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Recycling of hospital laundry wastewater using membrane technology

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ABSTRACT

The laundry wastewater from a Qatari hospital has been characterized and its membrane filtration behavior studied. 1,800–2,500 L or wastewater per cycle for washing a laundry load of 40–50 kg was determined, with the wastewater shown to be sufficiently polluted to require treatment prior to discharge. Two treatment approaches were adopted, the first being a single membrane technology employing a "tight" ultrafiltration (UF) membrane of 5 kDa molecular weight cut-off (MWCO) and the second a combination of coarser UF of 75 kDa MWCO followed by a nominally 200 Da nanofiltration (NF) membrane. Both approaches were found to be acceptable in terms of pollutant rejection (more than 87%), with the statutory wastewater discharge limit being met. Fluxes of (29–42, 72–100 and 27–54 LMH were determined for the 5 kDa UF the 75 kDa UF and UF-pretreated NF). However, only the dual technology (combination of UF-NF) was able to remove the dissolved solids as evident by the reduction in wastewater conductivity. Results demonstrated that the hospital wastewater can be successfully treated at a pressure of 2.5 bar, temperature 25°C and a crossflow rate of 1 L/min, with rejection and flux being sensitive only to temperature within the range of 25°C–45°C.

Keywords: Hospital laundry wastewater; Ultrafiltration; Nanofiltration; Reuse

1. Introduction

The Qatar climate is characterized by >40°C summer temperatures, an average annual rainfall ~80 mm only and an evaporation rate as high as 2,200 mm. The consequent water scarcity of renewable water [1], exacerbated by a population which has increased by 35% in the past 3 years [2] and a high per capita water consumption of 600 L/d [1], demands exploration of all possible water demand management and recycling options. This includes grey water treatment and reuse [3,4] to reduce the consumption of potable water.

Hospital wastewaters have received greater attention in recent years due to the focus on emerging pollutants [5,6], with studies encompassing assessment of toxicity of these effluents [7,8]. Amongst the different hospital wastewater streams, laundry wastewater is high in levels of COD and BOD, suspended substances, fats and proteins, detergents and surfactants and disinfectants [9,10], such that it is toxic in aquatic ecosystems up to two trophic levels and in soil ecosystems to one trophic level [11]. Hospitals contribute to around 2–3 times more of organic matter and suspended solids than domestic dwellings (Table 1, [12]). In Qatar hospital wastewater volumes have increased with increased patient numbers associated with the rapidly expanding population [2], whilst wastewater discharge standards have become more stringent. It is therefore reasonable to focus on treatment and reuse of the laundry wastewater stream, given its contribution to the overall pollutant load.

Reuse of recovered greywater for laundering requires the water to be hygienically safe, aesthetically acceptable, economically feasible and have limited environmental impact [13]. However, water quality standards for this duty are limited, with no internationally-agreed guidelines for water reuse [14,15], and very few for recovered greywater generally [16].

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Table 1
Loads in g per person (or patient) per day, hospital vs. domestic effluent [12]

Parameter	Hospitals	Urban
COD	260–300	100–120
BOD5	150–170	50–60
TSS	120–150	90–120

Guidelines instead exist on a national or regional basis, for example for the USA [17], China [18] and Italy [19] (see Table 6). Whilst there are other water quality determinants stipulated for reused recovered wastewater for these nations, including the microbiological and nutrient content [17–19], the key parameters regarding reuse for laundering concern organic carbon and dissolved solids.

Whilst many different physical and biological technologies for treating laundry wastewater have been studied, membrane technology is ultimately required to produce treated water quality reliably high enough for reuse, such as back to the laundering process. Membrane technologies tested for this recycling application include ultrafiltration [19], and combined microfiltration (MF) and ultrafiltration [13]. Whilst the permeate flux sustained was high, the permeate quality was reported as being to be too poor (>175 mg/L TOC) to permit reuse for laundering. The application of reverse osmosis (RO) downstream of the UF (of 20–400 kDa MWCO, or molecular weight cut-off) reduced the treated water BOD from 86 to 2 mg/L, enabling its reuse and demonstrating the importance of membrane selectivity.

There is a paucity of information on hospital wastewater reuse generally and almost none relating to laundry wastewater specifically. However, recycling of this stream represents a viable means of limiting discharge of micropollutants, known to be very onerous to the environment [20]. The current study compares the performance of a single low-MWCO UF stage with that of a two-stage UF-NF (nanofiltration) process challenged with actual hospital wastewater, in such a case where laundering is conducted within the hospital (i.e., not outsourced) . The performance of the two processes was assessed with reference to rejection of the organic matter and the sustained and flux over a time period of experiment following pre-conditioning. The impact of transmembrane pressure (TMP), flow rate and temperature were studied, and the viability of recycling of the treated water assessed.

2. Experimental

2.1. Laundering operation and wastewater sampling

Samples were taken from a Doha hospital laundry operating 14 h/d throughout the week on cycles of ~45 min, with one wash load equating to around 40 kg of linen segregated into contaminated and non-contaminated clothes zones. Four of the 11 machines are allocated to materials contaminated with potential biological hazards (blood, excrement, pathogenic microorganisms) and use a contaminated zone wash program (CZWP). The remaining seven machines are used for all other materials using an uncontaminated zone wash program (UZWP). Both programs comprise a prewash, wash, rinsing and spin cycle. The CZWP provides four consecutive rinse cycles, compared with three for the UZWP. Detergents are added in the prewash cycle and alkali and bleach in the wash cycle, with the CZWP employing higher concentrations of detergents and other chemicals. Softeners are added in the last rinsing cycle before the spin cycle, the wastewater being removed between cycles.

Samples were extracted from the pre-wash, wash and first rinse cycle of both the CZWP and UZWP programs and analyzed for pH, total suspended solids (TSS), conductivity, chemical oxygen demand (COD) and surfactant concentration. These water quality parameters are widely used in the characterization of wastewater, and can be considered appropriate and sufficient for quantifying the rejection performance of the membrane. Equal volumes of all cycle samples were blended to form a composite sample for membrane tests for both the CZWP and UZWP samples. Samples were analysed for COD, TSS, total chlorine (by the DPD method, *Hatch 8167*) and anionic surfactant (photometrically, using *Hatch 8006* reagent) on the day of collection or testing and stored at 5°C until required.

2.2. Membrane filtration testing

Filtration of the wastewater samples was by:

- A single-step treatment using 5 kDa MWCO polyethersulfone (PES) UF membrane, and
- A two-step treatment using a 75 kDa polyacrylonitrile (PAN) UF membrane followed by a 200 Da polypiperazine amide NF membrane (Table 2).

A *SEPA* cross-flow membrane test cell (*Sterlitech*, USA) was used for all tests, fitted with a high pressure feed pump (Baldor Reliance Industrial Motor) supplying magnetically-stirred feed water from a

Table 2
Specifications of membranes (from *Sterlitech*) and base test conditions

Membrane	Material	MWCO	Size	Operating conditions
NF	Polypiperazine amide	200 Da	40″ × 12″	Pressure (bar): 7.5 Flowrate (L/min): 2.5 Temp. (°C): 25
UF	Polyacrylonitrile	75 kDa	18″ × 18″	Pressure (bar): 2.5
UF	Polyethersulfone	5 kDa	18″ × 18″	Flowrate (L/min): 1.0 Temp. (°C): 25

temperature-controlled water bath to the inlet at the cell base (Fig. 1). The pressure was manually controlled using throttle valves and the concentrate stream flow constantly monitored. The temperature of the wastewater in the feed vessel was adjusted and maintained by passing the concentrate flow and diverted portion of feed through the circulating water bath to the feed tank. The mixing of wastewater in the feed tank was achieved by using magnetic stirrer. All tests were conducted on virgin membrane materials.

Further trials were conducted to establish (a) the extent of the flux decline, and (b) the sensitivity of the membrane selectivity and flux to the key operating parameters of pressure, crossflow and temperature (Table 3). Trials were based on a single CZWP wastewater sample and the rejection and flux recorded at the end for each trial.

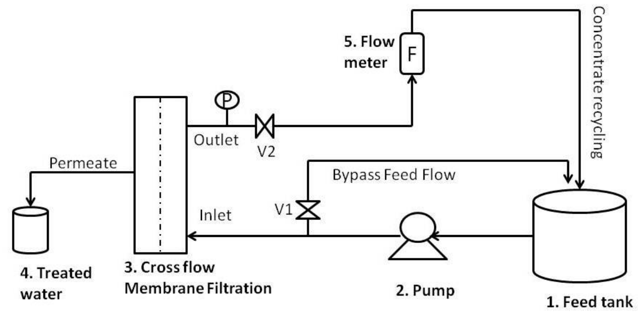

Fig. 1. Process flow diagram of the treatment system.

Table 3
Operating conditions, sensitivity test

Parameter	Base value	Range of values
Pressure, bar	2.5	2.5, 5, 7.5
Flow, L/min	1	1, 2.5, 5
Temperature, °C	25	25, 35, 45

Table 4
Laundry wastewater and permeate characteristics, single stage

Parameter, Feed water	CZWP			UZWP		
	Prewash	Wash	First rinse	Prewash	Wash	First rinse
pH	11.4	11.4	8.3	10.4	8.5	6.75
TSS, mg/L	214	178	88	127	61	55
Conductivity, μS/cm	4400 ± 66	2410 ± 36	316 ± 4	549 ± 8	307 ± 5	218 ± 3
COD, mg/L	1104 ± 41	1032 ± 39	592 ± 22	284 ± 11	214 ± 8	120 ± 5
Surfactant, mg/L	8.5 ± 0.4	5.8 ± 0.3	1.1 ± 0.04	7.8 ± 0.4	3.6 ± 0.2	0.6 ± 0.02
Permeate[a]	Feed	Permeate	% rejection	Feed	Permeate	% rejection
pH	10.9	10.7	–	9.2	7.5	–
TSS, mg/L	96	7	93	51	2	96
Conductivity, μS/cm	617 ± 9	512 ± 8	17	195 ± 3	146 ± 2	25
Total Cl, mg/L	33 ± 0.5	1.3 ± 0.02	96	19 ± 0.3	ND	100
COD, mg/L	360 ± 13	35 ± 1	90	147 ± 6	9.0 ± 0.3	94
Surfactant, mg/L	3.2 ± 0.1	0.41 ± 0.02	87	6.2 ± 0.3	0.64 ± 0.03	90

ND: not detectable. [a]5 kDa-filtered, combined feed.

3. Results and discussion

3.1. Wastewater characteristics

Wastewater analytical data (Table 4) indicate the water to be alkaline in nature due to the detergent content, the pH decreasing following the rinse cycle; this is consistent with the pH values of laundry water from industrial activities and hospitals [16,21]. A similar trend was evident for other parameters, where highest values were recorded for the prewash step followed by the washing step and, as would be predicted, the lowest at the rinsing step. Table 4 also indicates higher contaminant levels in the CZWP samples compared to those from the UZWP stream, for which pH, TSS and COD were found to be in similar level to those previously reported hospital laundry effluents [16], due to the nature of the laundering process. The water quality determinant values are all outside Qatari standards for discharged wastewater (pH 6–9, COD 100 mg/L, TDS 1,500 mg/L and TSS 50 mg/L); these standards do not specify surfactants, though some European standards stipulate a limit of 2 mg/L [19].

3.2. Wastewater purification, single vs. dual stage

3.2.1. Single-stage vs. dual stage

3.2.1.1. Membrane rejection The single-stage UF membrane removed 93%–96% of the suspended solids (Table 4), somewhat more than that reported by previous researchers for >20 kDa MWCO UF membranes for this duty [18,20], but was ineffective against conductivity. COD rejection was in the range of 90%–97% for both the single and dual-stage treatment (Table 5), with the NF membrane providing 95% COD rejection compared with 90% for the 5 kDa UF and 45% for the 75 kDa UF. Literature values of 45%–69% COD rejection have been reported for low-strength public shower greywater for UF MWCO values between 30 and 400 kDa [22], comparable to the data for the current study. Removal of the surfactant com-

Table 5
% Rejection of dual-stage UF (75 kDa) – NF (200 Da) treatment

Parameter	Feed	UF permeate (75 kDa)	% Rejection	NF permeate (200 Da)	% Rejection	Total % Rejection
UZWP						
pH	9.2	8.6	–	7.9	–	–
Conductivity, µS/cm	195 ± 2.9	187 ± 3	4	39 ± 0.5	79	80
TSS, mg/L	51.00	6	88	0	100	100
Total Cl, mg/L	19 ± 0.3	5.6 ± 0.1	71	ND	98	100
COD, mg/L	147 ± 5.5	77 ± 3	48	4 ± 0.2	95	97
Surfactant, mg/L	6.2 ± 0.3	3.4 ± 0.2	45	0.5 ± 0.02	85	92
CZWP						
pH	10.9	10.7	–	10	–	–
Conductivity, µS/cm	617 ± 9	530 ± 8	14	106 ± 2	80	83
TSS, mg/L	96	11	89	0	100	100
Total Cl, mg/L	33 ± 0.5	22 ± 0.3	65	0.9 ± 0.01	95.8	97
COD, mg/L	360 ± 14	197 ± 7.4	45	10 ± 0.4	95	97
Surfactant, mg/L	3.2 ± 0.14	1.5 ± 0.06	46	0.21 ± 0.009	85	93

ponent of the COD by a 200 Da NF membrane has been reported as being in the range of 87%–93% [23], compared with 92%–98% anionic surfactants and 88%–92% for an NF membrane [24]. These values are somewhat higher than the mean value of 85% recorded for the current study. Only the combined system provided a significant reduction in conductivity, comparable to the performance recorded for similar membrane systems for low-strength grey water treatment [22] Alternative treatment technologies such as combined granular activated carbon (GAC) with downstream filtration using a 20 kDa UF membrane has demonstrated the GAC treatment to achieve the Italian standards for discharge [19].

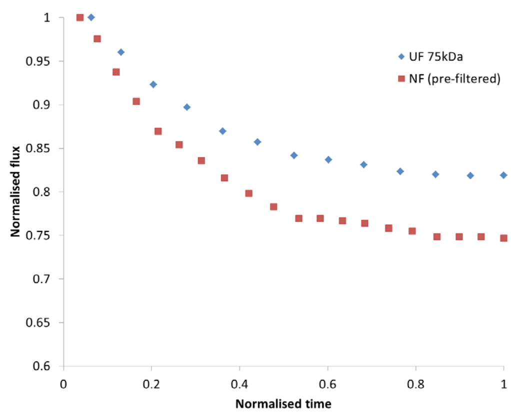

Fig. 2. Examples of flux decay transients, 75 kDa UF and 200 Da NF: Base conditions; UF: P = 2.5bars, F = 1 L/min, T = 25°C, NF: P = 7.5 bars, F = 2.5 L/min, T = 25°C; Feed water: UZWP

3.2.1.2. Flux trends The flux was found to generally decline to a pseudo-steady state value after 1–2 h, declining sharply within the first 1 h, according to a similar pattern across the different membranes (Fig. 2). Similar trends have been previously observed in many similar studies of UF membranes challenged with real wastewaters [23,25], with pseudo-steady state being attained when the rate of attachment of foulants on the membrane surface is in equilibrium with their detachment under the influence of shear [26].

The recorded flux ranges (Fig. 3) were somewhat lower than those reported in the literature for the same wastewater. The application of NF membranes (30–80 MWCO) for the recycling of laundry water on ships has been reported to yield pseudo-steady state fluxes of 49–75 LMH [25], with the characteristic sharp decrease in flux in the first 20 min of operation. The treatment of hospital laundry rinse water using a two-stage tubular 20–400 kDa UF and RO process [27] yielded UF fluxes of 110–130 LMH at TMPs of 3–5 bar, presumably due to the higher shear imparted in the tubular membranes combined with the increased membrane porosity and higher TMP. The equilibration period was 2–3 h in this instance.

3.2.2. Single-stage treatment, sensitivity analysis

A comparison with available national guidelines (Table 6) indicates that the treated effluent quality from both single and dual-stage treatment is satisfactory in that it is compliant with the standards. This being the case subsequent trials were conducted on the simpler, single-stage 5 kDa process.

The percentage rejection of COD decreased only slightly from 91% to 89% when the pressure was increased from 2.5 to 5 bar, with a further decrease to 86% on increasing to 7.5 bar (Table 7). A similar trend was observed for conductivity. Similar trends have been reported for treating oil sands process water using UF membranes [28], with a 3% decrease in absolute rejection resulting from a 50% increase in TMP. This is readily explained by the action of concentration polarisation (CP) increasing the solute concentration on the retentate side of the membrane and thus promoting diffusion of the membrane [29]. Since the flux did not increase above

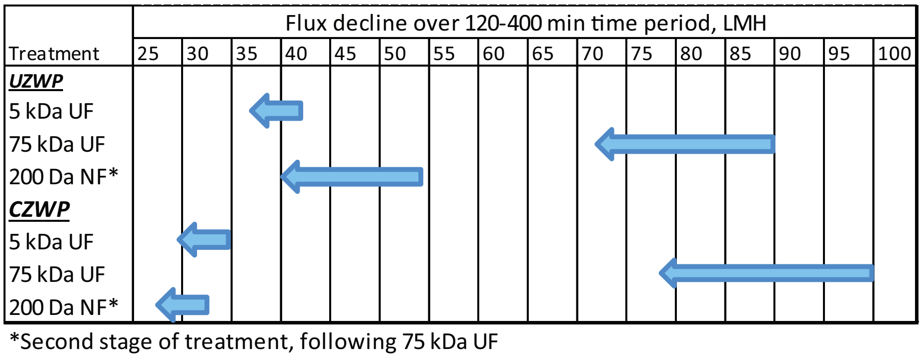

Fig. 3. Flux decline; UF: $P = 2.5$ bars, $Q = 1$ L/min, $T = 25°C$, NF: $P = 7.5$ bars, $Q = 2.5$ L/min, $T = 25°C$.

Table 6
Comparison of recorded mean effluent quality with standards

Parameter	UZWP		CZWP		USA [17]	Italy [19]	China [18]
	UF (5 kDa)	UF (75 kDa)-NF (200 Da)	UF (5 kDa)	UF (75 kDa)-NF (200 Da)			
pH	7.55	7.90	10.7	10	6–9.0	6.5–8.5	6–9
Conductivity (μS/cm)	146	39	512	106	–	<2,000	–
TSS, mg/L	1	2	7	0	–	<5	–
COD, mg/L	9	4	35	10	5	<100	–
Surfactants, mg/L	0.64	0.5	0.41	0.21	–	<20	0.5
Total Cl, mg/L	0.25	0.1	1.32	0.9	–	–	1

Table 7
Membrane performance under different conditions, influent 580 ± 22 mg/L COD, 660 ± 9.9 μS/cm conductivity, pH 11

	COD, mg/L	% COD rejection	Conductivity, μS/cm	% Conductivity, rejection	pH	Flux (LMH)
Operating pressure, bar						
2.5	53 ± 2	91	530 ± 8	14	10.8	29
5	69 ± 2.6	89	545 ± 8	12	10.8	59
7.5	79 ± 3.0	86	562 ± 8	9	10.8	70
Feed flow rate, L/min						
1	53 ± 2	91	530 ± 8	14	10.8	29
2.5	36 ± 1	94	520 ± 8	16	10.5	47
5	34 ± 1.3	94	499 ± 7	19	10.5	70
Temperature, °C						
25	53 ± 2	91	530 ± 8	14	10.8	29
35	70 ± 3	88	555 ± 8	10	10.9	39
45	90 ± 3	84	580 ± 9	6	10.9	49

Base conditions: $P = 2.5$ bar, $Q = 1$ L/min, $T = 25°C$, 5 kDa UF, Wastewater CZWP. Flux refers to pseudo steady-state values from sensitivity tests of single-stage technology.

5 bar TMP, the increased diffusion is not compensated by the increased flow of permeate. Operation should therefore be maintained below 5 bar in this instance.

The impact of a 2.5-fold increase in crossflow rate was to increase % COD rejection by around 3% (Table 7), with a negligible increase on further doubling of the crossflow. This can again be explained by the action of CP, with the increased shears at high crossflows reducing CP and thus the retentate-side solute concentration [30] as well as promoting flux. A more significant impact was recorded for temperature, where an increase from 25°C to 45°C decreased rejection from 91% to 84%, again consistent with studies of NF membranes [31–33] and attributable to increased solute diffusivity along with membrane pore size [34]. The latter is also likely to explain the increase in flux recorded.

4. Conclusions

Characterization of hospital laundry wastewater in terms of pH, chemical oxygen demand (COD), suspended and dissolved solids, and surfactants concentration revealed that it could not be discharged without treatment. The option of membrane technology was explored to establish whether recycling of this stream may be viable following separation using a single stage 5 kDa UF (ultrafiltration) membrane or a two-stage 75 kDa UF - 200 Da NF (nanofiltration) process. The study revealed:

- The dual-stage technology removed all of the total suspended solids and 80%–83% of the dissolved solids compared to 93%–96% TSS rejection achieved via single stage technique.
- COD and surfactant rejection achieved were approximately 6%–8% greater (at 97% and 92%–93%, respectively) using the dual technology compared with the single-stage one.
- The effluent quality provided from both processes was found to be compliant with both the Italian and Chinese guidelines relating to wastewater reuse for laundering.
- Flux ranges of 29–42 and 72–100 LMH were obtained for the 5 and 75 kDa UF membranes respectively challenged with raw laundry effluent, with 27–54 LMH determined or the 400 Da NF membrane challenged with pre-filtered water. The values were somewhat lower than those previously reported in the literature.
- % COD rejection and membrane flux for the 5kDa UF membrane were found to be more sensitive to changes in temperature in the range 25°C–45°C than to changes in both pressure and crossflow rate within the ranges of 2.5–7.5 bar and 1–5 L/min respectively. % rejection of COD was reduced by 7% (from 91%) when the temperature was increased from 25°C to 45°C.

While the study indicates that the water is appropriate for reuse according to the available guidelines, actual reuse of the water for laundering operations is likely to be susceptible to temperature changes.

References

[1] M.A. Darwish, R. Mohtar, Qatar water challenges, Desal. Wat. Treat., 51 (2012) 75–86.

[2] Ministry of Development Planning and Statistics, State of Qatar (http://www.mdps.gov.qa/en/statistics1/StatisticsSite/Pages/Population.aspx) (Accessed on October 2015).

[3] E. Eriksson, K. Auffarth, M. Henze, A. Ledin, Characteristics of grey water, Urban Water, 4 (2002) 85–104.

[4] B. Jefferson, A. Laine, S. Parsons, T. Stephenson, S. Judd, Technologies for domestic wastewater recycling, Urban Water, 1 (1999) 285–292.

[5] P. Verlicchi, A. Galletti, M. Petrovic, D. Barcelo, Hospital effluents as a source of emerging pollutants: an overview of micropollutants and sustainable treatment options, J. Hydrol., 389 (2010) 416–428.

[6] D.G.J. Larsson, C. Pedro, N. Paxeus, Effluent from drug manufactures contains extremely high levels of pharmaceuticals, J. Hazard. Mater., 148 (2007) 751–755.

[7] C. Santos, F. Taveira-Pinto, C.Y. Cheng, D. Leite, Development of an experimental system for greywater reuse, Desalination, 28 (2012) 301–305.

[8] C. Boillot, Y. Perrodin, Joint-action ecotoxicity of binary mixtures of glutaraldehyde and surfactants used in hospitals: use of the Toxicity Index model and Isoblogram representation, Ecotoxicol. Environ. Safe, 71 (2008) 252–259.

[9] L.T. Kist, C. Albrecht, E.L. Machado, Hospital laundry wastewater disinfection with catalytic photoozonation, Clean Soil Air Water, 36 (2008) 775–780.

[10] C.A. Lutterbeck, E.L. Machado, R.O. Schwaickhardt, A. Straatmann, D.I. Kern, F.V. Zerwes, Electro-oxidation combined with ozonation in hospital laundry effluents treatment, Clean Soil Air Water, 42 (2012) 601–608.

[11] D.I. Kern, R.O. Schwaickhardt, C.A. Lutterbeck, L.T. Kist, E.A. Alcayaga, E.L. Machado, Ecotoxicological and genotoxic assessment of hospital laundry wastewaters, Arch. Environ. Contam. Toxicol., 68 (2015) 64–73.

[12] P. Verlicchi, A. Galletti, M. Aukidy, Hospital Wastewaters: Quali-Quantitative Characterization and for Strategies for their Treatment and Disposal; Chapter 8; Wastewater Reuse and Management, Springer, Dordrecht, 2012.

[13] E. Nolde, Greywater reuse systems for toilet flushing in multistory buildings — over ten years' experience in Berlin, Urban Water, 1 (1999) 275–84.

[14] V. Lazarova, S. Hills, R. Birks, Using recycled water for nonpotable, urban uses: a review with particular reference to toilet flushing, Water Sci. Technol., 3 (2003) 69–77.

[15] R. Birks, J. Colbourne, S. Hills, R. Hobson, Microbiological water quality in a large in-building, water recycling facility, Water Sci. Technol., 50 (2004) 165–172.

[16] J. Ahmad, H. El-Dessouky, Design of a modified low cost treatment system for the recycling and reuse of laundry waste water, Resour. Conserv. Recycl., 52 (2008) 973–978.

[17] L. Abu Ghunmi, G. Zeeman, M. Fayyad, J.B. van Lier, Grey water treatment systems: a review, Crit. Rev. Environ. Sci. Technol., 41 (2011) 657–698.

[18] M. Ernst, A. Sperlich, X. Zheng, Y. Gan, J. Hu, X. Zhao, J. Wang, M. Jekel, An integrated wastewater treatment and reuse concept for the Olympic Park, Beijing, Desalination, 202 (2007) 293–301.

[19] I. Ciabatti, F. Cesaro, L. Faralli, E. Fatarella, F. Tognotti, Demonstration of a treatment system for purification and reuse of laundry wastewater, Desalination, 245 (2009) 451–459.

[20] J. Benner, D.E. Helbling, H.P.E. Kohler, J. Wittebol, E. Kaiser, C. Prasse, N. Boon, Is biological treatment a viable alternative for micropollutant removal in drinking water treatment processes? Water Res., 47 (2013) 5955–5976.

[21] M.C. Almeida, D. Butler, E. Friedler, At-source domestic wastewater quality, Urban Water, 1 (1999) 49–55.

[22] G. Ramon, M. Green, R. Semiat, C. Dosoretz, Low strength greywater characterization and treatment by direct membrane filtration, Desalination, 170 (2004) 241–250.

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

[24] N. Funamizu, Y. Kikyo, Direct Filtration of Wastewater from Washing Machine, Proc. Advanced Sanitation Conference, Aachen, Germany, 2007.

[25] J. Guilbaud, J.A. Masse, Y. Andres, F. Combe, P. Jaouen, Laundry water recycling in ship by direct nanofiltration with tubular membranes, Resour. Conserv. Recycl., 55 (2010) 148–154.

[26] H. Choi, K. Zhang, D.D. Dionysiou, D.B. Oerther, G.A. Sorial, Influence of cross-flow velocity on membrane performance during filtration of biological suspension, J. Membr. Sci., 248 (2005) 189–199.

[27] S. Sostar-Turk, I. Petrinic, M. Simonic, Laundry wastewater treatment using coagulation and membrane filtration, Resour. Conserv. Recycl., 44 (2005) 185–196.

[28] A. Alpatova, E.S. Kim, S. Dong, N. Sun, P. Chelme-Ayala, M.G. El-Din, Treatment of oil sands process-affected water with ceramic ultrafiltration membrane: effects of operating conditions on membrane performance, Sep. Purif. Technol., 122 (2014) 170–182.

[29] J. Xu, C.Y. Chang, C. Gao, Performance of a ceramic ultrafiltration membrane system in pretreatment to seawater desalination, Sep. Purif. Technol., 75 (2010) 165–173.

[30] I. Koyuncu, D. Topacik, Effects of operating conditions on the salt rejection of nanofiltration membranes in reactive dye/salt mixtures, Sep. Purif. Technol., 33 (2003) 283–294.
[31] J.M. Arsuaga, M.J. López-Muñoz, J. Aguado, A. Sotto, Temperature, pH and concentration effects on retention and transport of organic pollutants across thin-film composite nanofiltration membranes, Desalination, 221 (2008) 253–258.
[32] N. Ben Amar, H. Saidani, A. Deratani, J. Palmeri, Effect of temperature on the transport of water and neutral solutes across nanofiltration membranes, Langmuir, 23 (2007) 2937.
[33] H.Q. Dang, W.E. Price, L.D. Nghiem, The effects of feed solution temperature on pore size and trace organic contaminant rejection by the nanofiltration membrane NF270, Sep. Purif. Technol., 125 (2014) 43–51.
[34] J.M. Arsuaga, M.J. López-Muñoz, J. Aguado, A. Sotto, Temperature, pH and concentration effects on retention and transport of organic pollutants across thin-film composite nanofiltration membranes, Desalination, 221 (2008) 253–258.