents are organics, color, toxicants and inhibitory compounds, surfactants, pH, salts and colored dyes which are considered as the most troublesome constituents of the wastewater. In fact, dyeing is a combined process of bleaching and coloring, which generates voluminous quantities of wastewaters and causes environmental degradation [4,5].

Previous studies showed that various combination of biological and physico-chemical treatment processes decolorize the wastewater but generate huge quantity of sludge [6,7]. Several emerging technologies such as electrochemical destruction [8,9], advanced oxidation [10,11], coagulation, flotation [12,13] and sorption [14] have potential for color removal. However, these approaches often involve complicated procedures. Recently reports are available for treatment of real textile wastewater using membrane processes [15].

Membranes technologies provide an important solution in environmental fields such as pollution reduction and water reuse, recycling valuable components from the waste streams [16–19]. Microfiltration (MF) is suitable for removing colloidal dyes from the exhausted dye bath and the subsequent rinses. Ultrafiltration (UF) is effective as single step treatment of secondary textile wastewater. Nanofiltration (NF) allows the separation of low molecular weight organic compounds and salts. The permeate produced is usually colorless and low in total salinity [4].

Due to their high solid concentrations, textile effluents from a conventional treatment can cause membrane fouling especially if they are used directly as influent to NF or reverse osmosis (RO) membranes.

Thus, it is necessary to carry out a very exhaustive pretreatment in order to avoid fouling and membrane deterioration [20,21].

There are several techniques appropriate as pretreatments prior to NF or RO processes, including membrane processes as MF and UF [22]. In fact, UF is effective for the removal of particles and macromolecules but it does not decolorize the waste stream [20].

In this way, the main objective of this study is to optimize the UF process as a pretreatment of the NF for textile water reuse. A comparison between direct NF and UF/NF combination performances is carried out.

2. Materials and methods

2.1. Analytical methods

The conductivities were measured by a PHYWE type conduct meter. The turbidity of the samples was measured by a Turb 555 IR type turbid meter. The color intensity of feed and permeate samples were analyzed by Perkin Elmer Lambda 20 spectrophotometer. The color was measured using the integral of the absorbance curve in the whole visible range (400–800 nm). Anions were determined by ion chromatography using a Metrohm 761 Compact IC with conductivity detection. The anion chromatography measurements with chemical suppression were made with a Metrosep anion dual 2 column (4.6 × 75 mm) with a particle diameter of 6 µm. Ca^{2+} and Mg^{2+} amounts were determined by atomic absorption spectroscopy using an analytical AAS Vario 6 spectrometer. Na^+ and K^+ were analyzed by atomic emission spectroscopy using Genway PFP 7 spectrometer.

Rejection (R) and the Volume Reduction Factor (VRF) were calculated by the following equations:

$$R = 100 \times \frac{1 - C_p}{C_f} \tag{1}$$

$$\mathrm{VRF} = \frac{V_f}{V_r} \tag{2}$$

where C_p and C_f are respectively the permeate and the feed concentrations, V_f and V_r are respectively the feed and retentate volumes.

2.2. Biologically treated textile effluent

The characteristics of the biologically treated textile effluent (BTTE) used are presented in Table 1. The study was conducted with BTTE drawn from an activated sludge plant, supplied from a Tunisian textile factory.

2.3. Membrane filtration units

Two membrane filtration units were coupled. The first one was an UF/MF 50 CM2 pilot used for UF pretreatment and the second one was a P-28 CM-CELFA pilot used for NF treatment.

Fig. 1 represents the flow diagram of the NF unit and Fig. 2 represents the flow diagram of the coupled UF and NF units.

2.4. UF and NF used membranes characteristics

2.4.1. Compaction of membranes

Two membranes were used during this work. UF membrane was tubular and composed of several layers of porous ceramic with a well-defined texture. A flat sheet polyamide-based thin film composite membrane was used in NF. Table 2 indicates the main characteristics of these membranes.

Table 1
Textile wastewater characteristics

Parameter		
pH		8.04
Conductivity	µs cm^{-1}	8620
Turbidity	NTU	0.948
COD	mg L^{-1}	329.4
TDS	mg L^{-1}	4240
COT	mg L^{-1}	46.1
Color[a]		975.2
Cl^-	mg L^{-1}	609.6
SO_4^{2-}	mg L^{-1}	1326.0
CO_3^{2-}	mg L^{-1}	1800.0
HCO_3^-	mg L^{-1}	1098.0
Ca^{2+}	mg L^{-1}	89.0
K^+	mg L^{-1}	158.6
Mg^{2+}	mg L^{-1}	42.2
Na^+	mg L^{-1}	3295.1

[a] Integral of the absorbance curve in the whole visible range (400–800 nm).

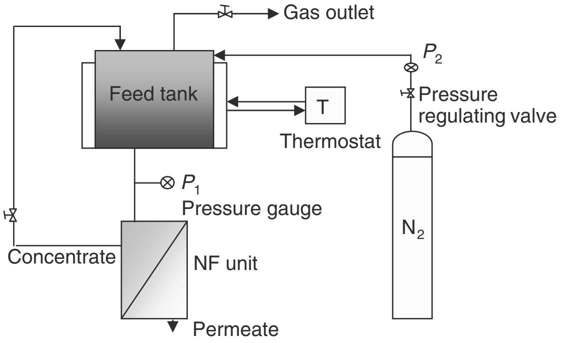

Fig. 1. Schematic diagram of cross-flow NF experimental set-up.

Before using a fresh membrane, it was compacted at high pressure using pure distilled water. In the case of UF membrane, the compaction pressure was about 5 bar and for NF membrane, the compaction was checked at 15 bar.

2.4.2. Determination of membrane permeability

Membrane permeability was determined using pure distilled water. Flux values of distilled water at different operating pressures were measured and were plotted against pressure difference. The average value of membrane permeability as measured was 381.7 L h^{-1} m^{-2} bar^{-1} for UF and 7.745 L h^{-1} m^{-2} bar^{-1} for NF, which remained almost constant throughout the conduction of all experiments.

2.4.3. Conduction of experiments

The operating parameters were the feed solution (BTTE or UF permeate) and transmembrane pressure (TMP). During each experiment, cumulative permeate volumes were collected and analyzed.

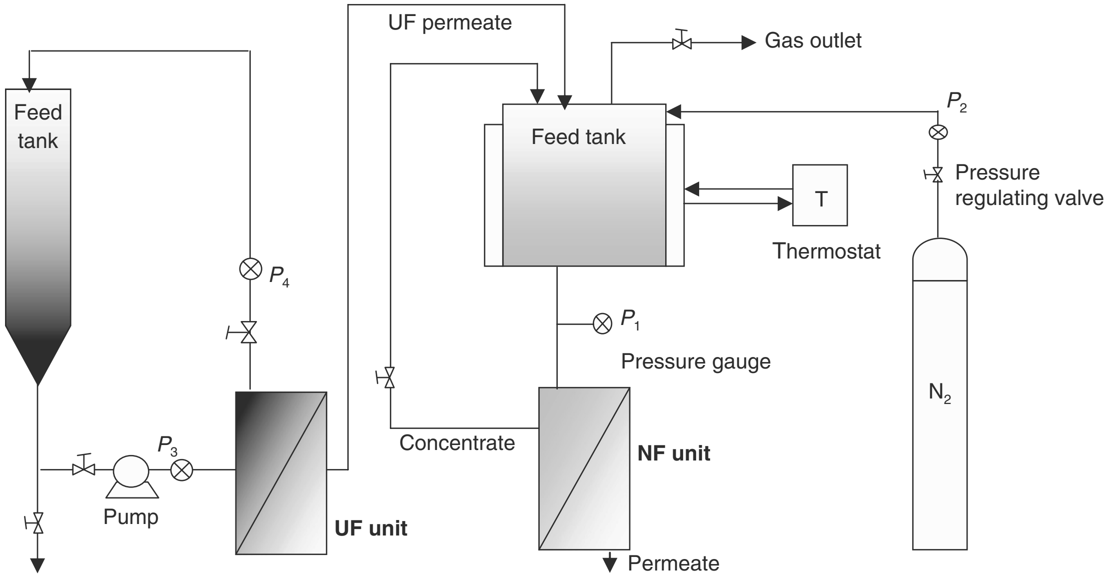

Fig. 2. Schematic diagram of cross-flow UF/NF combination experimental set-up.

After thoroughly cleaning the system several times by pure water, the membrane permeability was re-evaluated. It was observed that the membrane permeability remained almost constant between successive runs.

3. Results and discussions

3.1. Direct nanofiltration

The TMP was varied from 3 bar to 13 bar. Five permeate samples were collected and analyzed at every TMP.

A complete analyze was made using different analytical methods.

The variation of permeate flux with operating TMP for pure water and the textile effluent are presented in Fig. 3. It can be observed that permeate flux increases proportionally with TMP in the two cases. However, we observe a curve shifting towards high pressure in the case of the textile effluent. This result leads to an increase in osmotic pressure near the membrane- effluent interface and thereby a decrease in the effective driving force.

Figs. 4, 5 and 6 represent the retention evolution of the analyzed parameters with TMP after direct NF treatment. We observe that the retention rate, for all parameters, increases with TMP and we obtain considerable values at high pressure. It is also important to remark that the retention rate remained constant after applying a TMP higher than 9 bar for the majority of parameters.

Table 2
Membranes characteristics

Membrane	Geometry	Composition	Pore sizes	pH range
T170–50n TZ (UF 50)	Tubular	Zirconium oxides	50 nm	0.5–13.5
NF 270	Flat sheet	Polyamide	≈2 nm	3–10

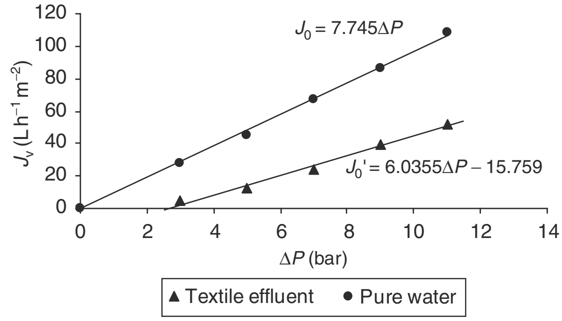

Fig. 3. Evolution of permeate flux with transmembrane pressure for pure water and textile effluent in direct NF treatment.

However, we observe a textile effluent decolorization exceeding 95% even at low pressure. This result confirms the good NF membrane capacity in retaining dyes molecules.

We conclude that the NF process performances depend on TMP and that we obtain better performances at high pressure. In fact, for a TMP higher than 9 bar, the direct NF treatment allows us to eliminate more than 70% of total dissolved salts (TDS) from the BTTE. Very high retention rates were obtained for divalent ions and especially for magnesium (>95%) and sulfate (>98%) at high pressure.

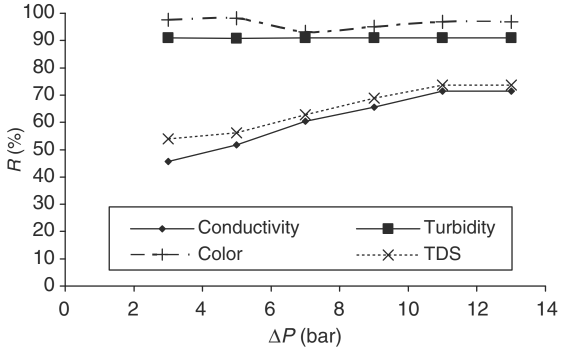

Fig. 4. Evolution of the retention rate of conductivity, turbidity, TDS and color with transmembrane pressure after direct NF textile effluent treatment.

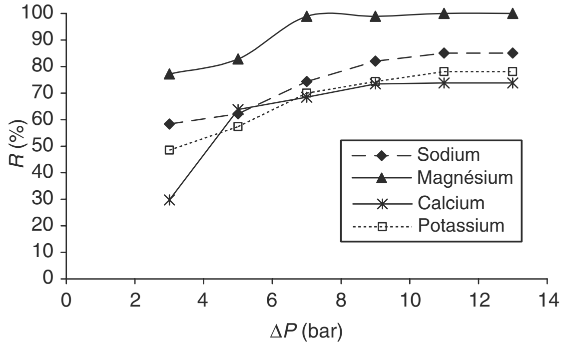

Fig. 5. Evolution of the retention rate of different cations with transmembrane pressure after direct NF textile effluent treatment.

The retention of monovalent ions was much lower than the retention of divalent ions due to their lower molecular weights. Due to its small size, chloride was the anion that can easily cross the membrane, while sulfates were highly rejected.

The direct NF performances were also studied at constant pressure. The same BTTE was treated by direct NF at optimized TMP which was fixed to 11 bar during this experiment. The permeate flux variation with the VRF is given in Fig. 7.

The initial permeate flux at 11 bar was about 50 L h^{-1} m^{-2}. For 1–1.3 VRF range and during direct NF, a slight variation of the permeate flux was observed in Fig. 7. A rapid permeate flux decline was seen for VRF value higher than 1.3.

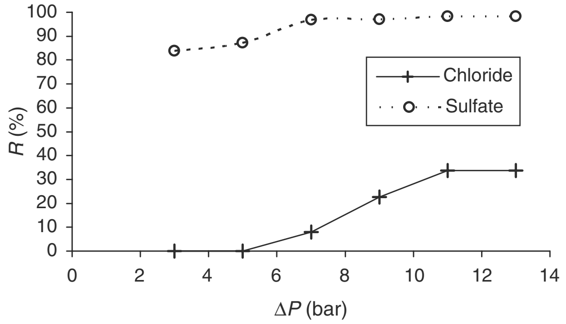

Fig. 6. Evolution of the retention rate of sulfates and chlorides with transmembrane pressure after direct NF textile effluent treatment.

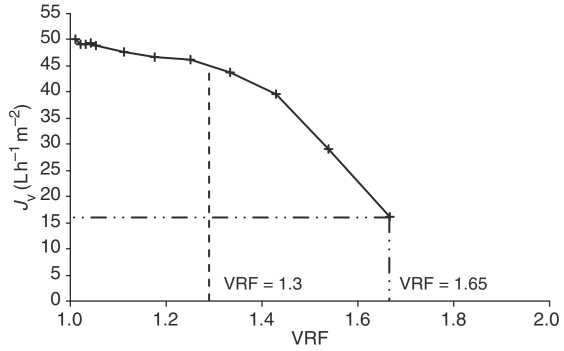

Fig. 7. Evolution of permeate flux with the volume reduction factor after direct NF textile effluent treatment at 11 bar.

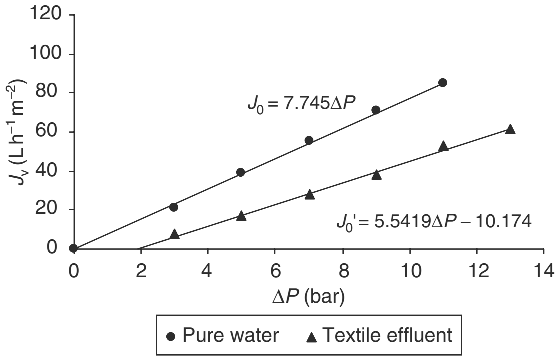

Fig. 8. Evolution of permeate flux with transmembrane pressure for pure water and textile effluent (UF permeate) in UF/NF combination treatment.

The same figure shows that permeate flux reached 15 L h^{-1}m^{-2} at 1.65 for VRF. This decline represents 30% of the initial permeate flux value.

It can be concluded that an increase of VRF has a significant influence on NF membrane fouling behavior which decreases rapidly the rate of flux decline even if we apply high TMP.

So, it was interesting to study the effects of TMP and VRF on the fouling behavior of the same NF membrane in the treatment of ultrafiltrated textile wastewater.

3.2. UF/NF combination

The TMP was varied from 3 to 13 bar and five permeate samples were collected and analyzed at every TMP.

Fig. 8 represents the permeate flux versus TMP for pure water and the UF treated textile effluent. It can be observed that permeate flux increases proportionally with TMP in the two cases.

Comparing to the direct NF, the curve shifting was less important in the case of UF/NF combination treatment which explains the decrease of present osmotic pressure. This result was expected because of the important UF membrane capacity in retaining a considerable number of plugging particles present in textile effluent.

Figs. 9, 10 and 11 represent the retention evolution of the parameters with TMP after UF/NF combination treatment.

Fig. 9 shows that the UF/NF combination improved the textile effluent decolorization. In fact, this combination lead to a retention rate exceeding 99% in color whereas this rate did not exceed 90% in the case of the direct NF treatment.

A retention rate improvement was also observed for bivalent ions: 99% for magnesium and sulfate ions and more than 90% for calcium ions were retained using UF/NF combination treatment even at low pressure.

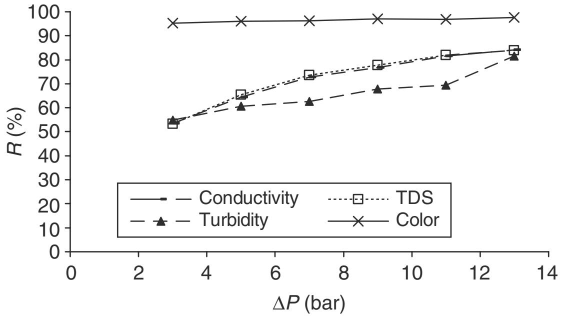

Fig. 9. Evolution of the retention rate of conductivity, turbidity, TDS and color with transmembrane pressure after UF/NF combination textile effluent treatment.

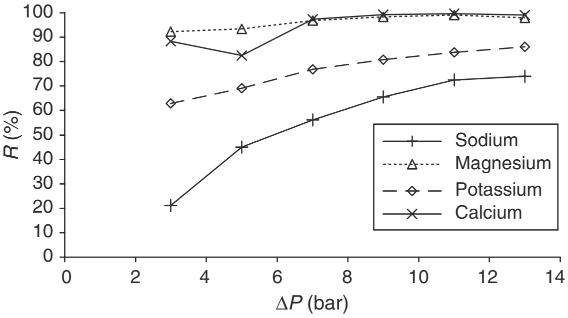

Fig. 10. Evolution of the retention rate of different cations with transmembrane pressure after UF/NF combination textile effluent treatment.

A considerable improvement was also observed for chloride ions retention especially at high pressure where their retention rate was about 60%.

Taking into account previous observations, we can conclude that using UF as pretreatment for NF process improved the quality of treated textile effluent.

The study of the UF/NF combination performances at optimized TMP (11 bar) is shown in Fig. 12 which represents the evolution of permeate flux with the VRF. It can be observed that the initial permeate flux was slightly lower for UF/NF combination than for direct NF. However, the coupled membrane processes make the permeate flux stable until a VRF value equal to 2.77. In the previous study, it was observed that direct NF permeate flux was stable for only 1–1.3 VRF range.

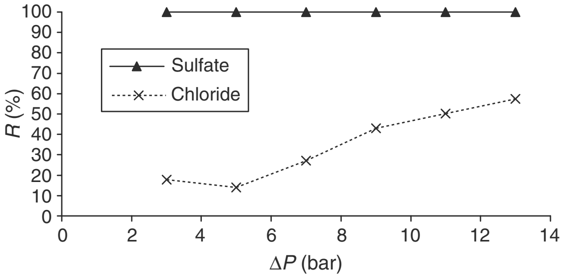

Fig. 11. Evolution of the retention rate of sulfates and chlorides with transmembrane pressure after UF/NF combination textile effluent treatment.

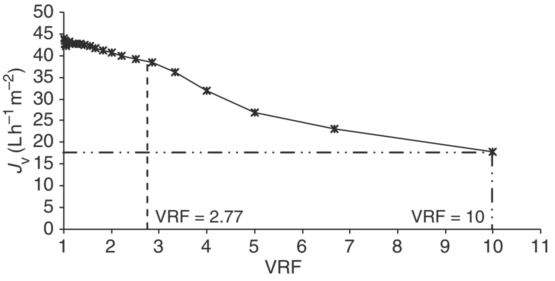

Fig. 12. Evolution of permeate flux with the volume reduction factor after UF/NF combination textile effluent treatment at 11 bar.

The same figure shows that the permeate flux decreases progressively and it can be seen that an increase in VRF value to 10 decreases flux to 40% of the initial permeate flux. Conversely, a decrease in flux to less than 30% resulted in slight VRF increase in the case of direct NF.

These results show that NF membrane fouling occurs progressively during UF/NF combination treatment and that UF process reduces the textile matrix complexity. So, UF process can be considered as efficient for NF pretreatment.

4. Conclusions

The most important limitations appeared in textile wastewater treatment by membrane processes is membrane fouling which causes a rapid flux decline. Membrane selection and operating conditions are important issues to optimize technically and economically the membrane processes.

Although the textile plant effluent was treated by a biological treatment process, the quality was not sufficient to reuse it on site.

NF process was successfully used to improve permeate quality, but this process required a pretreatment step.

The results of this study show that UF process seems to be an efficient method in the pretreatment of the textile wastewater. The comparison between direct NF and UF/NF combination shows that permeate quality and membrane process performances, in the second case, were better.

For direct NF, the average percent removals of color, conductivity, TDS and turbidity were in the range of 90–95%, 45–70%, 50–72% and 90–92%, respectively. All these percent removals were improved using UF/NF combination for textile wastewater treatment. A complete decolorization was observed even at low TMP.

The permeate flux improvement after UF pretreatment was six times more important than direct NF one. In fact, in the case of direct NF, permeate flux remained constant until a VRF reaching 1.35 and a rapid permeate flux decline was observed. Reaching a VRF equal to 1.65, the permeate flux was decreased to 30% of the initial value.

After coupling UF with NF process, a stable permeate flux was observed until a VRF equal to 2.77. The permeate flux decline takes place progressively and it does not surpass 40% of its initial value at VRF equal to 10.

This result shows that using UF process as pretreatment for NF process improves the efficiency of textile effluent treatment by increasing the membrane run-time.

Taking into account previous results, we can conclude that UF is an appropriate technique as a pretreatment of NF process to textile wastewater reuse.

References

[1] C. Hessel, C. Allegre, M. Maisseu, F. Charbit and P. Moulin, Guidelines and legislation for dye house effluents, J. Environ. Manage., 83 (2007) 171–180.

[2] ETAD, German ban of use of certain azo compounds in some consumers goods, ETAD Information Notice No. 6 (revised), 1997.

[3] G. Frank, H. Frank and O. Wilhelm, Ozonation an important technique to comply with new German laws for textile wastewater treatment, Water Sci. Technol., 30 (1994) 255–263.

[4] S. Chakraborty, M.K. Purkait, S. Dasgûpta, S. De and J.K. Basu, Nanofiltration of textile plant effluent for color removal and reduction in COD, Sep. Purif. Technol., 31 (2003) 141–151.

[5] K. Ranganathan, K. Karunagaran and D.C. Sharma, Recycling of wastewaters of textile dyeing industries using advanced treatment technology and cost analysis – case studies, Resour. Conserv. Recycling, in press (doi: 10.1016/j.resconrec.2006.06.004).

[6] R. Ganesh, G.D. Boardman and D. Michelsen, Fate of azo dyes in sludges, Water Res., 28 (1994) 1367–1376.

[7] B.V. Bruggen, E. Curcio and E. Driolli, Process intensification in the textile industry: the role of membrane technology, J. Environ. Manage., 73 (2004) 267–274.

[8] J. Jia, J. Yang, J. Liao, W. Wang and Z. Wang, Treatment of dying wastewater with ACF electrode, Water Res., 22 (1999) 881–884.

[9] A. Bes-Pià, J.A. Mendoza-Roca, M.I. Alcaina-Miranda, A. Iborra-Clar and M.I. Iborra-Clar, Reuse of wastewater of textile industry after its treatment with a combination of physico-chemical treatment and membrane technology, Desalination, 149 (2002) 169–174.

[10] F.A. Balcioglu and I. Arslan, Partial oxidation of reactive dye bath by the O_3 and O_3/H_2O_2 processes, Water Sci. Technol., 43 (2001) 221–228.

[11] V. Flous and C. Cabassud, A hybrid membrane process for Cu (II) removal from industrial wastewater – comparison with a conventional process system, Desalination, 126 (1999) 101–108.

[12] C. Suksaroj, M. Heran, C. Allegre and F. Persin, Treatment of textile plant effluent by nanofiltration and/or reverse osmosis for water reuse, Desalination, 178 (2005) 333–341.

[13] P. Banerjee, S. Dasgupta and S. De, Removal of dye from aqueous solution using a combination of advanced oxidation process and nanofiltration, J. Hazard. Mater., 140 (2007) 95–103.

[14] G.M. Walker and L.R. Weatherly, COD removal from textile industry effluents pilot plant studies, Environ. Pollut., 108 (2000) 201–211.

[15] A. Sungpet, R. Jironatananon and P. Luangsowan, Treatment of effluents from textile-rinsing

operations by thermally stable nanofiltration membranes, Desalination, 160 (2004) 75–81.

[16] M. Marcucci, et al., Treatment and reuse of textile effluents based on new ultrafiltration and other membrane technologies, Desalination, 138 (2001) 75–82.

[17] C. Fersi, L. Gzara and M. Dhahbi, Treatment of textile effluents by membrane technologies, Desalination, 185 (2005) 1825–1835.

[18] I. Kim and K. Lee, Dyeing process wastewater treatment using fouling resistant nanofiltration and reverse osmosis membranes, Desalination, 192 (2006) 246–251.

[19] C. Tang and V. Chen, Nanofiltration of textile wastewater for water reuse, Desalination, 143 (2002) 11–20.

[20] S. Sostar-Turk, M. Simonic and I. Petrinic, Wastewater treatment after reactive printing, Dyes Pigments, 64 (2005) 147–152.

[21] S. Petrov, et al., Ultrafiltration purification of waters contaminated with bifunctional reactive dyes, Desalination, 154 (2003) 247–252.

[22] S. Barredo-Damas, M.I. Alcaina-Miranda, M.I. Iborra-Clar, A. Bes-Pià, J.A. Mendoza and A. Iborra-Clar, Study of the UF process as pretreatment of NF membranas for textile wastewater reuse, Desalination, 200 (2006) 745–747.