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Treatment of spent filter backwash water from drinking water treatment with immersed ultrafiltration membranes

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ABSTRACT

The purpose of this study was to investigate characteristics of treatment of spent filter backwash water (SFBW) from two full-scale drinking water treatment plants (WTPs) with immersed ultrafiltration membranes in order to achieve reuse of permeate. During this study, 10% of daily generated SFBW from the treatment plants in Croatia were treated on two pilot-scale UF plants. Three different types of immersed membranes were employed and operated with fluxes, which ranged from 10 to 54 L/m^2 h in two continuous experiments, which lasted 75 and 96 days. During both experiments, transmembrane pressure, flux, and turbidity of filtrate were constantly measured. Rate of membrane fouling was very slow, and no chemical cleaning was needed but the membranes were regularly relaxed. Turbidity of permeate was always below 0.5 NTU. Results confirmed that permeate could be reused either for backwashing of sand filters, or as a source of raw water for drinking water treatment process.

Keywords: Ultrafiltration; Water reuse; Spent filter backwash water; Drinking water

1. Introduction

At the present time, almost all drinking water must undergo some kind of treatment, so that it could be used as safe drinking water for customers. Most of the drinking water treatment plants (WTP) use conventional methods in water treatment like oxidation, coagulation, flocculation, sedimentation, and sand filtration. During this process, a great amount of wastewater is produced, mainly from washing sand filters. It is estimated that almost 2–10% of all drinking water produced by conventional WTP is used for backwashing sand filters. Consequently, today this amount of processed drinking water becomes spent filter backwash water (SFBW), and it represents an extremely expensive cost. Generated SFBW represents a great cost in two points of view; firstly, because of

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sanitary regulations, for washing sand filters, drinking water is used, and secondly, generated SFBW is usually discharged into receiving waters or the public sewage system. Because of these issues, a lot of conventional WTP are considering new methods in treating SFBW.

Depending on raw water quality and implemented process technology, generated SFBW can be contaminated with *Giardia*, *Cryptosporidium*, precursors for disinfection by-products and heavy metals. This excludes direct recycling of SFBW to influent stream of WTP [1,2]. To eliminate this obstacle, membrane filtration can provide a safe and cost-effective method in treating SFBW, mainly because membrane filtration can remove present pathogens and suspended solids [3]. Use of microfiltration (MF) and ultrafiltration (UF) membranes in drinking and wastewater treatment is widely used. In the drinking water treatment process, low-pressure-driven MF and UF are used for removing pathogens and turbidity [3], immersed vacuum-driven MF and UF are generally used for wastewater treatment coupled with biological treatment [4]. Additionally, immersed vacuum-driven membranes are showing promising results in drinking water treatment operating under high fluxes with low observed fouling rates [5,6]. Furthermore, during biological wastewater treatment one of the main causes of membrane fouling is Extracellular Polymeric Substances (EPS) from activated sludge [7], which would be avoided in treatment of SFBW, because this treatment is based on physical separation. Selection of vacuum-driven membranes over the low-pressure can be attributed to its lower power consumption and easier concentrate disposal, because concentrate loaded with suspended solids is retained in filtration tank and can be discharged or disposed when preferred concentration of total suspended solids (TSS) is reached.

In this work, we have investigated a potential use of different immersed UF membranes in treatment of SFBW. Two pilot-scale UF plans were tested in two WTP in Croatia that use coagulation and rapid sand filtration for removal of turbidity. In order to determine potential reuse of generated SFBW after the treatment with three different immersed UF membranes, special emphasis of this pilot testing was set on membrane performance operated under different fluxes and on constantly monitored turbidity of the permeate.

Table 1
Average SFBW characteristics of two drinking WTP in Croatia

	Sv. Ivan WTP (SFBW 1)	Gradole WTP (SFBW 2)
Temperature (°C)	14–17	14–17
pH	7.38	7.26
Conductivity (μS/cm)	441	500
Total hardness (mg $CaCO_3$/L)	197	270
Alkalinity (mg $CaCO_3$/L)	188	240
Turbidity (NTU)	>200	>200
TOC (mg/L)	2.85	10.24
TSS (mg/L)	428	114.7
TS (g/L)	0.61	0.3652
TVS (g/L)	0.09	0.0616
TIS (g/L)	0.52	0.3036
Langelier saturation index (LSI)	−0.196 to −0.137	−0.152 to −0.093

2. Methodology

Two pilot plans with immersed UF membranes were set up in two major drinking WTP at spring Sv. Ivan near the city of Buzet and at the source Gradole, both located in Istria peninsula in northern Croatia. The Sv. Ivan WTP and the Gradole WTP produce nearly 25,000 and 95,000 m^3/d of drinking water, respectively, using a conventional process of coagulation, sedimentation and rapid sand filtration. Both WTPs use polyaluminium chloride as a coagulant for

Table 2
The physical characteristics of membrane modules

	MEM 1	MEM 2	MEM 3
Model	BIO-CEL®-BC-10-10	Memos® ME-P 540 × 200	Memos® ME-P550-12
Type	Flat sheet	Tubular	Tubular
Material	Polyethersulfone	Polyethylene	Polyethylene
Nominal pore size (μm)	0.04	0.05	0.05
Membrane area per module (m^2)	10	18	41
Total membrane area (m^2)	10	72	246

Table 3
Operation phases of membrane filtration during both pilot studies

		Phase	Filtration period (day)	Flux (L/m^2 h)
PILOT 1	MEM 1	I	3	54
		II	17	25–29
		III	9	40
		IV	6	30
	MEM 2	V	15	13
		VI	25	17–19
PILOT 2	MEM 3	VII	86	10–17
		VIII	10	29–31

removal of turbidity from underground water. During the water treatment process Sv. Ivan WTP and Gradole WTP generate approximately 300 and 1,000 m^3/d of SFBW, respectively, which are presently discharged into natural water recipients without any treatment. Characteristics of both SFBW are presented in Table 1.

First pilot plant (PILOT 1) was set up at Sv. Ivan WTP in September 2010 (Table 2). Two types of immersed UF membranes systems were tested, BIO-CEL® BC-10-10 (MEM 1) was operated with fluxes ranging from 25 to 54 L/m^2 h and Memos® ME-P550-12 (MEM 2) which operated with fluxes ranging from 13 to 19 L/m^2 h. (Table 3). UF membranes were placed in 2-m^3 filtration vessel, where SFBW 1 was pumped from discharge canal with a pump operating with a maximal flow rate of 2 m^3/h. During the pilot testing, turbidity of permeate, transmembrane pressure (TMP) and permeate flow were constantly monitored, and data were collected automatically on PC. Aeration used for membranes scourging and for mixing of the filtration vessel was constant at 42 m^3/h. Relaxation of the membranes was regularly conducted every 10 min of operation for 60 s and no backwashing was employed. In addition, no chemical cleaning of membranes was performed during the pilot testing. In PILOT 1, two different types of membranes were operated under six different fluxes (six phases) for total duration of 75 days. Detailed operation schedule is presented in Table 3.

Second pilot plant (PILOT 2) with an immersed UF membrane system was set up in Gradole WTP in March 2011 (Table 2). Used UF membrane was Memos® ME-P550-12 (MEM 3) which operated with fluxes ranging from 10 to 31 L/m^2 h (Table 3). Approximately, 10% of daily generated SFBW 2 was collected in 70 m^3 tank, from where it was pumped into 20-m^3 filtration vessel where UF membranes were placed. Membranes were aerated with air flow of 90 m^3/h, which were also used for mixing. During the pilot testing, turbidity of permeate, TMP, and permeate flow were constantly monitored, and data were collected on PC. In addition, membranes were only relaxed 60 s every 10 min without any chemical cleaning or backwashing during the entire experiment. In PILOT 2, only one type of membranes was used, and it operated under two different fluxes (two phases), in total 96 days (Table 3). During both pilot studies, concentrate from the filtration vessel was constantly discharged from the filtration tank to maintain desired TSS concentration.

The membrane filtration characteristics were monitored and determined by measuring and storing the TMP and the corresponding permeate flow rate every minute on PC. Results of TMP and permeate flow rate were then regularly downloaded from PC via internet connection and from the results, TMP and flux were expressed as daily average values. Membrane permeability was calculated from daily average values of TMP and membrane flux.

Besides continuously recorded membrane filtration performance (TMP, turbidity, flux) samples of influent SFBW, concentrate and permeate were regularly taken and analyzed for pH, conductivity, TSS, volatile suspended solids (VSS), inorganic suspended solids (ISS), and total organic carbon (TOC) which was determined on Shimadzu TOC Analyzer 5000A. Particle size distribution of SFBW was also performed using laser diffraction device Shimadzu SALD-3,101 (WingSALD II: Version 2.1.0) whose measuring range was from 0.5 to 3,000 μm. Analyses were performed according to Standard methods.

3. Results and discussion

3.1. Characteristics of SFBWs and TSS in membrane filtration vessels

Particle size distribution of both SFBWs is presented in Fig. 1. From the results presented in Table 1, it can be seen that both SFBWs have elevated turbidity, TSS and TOC. In addition, both SFBWs had rela-

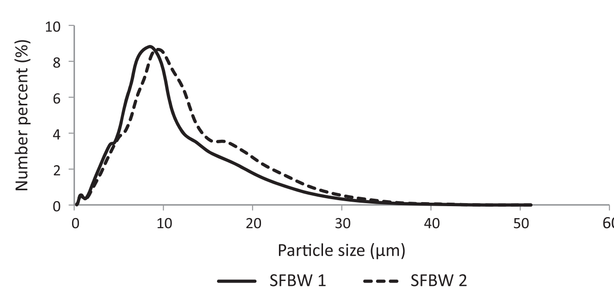

Fig. 1. Particle size distribution in SFBWs.

tively low dissolved salts concentrations, and the calculated LSI values indicated low propensity for scale precipitation and consequent fouling of immersed membranes during filtration. From Fig. 1, it can be seen that particles in SFBW ranged from 0.3–41 μm for SFBW 1 and 0.26–36.8 μm for SFBW 2. Particle size distributions for both SFBWs were similar, and close to 50% of particles were smaller than 9.6 and 8 μm for SFBW 1 and 2, respectively. In addition, 90% of all particles in both SFBWs were smaller than 18 and 16 μm and almost 10% of particles were smaller than 2.9 and 2.6 μm in both SFBW. From obtained results, it can be concluded that majority of particles ranged approximately 8–10 μm. Qi et al. [8] investigated reuse of alum sludge integrated with UF filtration in treating raw river water reporting similar particle size distribution for reused aluminum sludge before UF filtration. From obtained results in our study, particles in SFBW were generally larger than nominal pore size of all used membranes indicating successful removal of TSS by filtration.

During filtration of SFBW in both pilot plants, concentrate from the filtration vessel were constantly discharged and TSS for PILOT 1 and PILOT 2 ranged between 0.284–2.484 and 0.365–1.753 g/L, respectively (Fig. 2). In Fig. 2, it can be seen that TSS was composed of approximately 90% inorganic matter and 10% organic matter. That composition allows a landfill disposal of the sludge after appropriate dewatering, or use as a raw material for brick production, due to its low organic matter content.

3.2. Permeate characteristics in both pilot studies

During both pilot studies, permeate characteristics were measured periodically and they are presented in Table 4. Permeate pH value for PILOT 1 and PILOT 2 ranged from 7–7.9 and did not differ from the inlet SFBW, while conductivity varied slightly from SFBW,

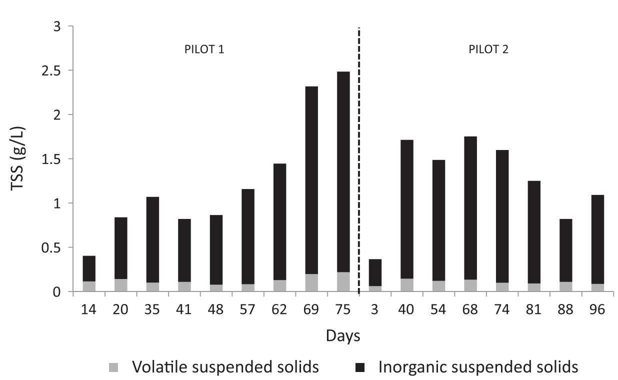

Fig. 2. TSS, VSS and ISS in the filtration vessels.

Table 4
Permeate characteristics of both pilot studies

		Day	pH	χ (μS/cm)	TOC (mg/L)	TSS (mg/L)
PILOT 1	MEM 1	14	7.6	519	2.684	nd
		20	7.41	470	2.515	nd
		35	7.89	308	3.685	nd
	MEM 2	41	7.49	249	2.726	nd
		48	7.81	374	3.723	3
		57	7.1	357	0.97	nd
		62	7.75	378	0.83	nd
		69	7.08	376	0.539	nd
		75	7.01	430	0.884	nd
PILOT 2	MEM 3	3	7.18	503	0.15	nd
		40	7.57	341	0.3	nd
		54	7.89	292	0.08	nd
		68	7.9	314	0.672	nd
		74	7.87	391	0.435	nd
		81	7.86	418	0.432	nd
		88	7.49	270	0.511	nd
		96	7.21	373	0.89	nd

nd – not detected.

which could be attributed to pronounced variation in composition of the feed water of both WTP which is here represented only by average value of SFBW. Furthermore, during both pilot studies, TOC concentration in permeate was relatively low (below 1 mg/L), and the only higher results were observed in phases I–V, ranging from 2.515 to 3.723 mg/L. These elevated results in TOC were attributed to problems with permeate pipe at PILOT 1, which was transparent and therefore, causing an occurrence of algae biomass in the permeate stream. The transparent pipe was replaced during phase VI. In addition, during this period TSS concentration also increased to 3 mg/L due to the algae growth, but after replacement of permeate pipe, it was not detected. The findings of the current study are consistent with those of Reissmann and Uhl [2] who additionally reported significantly lower concentrations of metals and microbial content in permeate from treating SFBW with UF membrane than the corresponding drinking water standards.

Turbidity of permeate was constantly monitored and collected, and the results of the measurements are presented in Fig. 3. During both pilot studies, turbidity was below 0.5 NTU, but better results were achieved during second pilot testing, where turbidity was always below 0.15 NTU. This difference in turbidity of permeates between two pilot studies was caused by already mentioned problems with algae growth in

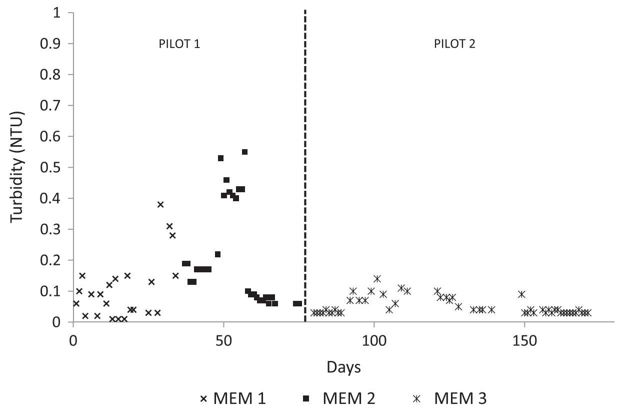

Fig. 3. Turbidity of permeate during both pilot studies.

PILOT 1 during phases I–V. Furthermore, after replacement of transparent pipe of permeate, drastic decrease in turbidity from 0.55 to 0.06 NTU and TOC from 3.726 to 0.97 mg/L in permeate can be noticed after 56th day of operation (phase VI). Similar results in turbidity removal was reported in work Qi et al. [8] where they achieved 99% removal using only UF filtration or combination of UF with aluminum sludge and powdered activated carbon in treating river water.

3.3. Membrane filtration performance

For the first pilot plant (PILOT 1) experiment lasted 75 days. During the experiment, two types of UF immersed membranes were tested (Table 3). First membrane (MEM 1) was tested for 35 days in four different phases (I–IV) that differed in the permeate flux (Fig. 4). During this period of operation, TMP was influenced by the flux changes, but there was no significant increase of TMP during any of the phases when the flux was kept constant. In the first phase, membrane flux was 54 L/m^2 h and membrane permeability ranged from 270 to 260 L/m^2 h bar. First phase was relatively short because of permeate pump problems, and when the pump was changed only smaller flux could be achieved during phases II–VI. During testing in phases II–VI, various fluxes were tested which ranged from 25 to 40 L/m^2 h for a different duration and no relevant TMP decrease was observed. In the longest phase (phase II) that lasted for 17 days, TMP decreased from −0.1 to −0.12 bar and membrane permeability changed from 290 to 250 L/m^2 h bar and again, no significant fouling was observed. Similar fluxes were used in the phases II and IV, and again, there were no significant differences in TMP and the permeability of membrane between those two phases.

In phases V and VI, MEM 2 was used for 40 days operating under two different fluxes (Fig. 4) that were smaller than fluxes used in phases I–IV. Phase V lasted 15 days and during this period TMP decreased from −0.38 to −0.45 bar and membrane permeability ranged from 30 to 36 L/m^2 h bar. The phase VI lasted 25 days and no significant TMP and permeability decrease were observed, with TMP ranged from −0.5 to −0.54 bar and permeability of membrane ranged from 33 to 37 L/m^2 h bar.

For the second pilot plant (PILOT 2), only one membrane type (MEM 3) was tested in two phases (VII and VIII) for total duration of 96 days (Fig. 5). In phase VII, membrane was operated under lower fluxes that ranged from 10 to 17 L/m^2 h. During this time, no significant membrane fouling was observed. TMP ranged from -0.2 to -0.28 bar and membrane permeability ranged from 69 to 40 L/m^2 h bar. Because of lower operating fluxes during phase VII, and no significant membrane fouling, higher fluxes were employed for duration of 10 days in the phase VIII. During this phase,

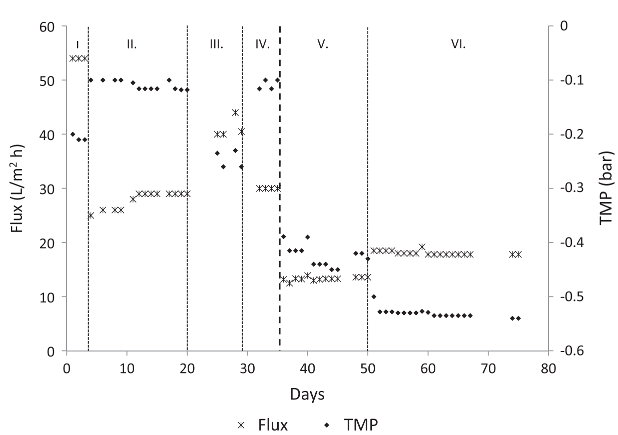

Fig. 4. Filtration characteristics of MEM 1 (phases I to IV) and MEM 2 (phases V and VI) in PILOT 1.

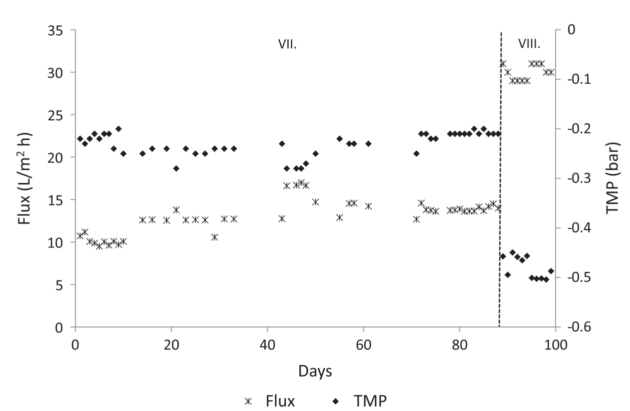

Fig. 5. Filtration characteristics of MEM 3 (phases VII and VIII) in PILOT 2.

fluxes ranged from 29 to 31 L/m^2 h and as it was mentioned before, no chemical cleaning of membranes was performed. These higher fluxes were achieved by switching off three membrane modules of total of six modules that were used in phase VII to achieve higher fluxes with same permeate flow. TMP during phase VIII ranged from −0.45 to −0.5 bar and membrane permeability ranged from 67 to 61 L/m^2 h bar. Again, although higher fluxes were used, no significant change of TMP and permeability was observed.

Based on similar results from all three UF membranes filtration behavior, namely low or negligible membrane fouling and taking into account the particle size distribution in SFBW with majority of particles in SFBW much larger than nominal pore size, it can be concluded that all observed fouling of the UF membranes can be attributed to blocking of pores and filtration cake formation on the surface of the membranes that both could be easily removed by air scourging. This is in agreement with previous results reported by Huang et al. [1] who calculated various resistances to filtration in a coagulation/filtration process. They suggested that cake resistance (due to filtration cake formation) represent an important role in membrane filtration coupled with coagulation, and if the majority of particles are larger than a nominal size of membrane, then pore blocking is negligible. Furthermore, in our experiment, TSS that had relatively low concentration in filtration vessel and did not exceed 2.484 and 1.753 g/L for PILOT 1 and 2, respectively, with small organic matter content (less than 10% of TSS) could not significantly foul the membranes. These results are consistent with those of Reissmann and Uhl [2] who reported that filtration treatment of SFBW with TSS ranging from 2 to 3 g/L (maximum 6 g/L) in the filtration vessel during long-term experiment operated with constant flux of 42 L/m^2 h did not significantly reduced membrane permeability. In addition, they reported continuous TMP increase when concentrate from the filtration vessel was not constantly removed.

Since both SFBWs in our experiment had low alkalinity and were stable toward scaling based on LSI calculation, it could be assumed that scale precipitation on the membrane surface was negligible. Consequently, irreversible fouling was not noticed. Major type of membrane fouling in our experiments, therefore, was reversible fouling, which needed no chemical cleaning throughout the filtration but only relaxation of membranes during which the cake layer would came off the membrane surface. In addition, although all used membranes can be backwashed, relaxation has proven as a sufficient and reliable method for fouling prevention.

4. Conclusions

All three different types of immersed UF membranes used for treatment of SFBW, in two filtration pilot plants tested in two WTP in Croatia achieved permeate quality based on measurement of turbidity, suspended solids and TOC that corresponded with drinking water limits. As a result, permeate could be reused either as water for washing the sand filters, or it could be return as a feed to drinking water treatment process. In addition, it is possible to landfill the concentrated sludge from the filtration vessel after appropriate dewatering, or used it for brick production. All the membranes were able to operate under different fluxes for a prolonged period without noticeable fouling and no need of chemical cleaning.

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References

[1] C. Huang, J.-L. Lin, W.-S. Lee, J.R. Pan, B. Zhao, Effect of coagulation mechanism on membrane permeability in coagulation-assisted microfiltration for spent filter backwash water recycling, Colloids Surf. A Physicochem. Eng. Asp. 378 (2011) 72–78.

[2] F.G. Reissmann, W. Uhl, Ultrafiltration for the reuse of spent filter backwash water from drinking water treatment, Desalination 198 (2006) 225–235.

[3] W.Q. Betancourt, J.B. Rose, Drinking water treatment processes for removal of Cryptosporidium and Giardia, Vet. Parasitol. 126 (2004) 219–234.

[4] S. Judd, The MBR Book: Principles and Applications of Membrane Bioreactors in Water and Wastewater Treatment, Elsevier Science, Oxford, 2006.

[5] P. Côté, D. Mourato, C. Güngerich, J. Russell, E. Houghton, Immersed membrane filtration for the production of drinking water: Case studies, Desalination 117 (1998) 181–188.

[6] P. Choksuchart, M. Héran, A. Grasmick, Ultrafiltration enhanced by coagulation in an immersed membrane system, Desalination 145 (2002) 265–272.

[7] P. Le-Clech, V. Chen, T.A.G. Fane, Fouling in membrane bioreactors used in wastewater treatment, J. Membr. Sci. 284 (2006) 17–53.

[8] L. Qi, H. Liang, Y. Wang, G.-b. Li, Integration of immersed membrane ultrafiltration with the reuse of PAC and alum sludge (RPAS) process for drinking water treatment, Desalination 249 (2009) 440–444.