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Application of Nanofiltration/Reverse Osmosis Membranes to Textile Effluents Aiming its Reclamation and Reuse: Influence of Operating Conditions

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Textile industry generates large amounts of wastewater with high chemical complexity. Owing to the demanding environmental legislation, textile sector is forced to introduce innovative water treatment methods, such as membrane technologies. This work studies the influence of operating conditions such as feed concentration and transmembrane pressure on a final stage of nanofiltration/reverse osmosis treating the raw effluent from a textile mill. The results show a linear relation between pressures and permeate flux for the lowest pressures. At the highest pressures tested, critical or limiting flux may be reached and efficiency decreases. The increase in the feed concentration involves a decrease in the permeate flux for both membranes. Regarding membranes rejection, the best overall results are achieved at 15 bar for the ESNA1-LF2 with COD and TOC removals of 94 % and 84 %, respectively, whereas conductivity is reduced in a 77 %. Almost complete pollutants removal (>94 %) is achieved by means of the LFC1 although the best overall results are obtained at 20 bar. Complete color and turbidity removal is achieved by both membranes.

1. Introduction

A growing shortage of freshwater and a constant increase in the demand of this valuable resource has led to new approaches in water and wastewater treatment. For some industrial sectors, water reclamation is becoming a necessary alternative (Lee et al. 2009). The textile industry is considered as one of the largest water consumers (Wijetunga et al. 2010). For the different processes, an estimated volume of 200 to 400 L/kg of fabric is required, with consumption peaks above 500 L (Capar et al. 2008; Amar et al. 2009). Consequently, textile industry generates large amounts of wastewater with a great chemical complexity. Textile wastewater typically shows caustic nature and consists of unfixed dyes, detergents, grease and oils, surfactants, heavy metals, inorganic salts and fibers (Allègre et al. 2006; Wijetunga et al. 2010). The disposal of these effluents without the appropriate treatment causes huge environmental damage (Ahmad et al. 2006).

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Innovative technologies as membrane processes have been proven as a feasible alternative to conventional treatments for water and reagents reclamation in textile industries (Allègre et al. 2006). Although there are extended works on membrane application to textile industrial effluents, the influence of the feed concentration have not been studied in the same extent. Thus, the main objective of this work is to analyze the influence of operating conditions such as feed concentration and transmembrane pressure on the behaviour of a final stage of nanofiltration/reverse osmosis to reuse the raw effluent generated in a textile mill.

2. Materials and Methods

2.1 Effluents Source

The effluent used for this work was provided from a textile mill and was previously treated through an ultrafiltration process by means of a ceramic ultrafiltration membrane with a molecular weight cut-off (MWCO) of 150 kDa.

The characterization of the wastewater was made according to the most frequently measured parameters for water quality control. In this way, total organic carbon (TOC), chemical oxygen demand (COD), conductivity, pH and color were initially measured and subsequently, monitored.

2.2 Analytical Methods

The measurements of both TOC and COD values were determined by means of a Spectroquant NOVA 60 photometer (Merck). The samples conductivity was determined using a CM 35 conductivity meter (Crison) whereas pH values were determined by means of a GLP 22 pH-meter (Crison). Both conductivity and pH sensors were provided with a temperature probe that allowed automatic correction of the measurements. Turbidity was determined with a Dinko D-112 turbidimeter according to the ISO 7027:1999. The SAC values were determined by means of absorbance measurements by the spectrophotometric method at three wavelengths (λ=436, 525 and 620 nm). The SAC values were obtained using a HP-8453 spectrophotometer according to the ISO 7887:1994.

2.3 Membranes

Two different commercial spiral wound membranes were used for the execution of the experiments. Nanofiltration tests were carried out by means of a membrane ESNA1-LF2 (Hydranautics-Nitto Denko) and RO essays were performed using a LFC1 membrane (Hydranautics-Nitto Denko). Both membranes have an effective membrane area of 2.6 m^2 and are made of composite polyamide. Experimental values of pure water permeabilities are 7.90 and 2.77 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$, respectively. The minimum salt rejection (reported by the manufacturer) was 70% and 98% for the ESNA1-LF2 (nominal MWCO: 200 Da) and LFC1, respectively.

2.4 Experimental Procedure

Membrane experiments were performed in a pilot plant equipped with a pressure vessel for one spiral wound membrane, a feed and a cleaning tank (60 and 40 L, respectively). The feed tank includes a stirrer to homogenize the feed solution. In order to evaluate the influence of the transmembrane pressure (TMP) for both NF and RO membranes, experiments were conducted at four different TMP (5, 10, 15 and 20 bar for NF tests and 10, 15, 20 and 25 for RO tests). The influence of Volume Reduction Factor (VRF) (1, 2, 3 and 4) was also studied. In order to increase the VRF, it was withdrawn from the system the volume needed according to equation 1:

$$VRF = \frac{V_F}{V_C} \tag{1}$$

where V_F is the initial feed volume and V_C is the concentrated volume. The permeate flux rate as well as the sampling was carried out when the steady-state was achieved for each VRF.

3. Results and discussion

3.1 Wastewater Characterization

The main characteristics of the influent used for this work are detailed in Table 1. Although the effluent corresponds to the permeate stream of a ultrafiltration process, it is worth pointing out the high values of some parameters (COD, TOC and conductivity) that would not allow these streams to be reused in processes such as dyeing or printing(Van der Bruggen et al. 2005; Capar et al. 2008).

Table :1 Influent to the NF/RO process characterization

Parameter	Range		
COD ($mg\cdot L^{-1}$)	330-952		
TOC ($mg\cdot L^{-1}$)	142-288		
Conductivity	2070-3760		
pH	7.3-7.7		
Turbidity	< 1		
SAC (m^{-1})	436 nm	525 nm	620 nm
	< 0.6	< 0.2	< 0.2

3.2 Effect of TMP and concentration on membrane flux

Figure 1 shows the relation between permeate flux with pressure at the different VRF tested for the ESNA1-LF2 membrane. As it can be seen, the permeate flux increases linearly with pressure for all the VRF until TMP reaches 15 bar. Beyond that pressure, process performance loses its linear behavior and decreases by increasing TMP. As feed solution is concentrated, the flux rate for a given pressure decreases.

Figure 2 shows the relation between permeate flux with pressure at the different VRF tested for the LFC1 membrane. In this case, the linear relation between flux and TMP is observed for the whole range of pressures tested except for the VRF 4. At this VRF, permeate flux loses its linearity for TMP higher than 20 bar. Similarly to the NF membrane, LFC1 also shows worst performance in terms of permeate flux as feed is concentrated.

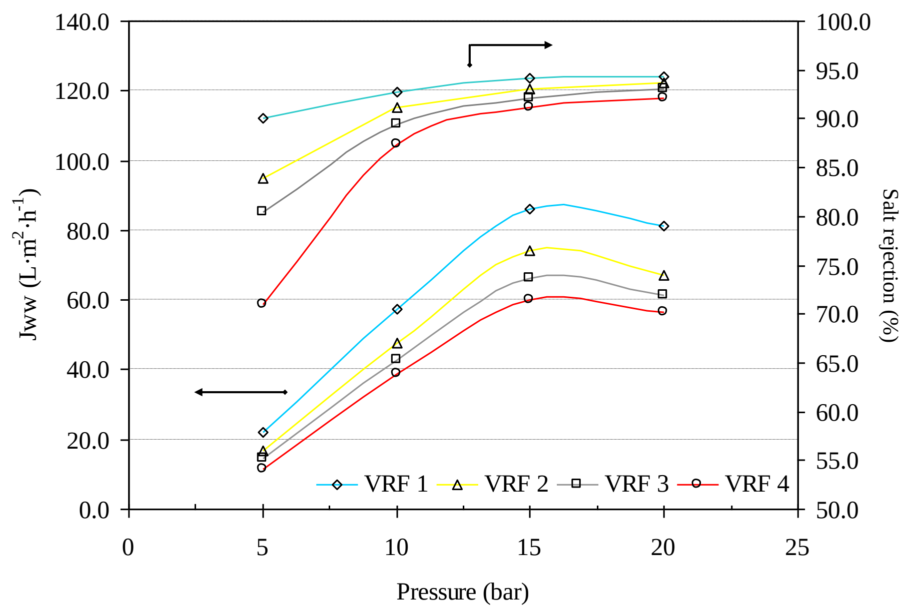

Figure 1: Relation between wastewater permeate flux rate and salt rejection with pressure (ESNA1-LF2).

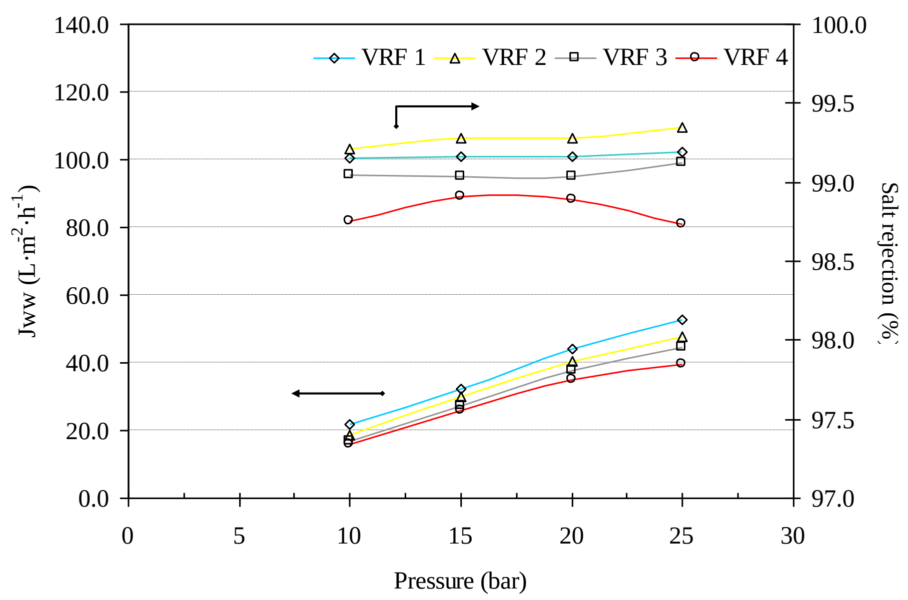

Figure 2: Relation between wastewater permeate flux rate and salt rejection with pressure (LFC1).

3.3 Effect of TMP and VRF on membrane rejection

Figure 1 also shows that the rejection coefficient increases as TMP increases for the ESNA1-LF2. Nevertheless, the increase is lower as TMP reaches higher values where the rejection coefficient tends to reach a plateau. From this figure, it can be observed that increasing feed concentration, for a given pressure, the rejection coefficient diminishes. For the LFC1 membrane, the rejections obtained for all the experiments are near or higher 99%. Rejection coefficient does not vary noticeably with TMP for a given feed concentration. However, slightly better results were obtained for VRF 2; whereas concentrating beyond that point the rejection coefficient for a given pressure diminishes.

Table 2 shows the accumulate percentage removal of pollutants concentration obtained at VRF 4. Both the turbidity and color are completely removed by means of the two membranes regardless the applied pressure. The rest of the parameters show the lowest rejection value for the lowest pressure tested. Conductivity reduction increases with pressure for the ESNA1-LF2. On the other hand, similar results are obtained for COD removal from 10 to 20 bar. TOC removal shows slightly better results at 10 bar instead. Regarding LFC1 performance, removals between 94-98% are obtained for all the pollutants from 15 to 25 bar.

Table 2: Accumulate percentage removal at VRF 4 (%)

Parameter	*ESNA1-LF2*				*LFC1*			
	5	10	15	20	10	15	20	25
COD ($mg \cdot L^{-1}$)	88	93	94	93	95	98	98	97
TOC ($mg \cdot L^{-1}$)	81	90	84	82	89	94	94	94
Conductivity	30	68	77	79	96	97	97	96
Turbidity	> 99	> 99	> 99	> 99	> 99	> 99	> 99	> 99
SAC (m^{-1})								
436 nm	> 99	> 99	> 99	> 99	> 99	> 99	> 99	> 99
525 nm	> 99	> 99	> 99	> 99	> 99	> 99	> 99	> 99
620 nm	> 99	> 99	> 99	> 99	> 99	> 99	> 99	> 99

According to the aforementioned results, both membrane processes are appropriate to the final reclamation of part of the effluent generated during textile processes. However, it would be possible to select the more appropriate treatment depending on the water quality needed. In this way, whether a slight salt quantity may not interfere with the process, NF would be more appropriate since higher flux may be obtained with considerable pollutant removals. Otherwise, RO would remove pollutants almost completely at the expense of a lower flux.

4. Conclusions

In this work, a final NF/RO stage for water reclamation of textile effluents was applied. The influence of different type of membranes, TMP and feed concentration were studied. The major conclusions are presented below:

An increase in TMP entails an increase of the permeate flux for both ESNA1-LF2 and LFC1. While ESNA1-LF2 seems to reach the critical pressure beyond 15 bar for the different VRF tested, LFC1 keeps a linear relation for all the VRF except for VRF 4. At this VRF, the limiting flux is reached at 20 bar. Regarding feed concentration, as the concentration is increased the permeate flux rate decreases for all the conditions tested.

Regarding membrane rejection, complete color and turbidity removals are achieved with both membranes. By means of LFC1 almost complete pollutants removal (between 94-98%) is reached for the TMP range from 15 to 25 bar. On the other hand, the best overall results for the ESNA1-LF2 are obtained at 15 bar. At that pressure, COD and TOC removals of 94 % and 84 %, respectively, are achieved whereas conductivity is reduced in a 77 %.

Both NF and RO processes may be suitable for water reclamation. Nevertheless, a selection criterion should be considered based on the water quality requirements. In this way, NF would be more appropriate whether a slight salt quantity may not interfere with the process since higher flux is obtained. Whether salt may hinder the process performance, RO would be required. Nevertheless, the almost complete pollutants removal achieved by RO would be at the expense of a lower flux.

Acknowledgments

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