Flux Decline Study of Tubular Ceramic and Flat Sheet UF Membranes in Textile Wastewater Treatment

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This work gives an assessment of the application of two ultrafiltration membrane types, which are the same in pore size but different in chemistry and configuration module, for textile wastewater treatment. Characterization was based on the solute rejection data of two commercial membranes, flat sheet polyethersulfone (PES) and tubular multi-channel ceramic membrane, and flux decline was provided using polyethylene glycol (PEG) solutions of different molar mass. The permeate flux recovery after chemical cleaning was evaluated, and the efficiency of wastewater treatment was estimated on the basis of the analysis of textile wastewater and permeate. The permeate flux decline study showed that fouling was less likely to occur when PES membrane was used for wastewater treatment. PES flat membrane has proven to be more effective in the treatment of wastewater with total organic carbon (TOC) and colour removal efficiency of 72 % and 85 % respectively.

Keywords:
textile wastewater, membrane processes, ceramic membrane, polymer membrane, membrane characterization

Introduction

Generally, wastewater can contain many contaminants, such as heavy metals,[1] surfactants,[2] pharmaceutical products,[3] dyes,[4] and inorganic salts.[5] There is no doubt that membrane-based treatment technologies are set to dominate due to their improved separation efficiency and lower energy cost.[6–8] With regard to their application in the textile industry in the processing of highly loaded wastewater, these technologies have additional importance for environmental protection.[9] Dyes are one of the principal constituents of textile-industry wastewater[10] and are major polluters of water receivers.[10–12] During the dyeing process, many auxiliary chemicals like acids, alkalis, salts, surfactants, and oxidation reagents are added to improve dye adsorption and stability of fibres,[10] causing the generation of huge amounts of wastewater containing dyes, complex chemicals, inorganic salts, having high pH value and high temperature, turbidity, and salinity.[12] Textile wastewaters are often discharged after partial treatment or without prior treatment, causing increased amounts of hazardous chemicals in the environment, directly affecting the aesthetic merit, water transparency, and dissolved oxygen content.[12]

Despite numerous advantages, any membrane process is regularly obstructed by a more or less intense fouling phenomenon, due to the presence of organic, inorganic, and colloidal substances and solid particles in the system, and should be the subject of further research and mitigation of this phenomenon. Fouling control strategies for the reduction of membrane fouling phenomena include flux, cross flow velocity (CFV), time of separation cycle, physicochemical cleaning procedure, etc.[13] Pore fouling can be temporary or permanent (irreversible), and can be reduced only with the use of chemicals.[14,15] Choi *et al.*[16] reported that a layer on membrane surface which cannot be removed by flushing or backwashing results in irreversible fouling. For complete flux recovery, chemical cleaning of the membrane should be carried out continuously.[17–20] It efficiency depends on concentration, pH, temperature, time, and hydrodynamic conditions. Determination of the optimum agent for the flux regeneration is a complex procedure and cannot be selected only on the basis of the nature of the membrane-containing material, chemical, and membrane composition.[20]

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Therefore, it is advisable to examine the optimum means and cleaning conditions for each type of membrane system (membrane-solution).

Permeate flux and selectivity of the membrane depend on the thickness of the active membrane layer and membrane pore size.[21] The pore size and their distribution can be determined using several methods, such as methods related to permeability and the retention rate of the dissolved substance, as well as methods associated with the morphology of the surface of the membrane.[21,22] The nominal cut-off of the membrane can be determined on the basis of separation of dilute solutions containing the uncharged solute and the retention rate proportional to its molar mass. As a result, the sieving curve is obtained from the plot of the efficiency of solute retention to the molar mass.[23] The nominal value of the molecular weight cut-off (MWCO) of the membrane is defined as the molar mass value of the solute, which is 90 % retained by the membrane.[23–29] Hassan et al.[21] presented the application of a polyethylene glycol (PEG) solution to determine pore size by log-normal distribution. Boussu et al.,[25] Kovács and Samhaber[27] and Matsuura et al.[28] determined MWCO using PEG solutions for commercial and laboratory prepared membranes. Platt et al.[23] identified MWCO commercial membranes with PEG solutions, and showed that the experimentally obtained separation values differed from those given by the manufacturer. Non-charged solutes (PEGs) are used to characterize membranes[27] because they are water soluble, can be obtained with molecular weight distributions, and their adsorption is very low.[30] PEG solutions were chosen as a model organic matter for fouling study, since they have been widely used as a standard macromolecule in previous reports examining polymeric membrane fouling.[31–33]

Polymeric membranes are the ones most widely used for commercial purposes,[34] but ceramic membranes have some advantages over polymeric ones, such as thermal, chemical, and mechanical stability. These characteristics make ceramic membranes suitable for the treatment of textile wastewaters, especially those that are extremely hot and those containing alkali solutions.[31,34–40] In addition, they also have longer lifetime than polymeric membranes[40] but still are more expensive.[40,41] Although ceramic membranes are used in water treatment industry, there is less knowledge about the fouling of these membranes by organic compounds in comparison with polymeric membranes,[42] nor have they been rigorously investigated and understood as is the case with polymeric membranes.[38]

This paper provides a comparative study of the characterization of tubular ceramic and flat sheet polymer membranes of the same pore size intended for the treatment of cotton thread dyeing wastewater. The fouling study was carried out on the basis of flux decline during the separation cycle of model PEG solutions. In this paper, the performance in terms of flux decline of both tested membranes in experiments with textile wastewater is presented. In addition, effectiveness of filtration treatments was assessed by monitoring the permeate quality in the terms of total suspended solids (TSS) content, total organic carbon (TOC) and colour, and the permeate flux decline.

Materials and methods

Permeate flux (J_p) at specific transmembrane pressure (TMP) for adequate CFV was measured during separation tests with model PEG solutions as well as with wastewater, and these results were used to investigate the fouling mechanisms for both membranes.

Membrane modules and membrane separation units

Separation experiments were conducted using two commercially available membranes: a tubular multi-channel ceramic membrane produced by Likuid Nanotek S.L., Spain, and flat sheet polyethersulfone (PES) membrane by NADIR Germany. The ceramic membrane was a tubular ceramic multi-channel type of membrane with a zirconium oxide active layer and an alumina oxide supporting layer of dimensions 200 mm in length, outer diameter of 25 mm, and channel diameter of 3.5 mm. It had 19 inside-out channels, active layer pore size of 2 nm, and a total membrane surface of 0.0418 m^2, placed in stainless steel housing. MWCO of ceramic membrane was 1 kDa.

The PES membrane was a flat sheet type of membrane with a polyethersulfone active surface layer and polypropylene/polyethylene support layer with thickness of 210 – 250 μm. The effective filtration area was 0.0138 m^2, MWCO 1 kDa, and separation efficiency for Na_2SO_4 of 35 – 75 %.[43] Pure permeate water flux (J_w) and TMP were experimentally tested at 20 °C for each membrane using deionized water.

Normalized pure water flux J_{DW} for both membranes was determinated experimentally according to equation 1:

$$J_{D_W} = \frac{J_W}{\text{TMP}} \qquad (1)$$

Each membrane was operated in a separate filtration unit in crossflow separation mode, as presented in Fig. 1a) and b).
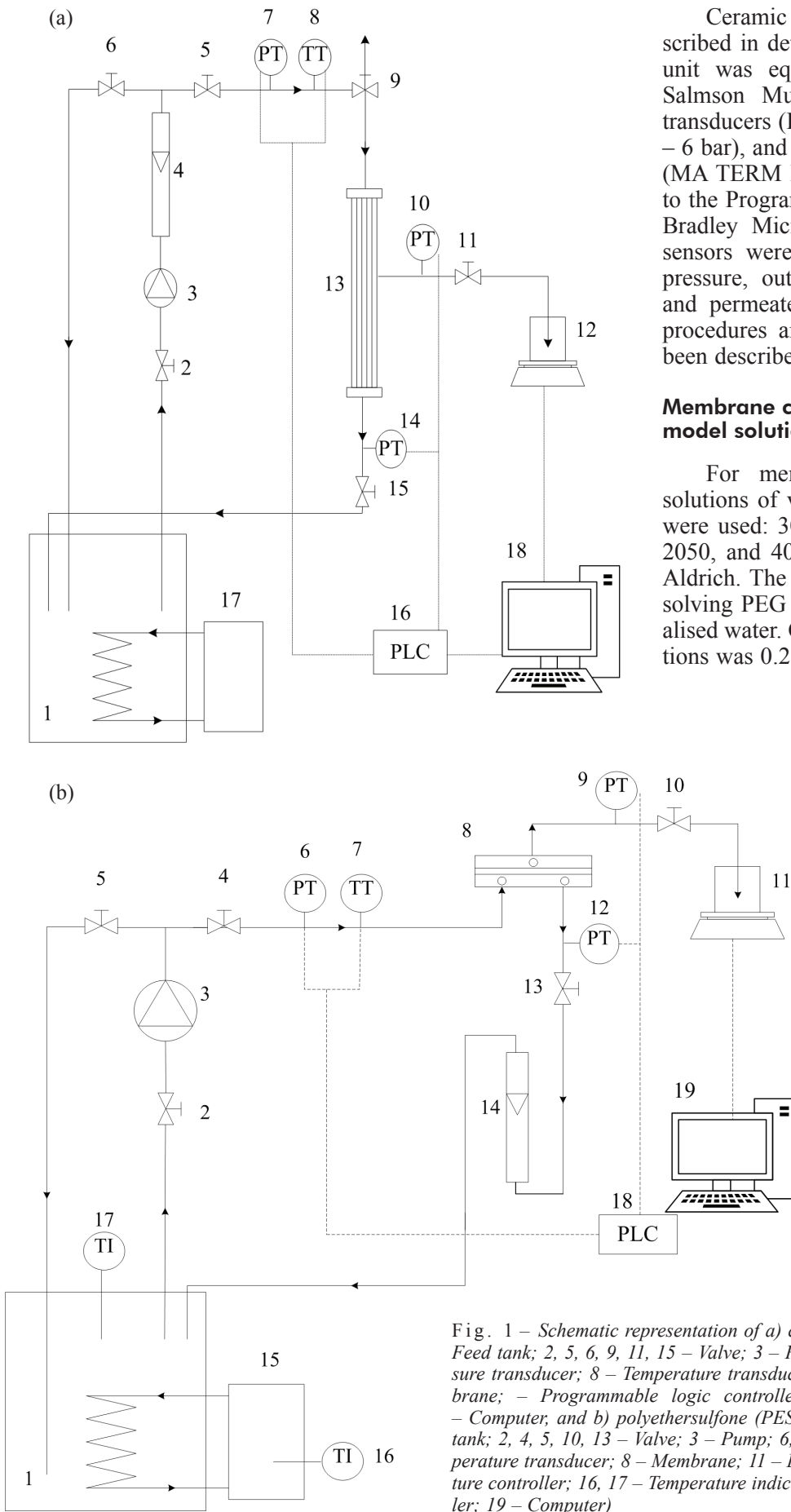
Ceramic membrane unit has been described in detail elsewhere.[44] PES membrane unit was equipped with centrifugal pump Salmson Multi – H205-SE-M/B, pressure transducers (Danfoss MB 3000; 060G3857; 0 – 6 bar), and a Pt-100 temperature transducer (MA TERM MWT 410) that were connected to the Programmable Logic Controller (Allan Bradley MicroLogix 1400). Three pressure sensors were used to measure feed stream pressure, outlet (retentate) stream pressure, and permeate pressure. The data collection procedures and TMP flux calculations have been described elsewhere.[44]

Membrane characterization model solutions

For membrane characterization, PEG solutions of various molecular weight (MW) were used: 300, 600, 950–1050, 1305–1595, 2050, and 4000 g mol^{-1}, supplied by Sigma Aldrich. The solutions were prepared by dissolving PEG of appropriate MW in demineralised water. Concentration of the model solutions was 0.25 g L^{-1}.

F i g . 1 – *Schematic representation of a) ceramic membrane separation unit (1 – Feed tank; 2, 5, 6, 9, 11, 15 – Valve; 3 – Pump; 4 – Rotametar; 7, 10, 14 – Pressure transducer; 8 – Temperature transducer; 12 – Balance; 13 – Ceramic membrane; – Programmable logic controller; 17 – Temperature controller; 18 – Computer, and b) polyethersulfone (PES) membrane separation unit (1 – Feed tank; 2, 4, 5, 10, 13 – Valve; 3 – Pump; 6, 9, 12 – Pressure transducer; 7 – Temperature transducer; 8 – Membrane; 11 – Balance; 14 – Rotameter; 15– Temperature controller; 16, 17 – Temperature indicator; 18 – Programmable logic controller; 19 – Computer)*

Textile wastewater characteristics

The textile wastewater samples were provided by a textile dyeing company (Unitas Co.) from Zagreb, Croatia, where mercerizing, dyeing, and finishing activities are conducted. The dyeing process is conducted in batch reactors of different capacity. During the dyeing process, auxiliary chemicals, such as sodium chloride, sodium carbonate, sodium hydroxide, and oxidants are added. After completion of staining, the alkaline, coloured water with high concentration of colorants auxiliary chemicals is released into the sewer system, and the thread is subsequently processed.

For the purpose of this work, original textile dyeing wastewater sample was used without correction or adding chemicals. The batch contained 48.9 $\pm$ 0.1 mg L^{-1} TSS, turbidity was 0.75 NTU, and TOC 339.63 $\pm$ 10.91 mg L^{-1}. Textile wastewater conductivity was 77 500 μS cm^{-1}, pH value 9.26, and colour intensity 2.690 $\pm$ 0.006 units, which refers to sample absorbance at three wavelengths in the visible range (436 nm, 525 nm, and 620 nm).

The membranes were chemically cleaned using technical grade NaOH, NaOCl, and analytical grade H$_2$O$_2$ (Kemika, Zagreb).

Analytical methods

For membrane characterization experiments, TOC values for model solutions and their permeates were measured. In experiments with wastewater, separation process performance was measured in terms of parameters such as pH, conductivity, turbidity, TSS, colour, and dissolved TOC. Conductivity was analysed with Knick Portamess conductometer, and pH values were determined using a pH-meter (Mettler Toledo). Concentration of PEG solutions and organic compounds in wastewater were measured using a TOC analyzer (SHIMADZU TOC-V$_{CPH}$) and expressed as non-purgeable organic carbon by NPOC method. TSS values were measured gravimetrically according the Standard Methods 2540 D. Turbidity was measured using HACH turbidimeter 2100 AN. Colour intensity measurements were carried out using HP 4853 spectrophotometer according to ISO 7887:2011 at three wavelengths, 436, 525, and 620 nm, by UV-visible absorption. Temperature was determined using Pt-100 temperature transducers (MA TERM MWT 410) and laboratory Pt-100 sensor.

Experimental procedures

Membrane characterization

Normalized pure water flux for both membranes was determined experimentally and at 20 °C its value for the ceramic membrane was 41.91 L m^{-2} h^{-1} bar^{-1}

(R^2 = 0.9927), and for the PES membrane it was 19.99 L m^{-2} h^{-1} bar^{-1} (R^2 = 0.9800).

When performing experiments with 0.25 mg L^{-1} PEG solutions for 120 min separation cycle, the flux and TMP evolution were observed for both tested membranes. Initial flux for all experiments was 70–80 L m^{-2} h^{-1} and the temperature was 20 °C $\pm$ 1 °C. The temperature of the model solutions was adjusted with a spiral heat exchanger, which was regulated with a thermostatic bath (Lambda) and controlled by Pt-100 sensors. For each experiment, samples of the initial PEG solution and permeate were taken and TOC values were measured. Characterization of the membranes was done regarding the separation of PEG for a given MW based on the measured TOC values in the PEG input solution and in the permeate, and the retention rates (R, %) for specific PEG were calculated. PEG solutions for membrane characterization were selected with respect to MWCO according to the membrane manufacturer (1 kDa).

The characterization of the ceramic membrane was carried out with PEG solutions for 120 min, at 2 bar, and 2 m s^{-1} CFV. After separation test, the membrane was rinsed with demineralized water on the pressure side, and TMP and flux values were measured for deionised water after the test. CIP (cleaning in place) procedure was also conducted as previously reported.[44]

PES membrane tests were conducted for 120 min at 3.5 bar and 0.32 m s^{-1} CFV. As in the case of ceramic membrane, after each performed experiment, the membrane was rinsed with demineralized water and normalized flux was measured. After rinsing, the initial flux value was achieved, and CIP was not conducted.

Textile wastewater treatment procedures

Effluent from the textile factory was put into a feed tank with a thermostat, and press through ceramic and PES membranes. Filtration experiments were conducted in cross-flow filtration mode with complete retentate recycling at CFV of 2 m s^{-1} for ceramic membrane, and 0.32 m s^{-1} for PES membrane for 30–40 L m^{-2} h^{-1} initial permeate flux. The TMP was 2.0 bar for ceramic membrane and 3.5 bar for PES membrane. The temperature of the feed wastewater in all experiments was T = 20 °C $\pm$ 1 °C, and was adjusted and regulated using the same procedure as for PEG solutions.

The water flux for deionized water (J_W) was determined before each experiment by measuring the pure water flux for adequate measured TMP value. The normalized flux of wastewater was also determined by measuring the permeate flux (J_{Pn}) at different TMPs. After each filtration test, mem-

branes were rinsed with deionized water in order to assess the degree of irreversible fouling and/or to achieve a satisfactory level of normalized flux recovery.[45] During the experiments with the PES and the ceramic membranes, the process of rinsing with deionized water was insufficient to reach a satisfactory level of normalized flux recovery. To achieve a better or nearly a complete flux recovery, a thorough chemical cleaning was conducted using CIP procedure, especially of the ceramic membrane. The CIP procedure for ceramic membrane has been described in detail elsewhere.[44] The PES membrane was cleaned using 0.1 % NaOCl at 40 °C and soaking time of 30 min. Permeate normalized flux was measured after each cleaning step and compared to initial value. If necessary, the membrane was cleaned again until the nearly initial normalized flux was restored for the next experiment. For all the experiments carried out, wastewater and permeate samples were analysed.

Results and discussion

Membrane characterization

Characterization of the 1 kDa ceramic and PES membranes was performed with PEG solutions of six different molar masses between 300–4000 g mol⁻¹. Solutions were used according to the MWCO declared by manufacturer for ceramic membrane and with respect to the stated pore size for 1000 g mol⁻¹ (1kDa) reported by Kaya *et al.*[46] and Carvalho *et al.*[43] for PES membrane. The results of the membrane separation efficiency are given graphically in Fig. 2, where the lines show the results of the cumulative log-normal distribution function.
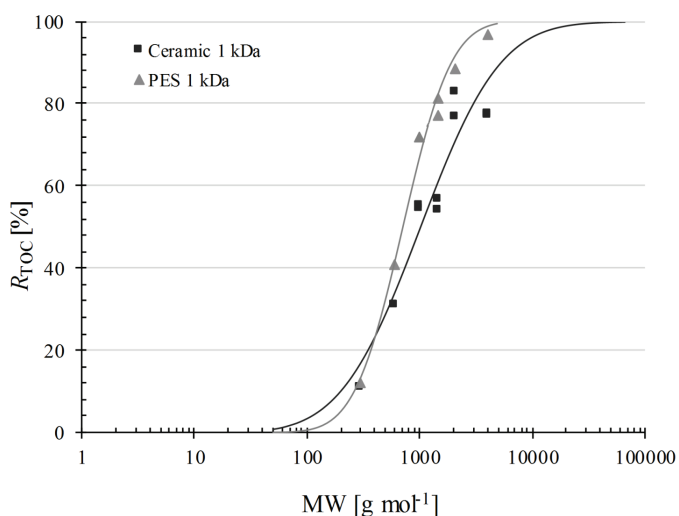

F i g . 2 – *Cumulative density distribution function of the polyethylene glycol (PEG) solutions molecular weight (MW) 300 – 4000 g mol⁻¹ for ceramic and polyethersulfone (PES) membrane calculated based on the measured total organic carbon (TOC) rejection efficiency R*

Based on the results for ceramic membrane, a rejection efficiency higher than 90 % was not achieved after separation of tested PEG solutions. The separation efficiency was more than 55 % for 950 – 1050 g mol⁻¹ PEG solution, and 83 % for 2050 g mol⁻¹ PEG solution.

For PES membrane, separation efficiency was higher than 89 % in the case of PEG solution of 2050 g mol⁻¹, and 96 % for the PEG solution of 4000 g mol⁻¹. The deviation from the declared value of the manufacturer can be explained by the structure of the non-spherical PEG molecule; it is elongated and can be "tapped" through the membrane pores. Additionally, in the characteristics of the ceramic membrane obtained by the manufacturer, the substance in which separation efficiency was expressed was not provided. Kim et al.,[24] in the characterization of membranes with PEG solutions, showed the differences between declared values of MWCO by manufacturers and those obtained by experiment, depending on the operating conditions.

Flux decline study

Evolution of the normalized J_{Pn} flux for separation PEG solutions 300 – 4000 g mol⁻¹ using ceramic and PES membranes are presented in Figs. 3 and 4, respectively.

According to the results for ceramic membrane, it is obvious that the decrease in normalized flux is less sensitive to the molar mass of the PEG molecule. The difference in flux decline for all tested solutions was within the interval less than 5 % of normalized flux. PEG molecules that are smaller than membrane pore size do not pass through the membrane but retained within the pores, and thus membrane fouling occurs. This results in flux decline and increase in TMP. The diagram shows that the normalized flux decline is lowest for the lowest PEG molar mass solution (16 %), and the most intensive for the PEG solution of highest molar mass (19 %).

In the case of PES membrane, the decrease in normalized flux is more intensive for PEG solutions with higher molar mass. For PEG solutions of molar mass less than 1000 g mol⁻¹, a smaller decline in normalized flux was observed: for 300 g mol⁻¹ 5 %, for 600 g mol⁻¹ up to 11 %. For PEG solutions with molar mass higher than 950 – 1050 g mol⁻¹ there was a higher decline in normalized flux value up to 19 %. Regardless of the membrane pore being larger than the PEG molecule, PEG molecules are retained on the membrane surface and in the membrane pores, causing a decline in flux and increase in TMP. Their retention by membrane can also be confirmed by the TOC rejection efficiency results. Therefore, the difference between flux decline for
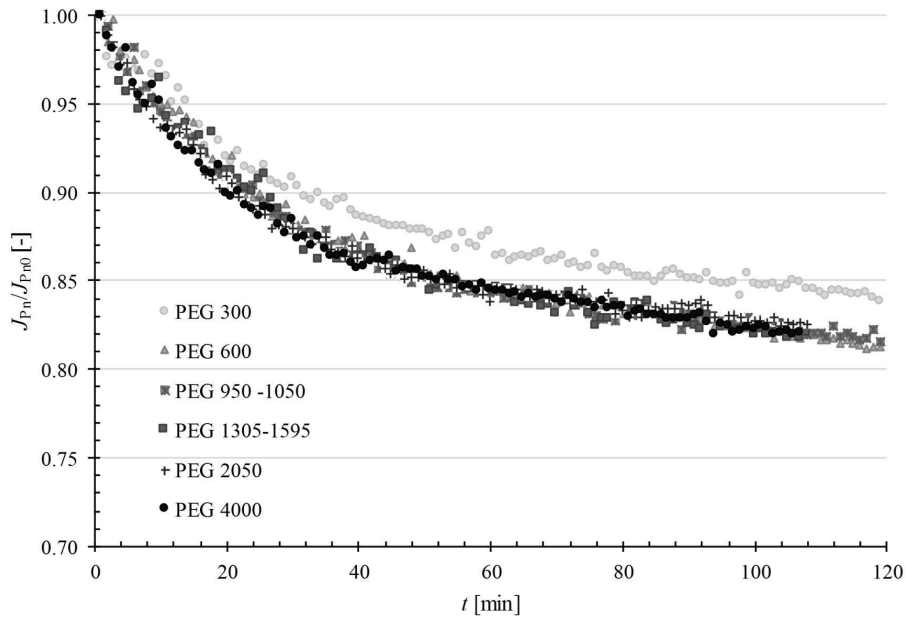
F i g . 3 – *Normalised flux evaluation for polyethylene glycol (PEG) 300 – 4000 g mol⁻¹ solutions separations tests using ceramic membrane, T = 20 °C, cross flow velocity (CFV) 2 m s⁻¹, initial permeate flux 80 L m⁻² h⁻¹*

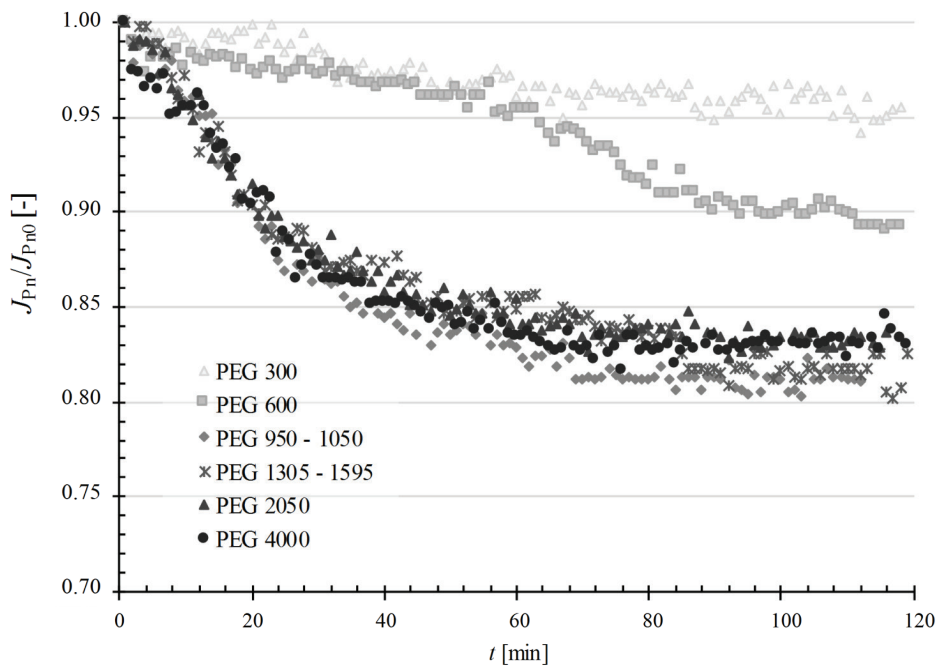F i g . 4 – *Normalised flux evaluation for polyethylene glycol (PEG) 300 – 4000 g mol⁻¹ solutions separations test using polyethersulfone (PES) membrane, T = 20 °C, cross flow velocity (CFV) 0.32 m s⁻¹, initial permeate flux 80 L m⁻² h⁻¹*

solutions of lower and higher molar mass than the membrane MWCO can be clearly seen from the results. For PEGs with molar mass higher than 950 – 1050 g mol⁻¹, flux decline was more intensive because a more intensive fouling phenomena on the membrane surface had occurred.

The PES membrane shows a clear boundary between the types of blocking present with respect to the size of the PEG molecule. The ceramic membrane shows a tendency toward fouling phenomena even in separation of solutions with lower PEG molar mass values. It can be assumed that blockage

Table 1 – *Evolution of the normalized permeate flux after forward flush and chemical cleaning using the ceramic and PES membranes for tests with polyethylene glycol (PEG) solution 300 – 4000 g mol⁻¹ (T = 20 °C)*

M_w(PEG) [g mol⁻¹]	300	600	1000	1450	2050	4000
Ceramic membrane						
J_{DW} (initial) [L m⁻² h⁻¹ bar⁻¹]	42	42	43	43	42	39
J_{DW} (after PEG solution tests) [L m⁻² h⁻¹ bar⁻¹]	32	33	36	36	32	35
Normalized flux recovery [%]	76	79	84	84	76	90
J_{DW} (after chemical cleaning) [L m⁻² h⁻¹ bar⁻¹]	39	43	43	42	39	42
Normalized flux recovery [%]	93	>100	>100	100	93	>100
PES membrane						
J_{DW} (initial) [L m⁻² h⁻¹ bar⁻¹]	20	20	21	20	20	20
J_{DW} (after PEG solution tests) [L m⁻² h⁻¹ bar⁻¹]	20	20	21	20	20	20
Normalized flux recovery [%]	100	100	100	100	100	100

inside the pores occurs first, then the formation of molecules on the surface, and the formation of cake.[34]

Table 1 presents the values of the normalized flux for demineralised water obtained prior to the PEG solution and after each experiment. Based on the results, after tests with PEG solutions using PES membrane, complete flux recovery was achieved by rinsing with demineralised water, and no chemical cleaning of the membrane was required. In the case of ceramic membrane, normalized flux recovery after rinsing was 76 to 90 %, and after chemical cleaning, was higher than 93 % for all tested solutions.

Textile wastewater treatment

Textile wastewater ultrafiltration tests with ceramic and PES membranes were carried out in 120-min cycles at 20 °C for 30 – 40 L m⁻² h⁻¹ initial permeate flux and TMP 2.0 bar for ceramic, and 3.5 bar for PES membrane. The normalized permeate flux (J_{Pn}/J_{Pn0}) evolution is presented in Fig. 5.

The most intensive normalized flux decline of 23 % was noticed at the end of the separation cycle using ceramic membrane. For PES membrane, the normalized flux decline was up to 7 %. Relatively low normalized permeate flux decline is the result of low membrane fouling level at the PES membrane surface. Forward flush and chemical cleaning were conducted to achieve a flux recovery. According to Zuriaga-Agusta et al.,[45] prior to chemical cleaning, the normalized flux was measured with

regard to demineralized water to determine the intensity of reversible pore blocking. After the chemical cleaning procedure, the normalized flux of deionized water was determined, and the effectiveness of the cleaning processes was evaluated using the membrane permeability ratio defined as the ratio between the deionized water normalized permeate flux after the test or chemical cleaning, and the initial normalized flux of deionized water before the test.[45] Results are presented in Table 2.

Flux recovery after testing the wastewater, for both the ceramic and PES membrane was 75 %, and after chemical cleaning 98 % and 90 %, respectively.

For experiments with ceramic membrane, the normalized flux reduction after chemical cleaning compared to the initial value before the experiment related to irreversible blockage of the pores. Flux change occurs due to the formation of a permanent layer on the surface of the new membrane that occurs by precipitation, adsorption, and binding to macromolecules that prevent chemical cleaning from being effective. Adsorbed molecules under pressure create a thin and compact layer that is resistant to chemical cleaning. This phenomenon is described by Gan et al.[47] based on their research results of chemical cleaning of ceramic membranes. Water rinsing after separation is not sufficient to restore the initial value of the normalized flux, and only 75 % of the flux regeneration is achieved. By chemical purification, almost complete flux regeneration (98 %) was achieved.

Regardless of low fouling intensity for PES membrane, the normalized flux decline was less
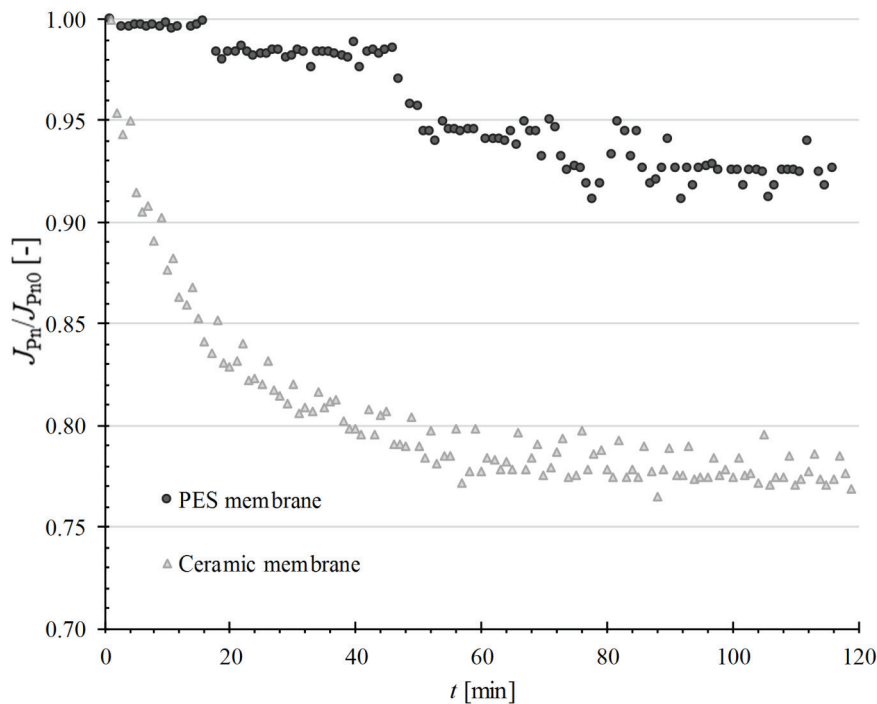
F i g . 5 – *Evolution of the normalized permeate flux of textile wastewater with ceramic (cross flow velocity (CFV) 2 m s⁻¹, 2 bar) and polyethersulfone (PES) membrane (cross flow velocity (CFV) 0.32 m s⁻¹, 3.5 bar), and initial permeate flux 30 – 40 L m⁻² h⁻¹, T = 20 °C*

than 7 %, the membrane permeability ratios of deionized water after the tests were relatively low (75 %), meaning that irreversible fouling had developed. This deterioration of the membrane was caused by the material accumulation in the membrane pores, and chemical procedures were required

Table 2 – *Normalized permeate flux of ceramic and polyethersulfone (PES) membrane after rinsing and chemical cleaning for ultrafiltration tests with textile wastewater (T = 20 °C)*

Membrane	Ceramic	PES
J_{DW} (new membrane) [L m⁻² h⁻¹ bar⁻¹]	41.9	20.0
J_{DW} (initial) [L m⁻² h⁻¹ bar⁻¹]	37.1	20.0
J_{Pn} (start of test) [L m⁻² h⁻¹ bar⁻¹]	19.9	10.3
J_{Pn} (end of test) [L m⁻² h⁻¹ bar⁻¹]	15.4	9.6
J_{DW} (after rinsing) [L m⁻² h⁻¹ bar⁻¹]	27.9	15.0
Normalized flux recovery [%]	75	75
J_{DW} (after chemical cleaning) [L m⁻² h⁻¹ bar⁻¹]	36.5	18.0
Flux recovery [%]	98	90

to maintain a satisfactory membrane performance. Based on the flux recovery after chemical cleaning, the PES membrane showed higher irreversible fouling tendency compared to the ceramic membrane. This could be due to weaker interaction of the foulant with ceramic membrane as previously reported by Lee *et al.*[31] Additional research is necessary to understand many factors that affect the separation behaviour and fouling mechanisms of ceramic membranes, i.e., water quality parameters, different membrane material, pore geometry or the impact of the more hydrophilic nature of the ceramic membranes.[31]

Table 3 shows the effects of using the two membranes in the ultrafiltration process determined by the rejection rates of the evaluated parameters. According to expectations, the pH values of tested membrane permeates were approximately the same because the membrane pores were too large to maintain the dissolved sodium hydroxide that affects most these pH values. The conductivity level in the case of ceramic membrane was 3 % lower, and for PES membrane 10 % lower than in the case of the raw wastewater.

TSS, turbidity, TOC, and colour had reduced by 66, 61 %, 71 %, and 67 %, respectively, when ceramic membrane was used. For PES membrane, these parameters had reduced by 56, 39, 72 %, and 85 %.

Table 3 – *Characteristics of permeate samples and rejection rates of total suspended solids (TSS), turbidity, and total organic carbon (TOC), and colour intensity with the polyethersulfone (PES) and ceramic membranes for textile wastewater at T = 20 °C*

Membrane	Ceramic	PES
pH	9.26±0.01	9.21±0.00
Conductivity [mS cm^{-1}]	74.8±0.5	71.4±2.7
TSS [mg L^{-1}]	16.61±0.78 $R = 66.0 \%$	21.4±1.0 $R = 56.2 \%$
Turbidity [NTU]	0.29±0.04 $R = 61.2 \%$	0.45±0.06 $R = 39.4 \%$
TOC [mg L^{-1}]	100.03±7.05 $R = 70.54 \%$	96.18±4.49 $R = 71.7 \%$
Colour	0.895±0.086 $R = 66.72 \%$	0.393±0.056 $R = 85.39 \%$

Conclusion

Fouling significantly influences the flux decline of membranes. The experimental results obtained with model organics (non-charged solutes (PEGs)) showed that fouling was less intense for PES membrane, the permeate normalized flux decline stayed within 7 %, while for ceramic membrane, it was three times higher (23 %). The permeate normalized flux ratios of deionized water after the tests were relatively low (75 %) for both tested membranes, meaning that irreversible fouling had developed. In case of TOC and colour removal from textile wastewater, the PES membrane outperformed the ceramic membrane with removal efficiencies of 72 % and 85 %, receptively, while for TSS and turbidity, the latter gave better results by 66 % and 61 %. Satisfactory flux recovery could be achieved with a chemical cleaning procedure.

List of symbols

CFV — cross flow velocity, m s^{-1}

J_{DW} — normalized pure water flux, L m^{-2} h^{-1} bar^{-1}

J_{p} — permeate flux, L m^{-2} h^{-1}

J_{Pn} — normalized permeate flux, L m^{-2} h^{-1} bar^{-1}

J_{Pn0} — initial normalized permeate flux, L m^{-2} h^{-1} bar^{-1}

J_{w} — pure water flux, L m^{-2} h^{-1}

MW — molecular weight, g mol^{-1}

TMP — transmembrane pressure, bar

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