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Nanofiltration and Reverse Osmosis for Reuse of Indigo Dye Rinsing Waters

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A membrane based treatment strategy was developed for the possible recycling of rinsing wastewater from indigo dyeing to the process itself. Performances of three different nanofiltration (NF) (NF 270 and NF 90, Dow Film Tech, USA and NF 99, Alfa Laval, Denmark) and two different reverse osmosis (RO) (HR 98 PP and CA 995 PE, Alfa Laval, Denmark) membranes were investigated with wastewater collected from the first post-rinsing tank of indigo dyeing process of a denim manufacturing plant. Dead-end microfiltration with a 5 μm filter was employed to remove coarse particles and minimize fouling of further NF and RO membranes. For NF and RO, a lab scale plate-and-frame membrane module was operated at a pressure of 5.07 bar and at a 0.62 m/s cross-flow velocity. The permeate quality from all the tested NF and RO membranes was acceptable for reuse in terms of COD and color. However, only the permeate from HR 98 PP RO and NF 90 membranes were with an acceptable conductivity. On the other hand, NF 270 membrane was superior to all the other NF and RO membranes in terms of the permeation rate. Flux declines obtained for all membranes were higher than 50% but fouling was not considerable and completely reversible. The good performance of NF 270 in terms of permeate quality (permeate conductivity, color, and COD values were 4.3 mS/cm, 8 Pt-Co, and 87 mg/L, respectively) together with a higher flux makes this membrane preferable over the other membranes to recycle denim textile rinsing wastewaters.

Keywords indigo dyeing; nanofiltration; reuse; reverse osmosis; textile wastewater

INTRODUCTION

In a textile processing plant, water is a vital raw material not only for the wet processes such as scouring, bleaching, dyeing, printing, and finishing but also for the boiler systems for heating and drying purposes. Among these processes, dyeing is of primary concern from the environmental pollution point of view due to generating voluminous quantities of wastewaters that include a moderate amount of chemical oxygen demand (COD), suspended solids, dissolved solids dye ingredients (1,2) causing color which requires extensive treatment both for reuse and discharge.

One of the major classes of dyes that are extensively used for dyeing fabrics is vat dyes. Amongst vat dyes, indigo is commonly used for the manufacture of denim. It is synthetic with a complex chemical structure, alien to the environment and hence considered as persistent (2,3). Indigo is a dark blue dye with molecular weight of 262.27 atomic units of mass ($C_{16}H_{10}N_2O_2$) (4). It is virtually insoluble in aqueous solution and thus for dyeing, it has to be reduced to its water-soluble "leuco" form by a reduction stage. In textile dyeing, this is carried out in alkaline aqueous solution at a pH of 11–14 using strong reducing agents among which sodium dithionite ($Na_2S_2O_4$) is of major importance (5). Indigo penetrates and adheres to fabric fibers. When the fabric is removed from the vat and exposed to the air, it is bright green. The air changes it to deep blue with in-situ re-oxidation of the dye to its original water-insoluble form which is trapped in the matrix of the fabric. These two steps (dipping/exposing) are repeated many times to obtain the desired shade (5,6).

Various physicochemical, advanced oxidation processes, biological processes and usually a combination of processes can be applied to treat indigo dyeing wastewaters. In general, chemical coagulation is the most widely used method (2). However, this method produces a large amount of sludge which poses handling and disposal problems. Conventional biological processes are not very effective in the complete removal of vat dyes (including indigo) therefore not satisfactory in providing the desired effluent quality especially when water reuse is of concern. In recent years, the investigators have tested advanced oxidation techniques (4), various non-conventional biological treatment methods [e.g.], sequential anaerobic/aerobic (5) and fungi assisted processes (6) for the complete treatment of indigo dyeing wastewaters. However, textile effluents treated with

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all these methods still contain a significant amount of dyestuffs and other dyeing auxiliaries and therefore can not be reused.

Membrane filtration technology provides interesting possibilities of separating dyestuffs and other dyeing auxiliaries (7) providing reusable water and thus reducing the freshwater consumption (8). Nanofiltration (NF) allows for the removal of organic compounds of low molecular weight, divalent ions or large monovalent ions, such as hydrolyzed dyes as well as dyeing auxiliaries (7). Jiraratananon et al. (9) investigated the application of NF membranes for the treatment of a textile effluent containing reactive dyes and salt, and indicated that NF is effective in retaining color and producing permeate with reuse possibility. In another study, Chakraborty et al. (10) used NF to treat the effluent from a cotton textile mill which employs reactive dyes. They reported complete removal of dyes with a total COD removal of 94%. In a similar study, Qin et al. (11) investigated the feasibility of water recovery from a dyeing wastewater using NF and reported similar results. COD removal was over 99% with a total color removal making permeate suitable for reuse.

Reverse osmosis (RO), which is with a history in industrial applications in the removal of salts from solutions (12), permits the removal of all mineral salts, hydrolyzed reactive dyes, and other chemical auxiliaries from the dye bath effluents and therefore appears as another alternative. However, rapid fouling that results in low flux and high osmotic pressure differences limits its applicability (7). Kim et al. (13) investigated the applicability of combined process of NF and RO to recycle permeate back to the process from the treatment of reactive dye manufacturing industry wastewater. A high quality of water reusable as a refrigerating water, a washing water, and a process water could be recovered by the combined process of NF and RO.

The objective of this study is to develop a membrane based treatment scheme targeting at removing the impurities from the indigo dyeing wastewater and producing reusable water. Throughout the study, wastewater samples obtained from the indigo dyeing process of a denim producing textile mill located in the Central Anatolia Region of Turkey were utilized. Indigo dyeing process in the mill is composed of pre-rinsing, dyeing, post-rinsing, and softening operations. At the pre-rinsing stage, fibers are washed several times to remove impurities and then subjected to dyeing which is followed by post-rinsing. In post-rinsing, dyes and chemicals that are not fixed onto the fibers are removed in a number of sequential rinsing tanks. Rinsing stages consume a high amount of water and therefore generate large volumes of wastewater. The major part of the pollution in these wastewaters originate from post-rinsing tanks and especially from the first post-rinsing tank as it removes residual dye and other unused chemicals, first from the cotton fibers coming from the dye bath. Therefore, in the present study, rinsing wastewater discharged from the first post-rinsing stage was used, and single and two-stage NF and single stage RO performances were evaluated in accordance with the reuse criteria given in Table 1. In the first part of the study, the performances of three different NF membranes were tested in terms of permeate flux, color, COD, and conductivity retentions. In the second part, two-stage NF (double-pass NF) and RO tests were run in order to determine the best membrane treatment scheme for reusable water production.

TABLE 1
Textile wastewater reuse criteria

Parameter	Goodman and Porter (14)
pH	6–7
COD (mg/L)	178–218
Conductivity (μS/cm)	1650–2200
Color (Pt-Co)	20–30

EXPERIMENTAL

Wastewater

A number of first post-rinsing stage wastewater samples were taken from the indigo dyeing process of the textile mill at volumes of 150–200 L to compensate for the diverse characteristics of individual samples. Wastewater samples were pre-filtered through a 0.8 mm metal filter, analyzed for their constituents, and then stored in 25 L plastic containers in a temperature controlled room at 4°C. Table 2 presents the characteristics of the wastewater samples used for experimental practice.

NF and RO Membranes

All membranes used in the NF and RO tests are commercially available membranes. The specifications of the membranes given by the manufacturer and also by some reports in the literature data are summarized in Table 3. NF 99 membrane is reported to have a sulfonated polyamide skin layer on top of a polyether support (15).

TABLE 2
Characterization of the first post-rinsing tank wastewater of the indigo dyeing process

Parameter	Average value
pH	11.2 ± 0.12
COD (mg/L)	1591 ± 62.2
Conductivity (mS/cm)	11.2 ± 0.07
Color (Pt-Co)	4887 ± 64.9
Alkalinity (mg/L $CaCO_3$)	4100 ± 141.4

TABLE 3
Specifications of the membranes used in NF and RO tests

Membrane	Manufacturer	Pore size
NF 270	Dow-Filmtec (USA)	200–300 Da, 0.84 nm (18,19)
NF 90		100 Da, 0.68 nm (16,18)
NF 99 (NFT50)	Alfa Laval (Denmark)	159 Da (15)
CA 995 PE		NaCl rejection ≥95%
HR 98 PP		NaCl rejection ≥85%

Boussu et al. (16) reported that the NF 270 membrane is a negatively charged hydrophilic and has a smooth surface. On the contrary, the NF 90 membrane is a hydrophobic and has a rougher surface than the NF 270 membrane. The membrane NF 270, made from piperazine and benzenetricarbonyl trichloride, and benzenetricarbonyl trichloride is a starting material for the membrane NF 90. However, instead of piperazine, 1.3 phenylene diamine is used to complete the interfacial polymerisation. CA 995 PE membrane made from cellulose triacetate/diacetate blend on polyester and HR 98 PP membrane was made from thin film composite on polypropylene (17).

NF and RO Tests

The NF and RO tests were carried out by a lab-scale plate-and-frame module, LabStak M20 (product of DSS Company) in cross-flow operation under total recycle mode of operation at 5.07 bar transmembrane pressure (TMP) and 0.62 m/s cross-flow velocity conditions. All NF and RO tests lasted about 10–15 h till the permeate flux reached steady-state. Meanwhile, the feed and the permeate streams were sampled regularly for color, COD, and conductivity measurements. Sample volumes of feed and permeate were 50 mL. In the experiments, the temperature was maintained at 20 ± 2°C by a cooling water circuit.

In order to eliminate large particles that could cause damage to the membranes, a 5 µm dead-end microfiltration (MF) was employed as a pretreatment before NF and RO tests. This MF step removed 88% and 10% of color and COD, respectively (20). Following pH adjustment to 7.2 ± 0.4, NF and RO experiments were carried out. The performances of three different NF membranes and two different RO membranes were investigated. After single stage experiments, sequential NF experiments were also conducted by employing NF 270 membrane. The schematic representation of the treatment strategy followed in NF and RO experiments is given in Fig. 1.

Cleaning and Preparation of Membranes

The experimental protocol followed for cleaning and preparation of membranes were the same for all of the NF and RO membranes. First, virgin membrane pairs were rinsed with ultra pure water to remove impurities from the surface of the membrane. As a subsequent step, in order to minimize membrane compaction during the wastewater filtration experiments, first 10 h compaction was applied under 7.0 bar TMP with ultra pure water. After compaction, chemical cleaning was applied at 2 bar TMP following the procedure given in Table 4.

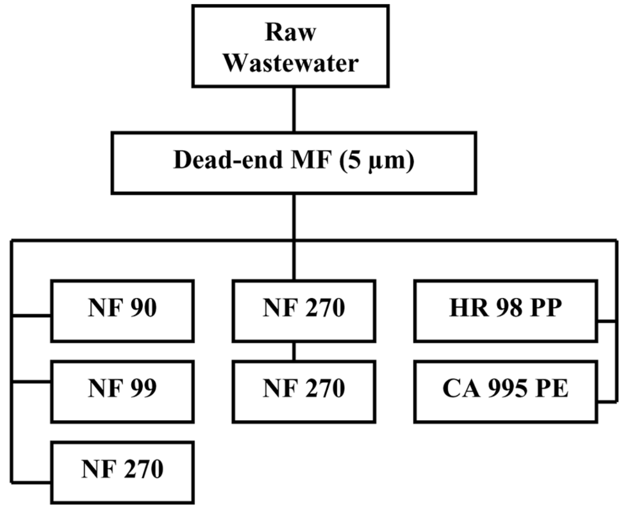

FIG. 1. Schematic representation of treatment strategy followed in NF/RO tests.

Pure water fluxes were measured after cleaning and after wastewater applications. Chemical cleaning was only applied when flux recovery was lower than 90%. To evaluate the total flux decline, irreversible fouling and flux recovery, the equations given in Uzal et al. (21) were utilized.

Analytical Methods

Color measurements were performed by a HACH DR-2000 Model spectrophotometer following USEPA approved HACH Method #8000. For color measurements, this device was calibrated at a wavelength of 455 nm with Pt-Co standard solution. Conductivity and pH measurements were conducted using a Hach Sension 378 pH-conductivity-dissolved oxygen meter. Alkalinity measurements were performed according to Standard

TABLE 4
Chemical cleaning procedure applied to membranes

Operation	Cleaning solution	Application time
Acid cleaning	HNO_3 (pH of 3 ± 0.2)	20–30 min
Rinsing	Distilled water	5 min
Base cleaning	NaOH (pH of 9 ± 0.2)	20–30 min
Rinsing	Distilled water	5 min

Methods (22). COD was measured according to a USEPA approved HACH Method 8000 using a Hach spectrophotometer (Model no DR-2000) and vials for low and high COD range (0–50 and 0–1500 mg/L COD).

RESULTS AND DISCUSSION

NF

In this series of experiments, the performances of three NF membranes were evaluated in terms of the permeation rates and the permeate quality for the rinsing wastewater after 5 μm MF. Permeate fluxes of the NF membranes were measured till steady state and the results given in Fig. 2 were obtained. The permeate fluxes of NF 99 and NF 90 membranes were close to each other and quite lower than that of the NF 270 membrane. As can be seen, the highest permeate flux was obtained for the NF 270 membrane. The permeate flux of NF 270 membrane was significantly high and about 4 to 6 times higher than those of the other two membranes. But, in all cases, permeate fluxes were stable throughout the experiments indicating the possibility of low sorption of organic material on the membrane material.

In order to better assess the flux reduction of NF membranes with the use of this type of wastewaters, permeate fluxes with pure water, with wastewater, and also flux declines and recoveries at steady state were evaluated (Table 5). As can be seen, the permeate fluxes, with pure water and wastewater from NF 270 membrane were quite higher than those of NF 99 and NF 90 membranes. On the other hand, NF 99 and NF 270 membranes presented similar lower flux declines and irreversible fouling than the NF 90 membrane. In literature, contact angles of NF 270 and NF 90 membranes were reported as 27° and 54°, respectively (16). This implies that NF 90 is more

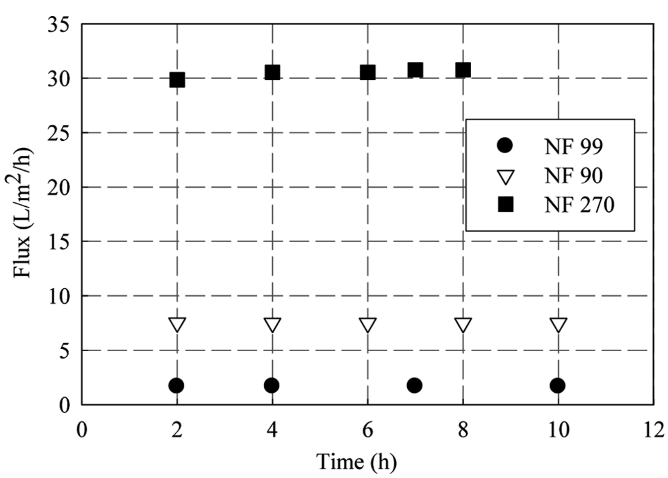

FIG. 2. Comparison of permeate fluxes of NF membranes (NF99, NF90 and NF 270) after 5 μm MF (TMP: 5.07 bar and CFV: 0.62 m/s T: 18 ± 2°C).

TABLE 5
Flux decline, recovery, and irreversible flux decline of NF membranes at steady state

Membrane	NF 99	NF 90	NF 270
Permeate flux with pure water (L/m^{2}h)	3	31	64
Permeate flux with wastewater (L/m^{2}h)	2	8	31
Permeate flux with pure water (fouled membrane) (L/m^{2}h)	3	28	63
Flux recovery (%)	99	90	98
Flux decline (%)	48	76	52
Irreversible flux decline (%)	1	10	2

hydrophobic than NF 270 membrane. Flux decline was severe with NF 90 membrane possibly due to the hydrophobic nature of this membrane. Another reason was speculated as that NF 90 is a relatively tight NF membrane with an average pore diameter of only 0.68 nm while NF 270 can be considered as a loose NF membrane with an average pore diameter of 0.84 nm (Table 3) (18). As presented in Table 3, NF membranes tested in this study also differ from each other in their characteristics. Molecular cut-off of the membranes tested is in the increasing order of: NF 90 < NF 99 < NF 270, which is in agreement with water fluxes given in Table 5.

As can be seen from Table 5, for all three membranes, irreversible flux decline was just a small portion of the total flux decline. After cleaning just with pure water, fouling has almost been removed completely and it was realized that real fouling was more or less absent. This could be an indication that the main causes of flux reduction are change in osmotic pressure and concentration polarization.

As it is known, fouling occurs in large time scales (days, hours); however, the more temporary phenomenon of concentration polarization is built up in minutes or seconds. While the increased concentration of the rejected particles in the boundary layer is not itself a type of fouling it promotes adsorption, pore blocking and cake/gel layer formation and hence often is a fouling precursor. Membrane lifetime is mostly limited by irreversible fouling. Irreversible fouling of NF 270 and NF 99 membranes were quite low, 2% and 1%, respectively and flux reduction thought to be due to concentration polarization and osmotic pressure as it was almost completely reversible (19).

Permeate quality and permeate flux achieved for these NF membranes are given in Table 6. As seen, color retentions were quite high and not significantly different from each other for the three NF membranes tested. The lowest color retention was measured for NF 99 membrane (91%)

TABLE 6
Comparison of flux and permeate quality performances of NF membranes at steady state

Membrane	Flux (L/m^{2}h)	Final permeate quality			Cumulative retention (%)		
		COD (mg/L)	Color (Pt-Co)	Conductivity (mS/cm)	COD	Color	Conductivity
NF 270	31	87	8	4.3	92	93	60
NF 90	8	67	8	1.0	94	93	91
NF 99	2	113	15	4.9	88	91	55

with a permeate color of 15 Pt-Co. The color retention by NF 270 and NF 90 membranes were the same (93%) resulting in a permeate value of 8 Pt-Co. So, the color in the wastewater was very well retained by all NF membranes tested and the permeate color values were acceptable for reuse when compared with the reuse criterion given in Table 1. The color retentions achieved were similar to those reported by Chakraborty et al. (10) who obtained 92–94% color retentions with NF membranes from the reactive dyeing effluents.

In addition to high color retention, NF 270 and NF 90 membranes also provided high COD retentions (Table 5). The COD retention of NF 270 and NF 90 membranes were at around 92% and 94% respectively, while that of NF 90 was 88%. Lopes et al. (24) also reported 87% COD retention by NF for the treatment of textile wastewaters. In another study, Chakraborty et al. (10) obtained COD retentions up to 94% using NF for the treatment of dyeing wastewaters. As color in wastewater, organics were also almost completely removed by NF and therefore the permeate COD values were meeting the reuse criteria given in Table 1.

NF membranes have the potential to remove dissolved solids causing conductivity. However, complete conductivity removal was not achieved with the NF membranes tested. As seen from Table 5, the permeates of the NF membranes contained a very low amount of organic carbon but a relatively high amount of dissolved solids due to the fact that the NF membranes transmit monovalent ions. The lowest permeate conductivity was obtained for NF 90 membrane as 1.0 mS/cm which is satisfactory in meeting the reuse criterion given in Table 1. However, permeate conductivities for NF 99 and NF 270 membranes (4.9 mS/cm and 4.3 mS/cm, respectively) were slightly higher than the reuse criterion. These two membranes provided only 55 to 60% conductivity retention which is well below that of NF 90. All these findings were consistent with the results obtained by Nghiem et al. (18) who reported similar conductivity retention performances for NF 90 and NF 270 membranes (95% and 50%, respectively).

All of the above results from the comparison of three NF membranes indicated that the NF 270 membrane is superior to the other two membranes with regard to the permeate flux; while NF 90 is superior with regard to conductivity retention. Nevertheless, all three NF membranes were found to be satisfactory in meeting the COD and color reuse criteria (Table 1). However, only the NF 90 membrane did satisfy the conductivity criterion.

Sequential NF

Considering the relatively poor permeate conductivity but high permeation rate from NF 270 membrane, its sequential application was worth investigating. Permeate from the first stage was collected and fed to the second stage NF 270 membrane. Table 7 presents the permeate quality of sequential and single stage NF experiments in a comparative way. With sequential NF application, the permeate color decreased to 1 Pt-Co from its earlier value of 8 Pt-Co. Similarly, there occurred about a 50% reduction in the permeate COD value. More importantly the permeate conductivity improved to a great extent with the sequential application of NF 270, reaching to almost the reuse criterion of 2.2 mS/cm.

TABLE 7
Comparison of performances of single and sequential stage NF 270 membrane at steady state

Application	Flux (L/m^{2}h)	Final permeate quality			Cumulative retention (%)		
		COD (mg/L)	Color (Pt-Co)	Conductivity (mS/cm)	COD	Color	Conductivity
Single	31	87	8	4.3	92	93	60
Sequential	54*	39	1	2.8	97	99	74

*Permeate flux of second stage NF 270 membrane.

Another achievement with the sequential application of NF 270 was a considerable improvement in the permeate flux (Table 7). As presented, the permeate flux has almost doubled with sequential application. It was quite steady after 2 h for both applications (Fig. 3), indicating the possibility of low sorption of organic material on the membrane material.

In Table 8, a flux decline analysis is presented for single and sequential application of NF 270 membrane. As seen from the table, permeate flux from the second stage NF 270 was almost twice that of the first stage. The irreversible flux decline for the second stage NF 270 is zero. The flux decline was quite higher in single NF when compared to sequential NF. For single NF 270, flux declines were around 52% and for sequential NF 270 this value decreased to 22%. Although the flux decline of a single NF application was higher than that of the sequential NF application, nearly no irreversible fouling was obtained for both of the NF applications and the fouling was completely reversible. All these findings indicated that using a second stage NF should be evaluated based on its economic feasibility during which the permeate flux data should also be considered.

In addition to color and COD retentions, the permeate conductivity value of 2.8 mS/cm obtained for sequential NF 270 was lower than 4.3 mS/cm obtained for single NF 270. With sequential NF application, although 35% improvement was achieved, the permeate conductivity was still not satisfactory in meeting the reuse criterion given in Table 1.

TABLE 8
Flux decline, recovery and irreversible fouling of single and sequential stage NF 270 membrane at steady state

	Single NF	Sequential NF
Permeate flux with pure water (L/m^2h)	64	70
Permeate flux with wastewater (L/m^2h)	31	54
Permeate flux with pure water (fouled membrane) (L/m^2h)	63	70
Flux recovery (%)	98	100
Flux decline (%)	52	22
Irreversible flux decline (%)	2	0

RO

In textile wastewater reuse or reclamation, RO processes generally preferred when salt concentrations are considerably high and NF permeate quality was not enough to be reused in the process as in this study. As presented in the preceding section, the permeates of the NF membranes were found to be almost free of organic substances. But the retention of monovalent ions causing conductivity could not be achieved. In order to remove monovalent ions and therefore to produce a permeate with acceptable quality, low pressure RO membranes were employed. RO experiments were performed using two different RO membranes; CA 995 PE and HR 98 PP. The performance of these two RO membranes were evaluated in terms of flux, color, COD, and conductivity retention at very low pressure of 5.07 bar TMP and 0.62 m/s cross-flow velocity conditions after 5 μm MF prefiltration. Color, COD and conductivity retentions and permeate fluxes of the RO membranes are given in Table 9. Color retentions of RO membranes were not significantly different from each other; and 94% for CA 995 PE and 97% for HR 98PP. The COD retention of HR 98 PP was 96% and higher than that of CA 995 PE which is 90%. Thus, in terms of COD and color retentions, the performance of HR 98 PP membrane was slightly better than that of CA 995 PE membrane.

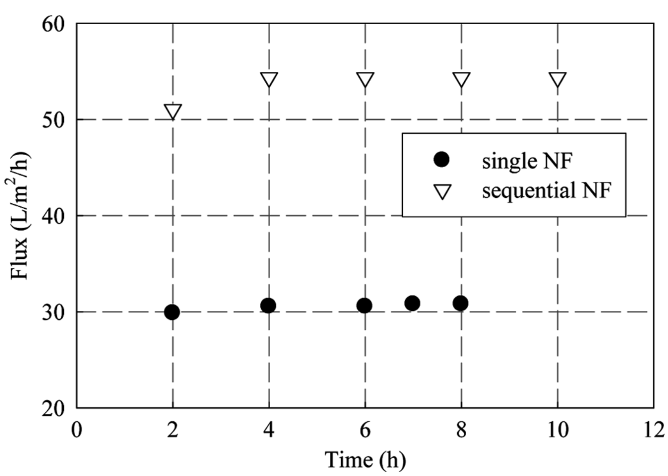

FIG. 3. Comparison of permeate fluxes of single and sequential application of NF 270 after 5 μm MF (TMP: 5.07 bar and CFV: 0.62 m/s T: 18 ± 2°C).

Permeate fluxes from HR 98PP and CA995PE membranes are given in Fig. 4. As can be seen, steady state permeate fluxes were reached after about 5 h of operation for both of the membranes tested. But, the steady state permeate flux of HR 98 PP membrane was higher than that of CA 995 PE membrane which is in agreement with the NaCl rejections reported (Table 3).

In Table 10, the permeate fluxes with pure water and wastewater and also fouling of RO membranes are presented. Although the permeate fluxes with both pure water and wastewater from HR 98 PP membrane were quite higher than from CA 995 PE membrane, the flux decline obtained for HR 98 PP was higher (74%). Nevertheless,

TABLE 9
Comparison of performances of RO membranes tested at steady state

		Final permeate quality			Cumulative retention (%)		
Membrane	Flux (L/m^2/h)	COD (mg/L)	Color (Pt-Co)	Conductivity (mS/cm)	COD	Color	Conductivity
CA 995 PE	3	115	7	3.2	90	94	71
HR 98 PP	5	46	3	0.9	96	97	92

flux recovery and irreversible fouling of these two membranes were quite similar. As in NF membranes, very low irreversible fouling values were measured and the fouling was completely reversible.

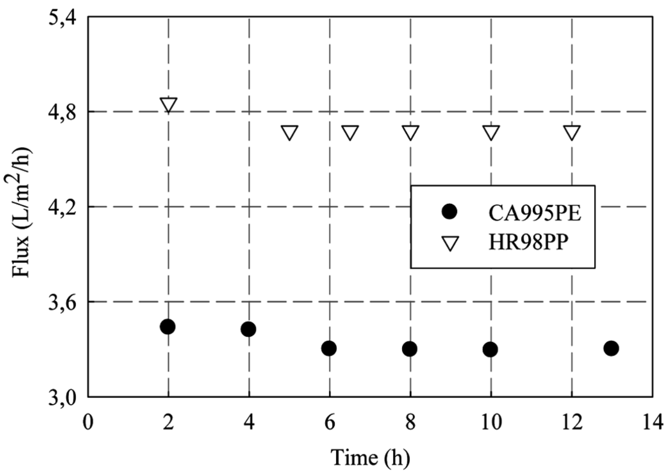

FIG. 4. Comparison of permeate fluxes of RO membranes (HR98PP, CA995PE) after 5 μm MF (TMP: 5.07 bar and CFV: 0.62 m/s T: 18 ± 2°C).

TABLE 10
Flux decline, recovery and irreversible fouling of RO membranes tested at steady state

Membrane	CA 995 PE	HR 98 PP
Permeate flux with pure water (L/m^{2}h)	8	18
Permeate flux with wastewater (L/m^{2}h)	3	5
Permeate flux with pure water (fouled membrane) (L/m^{2}h)	7	17
Flux Recovery (%)	96	97
Flux Decline (%)	57	74
Irreversible fouling (%)	4	3

CONCLUSIONS

The effectiveness of three different commercially available NF membranes-NF 99, NF 90, and NF 270 and two different RO membranes—CA995PE, HR98 PP, were evaluated for water recovery from the indigo dyeing wastewaters after 5 μm microfiltration. All NF membranes provided similar COD and color retention (91–93% and 88–94%, respectively), but different conductivity retention. Regarding conductivity retention, NF 90 membrane was superior to the other NF membranes providing an effluent conductivity of 1.0 mS/cm. However, with respect to permeate flux, NF 270 was the one providing the highest permeate flux of 31 L/m^{2}h which is about four times higher than that of NF 90 (8 L/m^{2}h). Considering the high permeate flux but low permeate quality (4.3 mS/cm conductivity) from NF 270, the sequential application of this NF membrane was considered. With its sequential application, conductivity retention increased from 60% to 74% with an effluent value of 2.8 mS/cm which can be considered as acceptable for reuse. On the other side, both RO membranes were more satisfactory regarding the permeate quality. But, the permeate fluxes from RO membranes were very low at the tested TMP of 5.07 bar.

Based on the results obtained, the NF 270 membrane appeared to be the best alternative for water recovery from rinsing the wastewaters of indigo dyeing process. The possible use of the NF 270 permeate with a conductivity of 4.3 mS/cm, in the initial rinsing stages after dyeing was considered to be an option worth being investigated when a full-scale application of NF 270 is practiced.

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