Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2018.22600

128 (2018) 89–95
October

The application of membrane filtration for recovery of water from filtration bed backwashing stream

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Received 7 April 2018; Accepted 29 May 2018

ABSTRACT

The objective of the article is to evaluate the transport and separation abilities of membranes in a multistage systems for treatment of washings from swimming pool flushing. The studied system was a two-stage ultrafiltration process (UF I–UF II), in which membranes with different the molecular weight cutoff equal to 200 and 30 kDa were used, followed by nanofiltration (NF) process (150–300 Da). Washings were taken from a children's and a adults pool circuits. The process of UF I enabled a significant decrease of the studied parameters and a reduction of transport of pollutants to the membrane used in UF II. The turbidity of the permeate from UF II did not exceed 0.45 NTU and the concentration of total organic carbon was in the range of 1.64–2.69 mg C/L. In order to prevent elevated concentrations of harmful low-molecular-weight organic compounds in closed water circuits, it was justified to use a third treatment stage in the form of a NF process. The high separation ability of the studied NF membranes made it possible to reduce the turbidity of the washings below 0.10 NTU. The treated flux could be safely returned to the pool.

Keywords: Swimming pool water; Wastewater treatment; Ultrafiltration; Nanofiltration; Water recovery

1. Introduction

Pool water is a complex system, the quality and composition of which depend on a number of factors. Introduction and circulation of pollutants in pool water circuits start at the supply of mains water, which contains natural inorganic and organic compounds as well as disinfection by-products [1,2]. However, the main source of pollution is associated with the use of pools. Organic matter, proteins, mineral compounds, and micropollutants come mostly from urine, sweat, epidermis, and hair residues [3–5]. The increased reactivity of those compounds in contact with disinfecting agents contributes to the formation of numerous disinfection by-products [1,4].

The water treatment technologies commonly used in pool facilities include the process of filtration on beds. Such filtration is conducted in one- and multilayer systems, whereas the most common form of implementation of the process consists of single- or multilayer pressure sand, carbon, or sand and carbon filters. The process of filtration on beds in pool water treatment circuits is usually associated with the process of contact coagulation. However, the effectiveness of the coagulation process in removal of micropollutants (especially the small-molecular-weight ones) is low, in the range of 10%–20% [6–8]. Additionally, in many swimming pool facilities, water treatment systems still use single-layer sand filtration beds, which do not ensure complete elimination of pathogens [9,10]. Improvement of the effectiveness of the filtration bed may be achieved by using an additional sorption layer, for example, activated carbon. Depending on the type of micropollutant, the removal efficiency can be at the level of 20%–85% [11].

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Presented at the XII Scientific Conference "Membranes and Membrane Processes in Environmental Protection" – MEMPEP 2018 13–16 June 2018, Zakopane, Poland.

1944-3994/1944-3986

Regardless of the type of the filtration bed used in the facility, each requires regular cleaning (flushing). Water is continuously filtered on the filtration bed until the pressure drop reaches 3 m of water. In order to meet the physicochemical and sanitary requirements on water quality, the filtration bed flushing process must be performed once per every 2–3 d. In order to perform the filtration bed flushing process, 4–6 m^3 of water (taken from an overflow tank) is required for every m^2 of the filtration bed [12]. This process generates a large volume of wastewater, which is usually drained to the sanitary sewer system. The high costs of water intake and wastewater drainage force operators of swimming pool facilities to look for savings and the washings are considered to be their most probable source [13,14].

Due to the wide spectrum of pollutants present in washings, that is, residues of postcoagulation suspensions, disinfection by-products, and pathogens, it is necessary to use multistage processes that enable safe reuse of the washings in the circuit without any threats or risks to swimming pool users. A possible alternative to classic water treatment systems are pressure driven membrane processes, which reveal high efficiency in elimination of all common washings contaminants [15–18].

The use of integrated membrane processes, which include ultrafiltration as a process of preliminary treatment, and nanofiltration (NF), as a highly efficient method of removal of ca. precursors of disinfection by-products, may be a solution enabling a reduction of the quantity of washings and prevention of water losses in swimming pool circuits [19,20].

The objective of the article is to evaluate the transport and separation abilities of membranes in a multistage systems for treatment of washings from a swimming pool water system with regard to the ability to reuse them to refill losses in the swimming pool water circuit. The studied parameters included the volumetric and relative permeate fluxes and pollutants retention coefficients (turbidity, concentration of total organic carbon (TOC), and absorbance in ultraviolet light UVA254). The applied system comprised of a two-stage ultrafiltration process using membranes with different capacity to pollutants separation (the molecular weight cut-off MWCO of the membranes was 200 and 30 kDa) and NF process (MWCO = 150–300 Da). For the comparison purposes, washings from two circuits – a children's pool and a regular swimming pool – were used.

2. Materials and methods

An integral element of the conventional treatment circuits of the examined washings is multilayer pressure filters with an activated carbon layer, with diameters of 1,800 mm and heights of 1,500 mm. The filtration surface area is equal to 2.54 m^2. Water is filtered in the filters at the rate of 30 m/h (the output of a single circuit is equal to 153 m^3/h). The washings were sampled in batches in the course of flushing of the filtration beds through the discharge valves draining the washings into a channel and then a sanitary sewer system. Flushing of filtration beds (with air and water) is usually performed every 48 h. Water for the flushing of the filtration beds is taken from overflow tanks. After each flushing, the tanks are filled with water from the municipal water mains. The amount of washings produced in the process each month is estimated to be 365 m^3 per filter. Knowing the quantity of the washings and the costs associated with their discharge into the sewer system, it is reasonable to make an attempt to treat the washings to an extent that would enable their reuse to make up for losses in the circuits.

2.1. Membrane filtration methodology

Flat ultrafiltration and NF membranes with different physicochemical parameters were used in the tests. Flat ultrafiltration membranes with a polyvinylidene difluoride coat (Synder Filtration, Vacaville, USA) and MWCO equal to 200 and 30 kDa were characterized by their manufacturer as resistant to fouling and useful even in treatment of industrial wastewater. NF membranes (GE Osmonics, Kent, USA) with the capacity to remove particles with molecular weight above 300 Da were used mostly to remove uncharged organic particles and, depending on the composition of the feed, of multi- and bi-valent ions. They are recommended by the manufacturer ca. for reduction of trihalomethanes in water. The characteristics of the membranes and the basic operating parameters of the filtration processes are presented in Table 1.

The treatment processes were conducted in a multistage UF I – UF II – NF system, in accordance with the block diagram shown in Fig. 1, independently for washings from the children's pool and the swimming pool. The membranes were placed in a steel filtration cell of the volume of 3.80×10^{-4} m^3, where the active surface of the membrane was equal to 38.5×10^{-4} m^2. Before the filtration started, every new membrane was conditioned by filtering deionized water in order to stabilize the volumetric permeate flux. The processes were performed in a dead-end filtration layout for collection of 50% of the feed volume. Then the membranes were rinsed with water (in the same flow direction as during the filtration) with deionized water in order to document the presence of harmful phenomena accompanying membrane filtration. The process of filtration of a half volume of the feed with flushing constituted one filtration cycle. Within one treatment stage (UF or NF), filtration cycles were performed consecutively, without changing the membrane.

In accordance with the filtration procedure presented herein, the UF I process comprised of 12 filtration cycles (total duration of approximately 11 h). The duration of the second treatment stage was approximately 4 h (six filtration cycles). On the other hand, the NF process comprised of four filtration cycles, duration of which was approximately 6 h. This allowed to achieve a sufficient volume of permeates for effectiveness evaluation of the filtration processes and to use them as feed for further treatment stages.

In order to evaluate the transport properties of the membranes in the multistage system, the volumetric flow rate of deionized water, J_w (aiming at conditioning of the membranes with water), and of permeate, J_v (for the proper filtration process), were determined using the following formula:

$$J_{w/v} = \frac{V}{F \cdot t}, \frac{m^3}{m^2 \cdot s}$$

where V – volume of water or permeate, m^3; F – active surface area of the membrane, m^2; and t – filtration time, s.

Table 1
Characteristics of membranes and the operating parameters of the process

Process	Membrane symbol	Membrane material	Molecular weight cutoff (Da)	Process pressure (MPa)	Volumetric flow rate of deionized water J_w^a (10^5 m^3/m^2 s)	Permeate recovery rate (%)
UF	YMV53001 YMV33001	Polyvinylidene difluoride (PVDF)	200,000 30,000	0.2	1.80 ÷ 2.13 1.73 ÷ 2.18	50
NF	YMHLSP3001	Polyamide-TFC	150–300	1.0	1.93 ÷ 1.96	

[a]Tested independently for each filtration cycle.

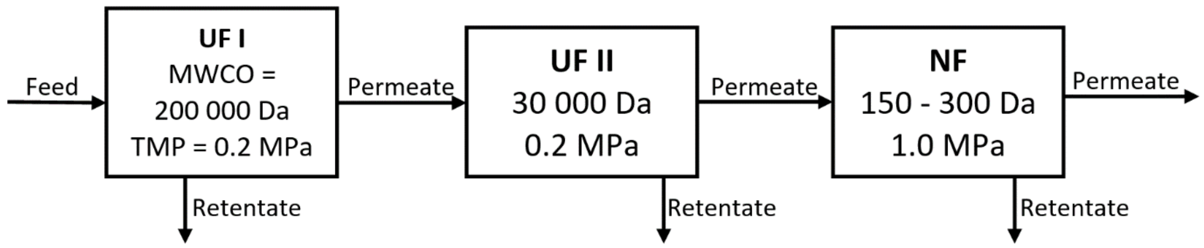

Fig. 1. The diagram of the studied multistage system with the values of the molecular weight cutoff of the membranes (MWCO) and the *trans*-membrane pressure of the processes.

In order to evaluate the separation properties of the membranes, the retention coefficient (*R*), value of which was determined basing on a reduction of the selected pollutant indicators, namely turbidity, concentration of TOC, and the level of the absorbance in ultraviolet light:

$$R = \left(1 - \frac{c_p}{c_n}\right) \times 100$$

where c_p – concentration (indicator value) of pollutants in the permeate; c_n – concentration (indicator value) of pollutants in the feed.

Moreover, the reduction of the hydraulic performance of the membrane was determined by the use of an intermediate parameter – the relative volumetric permeate flux (α), that is, the quotient of the fluxes determined during washings treatment to deionized water flux (membrane conditioning process). This parameter is a measure of the disadvantageous phenomena accompanying membrane filtration. It defines the rate of pollution of the surface of the membrane with organic and/or inorganic substances [21].

2.2. Analysis of physicochemical parameters

The conductivity, the redox potential, and the pH of the raw washings samples were measured with the inoLab® 740 (WTW, Measuring and Analytical Technical Equipment, Wroclaw, Poland) multiparameter meter. Absorbance in ultraviolet light, at the wavelength of 254 nm, was measured using the UV VIS Cecil 1000 by Analytik Jena AG (Jena, DE), with the optical path length of the cuvette equal to 1 cm. The turbidity of the samples was determined using the EUTECH Instruments TN-100 turbidimeter, Warsaw, Poland. The chlorine concentration was measured by in situ the calorimetric method using the portable Hach® Pocket Colorimeter™ II device, Wroclaw, Poland. The concentration of total nitrogen, ammoniacal nitrogen, nitrate nitrogen, total phosphorus, aluminum, sulfides, sulfates, and the value of the phenol index, the concentration of absorbable halogenated organic substances, and chemical oxygen demand were determined using the photometric methods in cuvette tests using the VIS Spectroquant® Pharo 300 UV spectrophotometer (Merck, Warsaw, Poland). The TOC was determined using the TOC-L series analyzer with the method of catalytic oxidation by combustion at the temperature of 680°C (Shimadzu, Columbia, USA). The specific ultraviolet absorbance SUVA254 value was determined as the ratio of UVA254 to dissolved organic carbon values [22]. The permeates obtained in the membrane filtration processes were analyzed toward the turbidity, the TOC concentration, and the specific absorbance in ultraviolet. SUVA254 values for equalized permeates were also determined. The characteristics of the studied raw washings are presented in Table 2. Considering that the operator of the facility outsources monthly inspections of selected physicochemical parameters to an accredited laboratory, the analysis also covered the average concentration of the sum of trihalomethanes and chloroform (in the period, in which the authors of the article took samples for the study). The obtained values were compared with the standards on pool and potable water quality (which are significantly more stringent in requirements) [23,24].

3. Results and discussion

3.1. Evaluation of the physicochemical quality of raw washings

The concentration of washings produced as a result of flushing of filtration beds in pool water treatment systems is the basic criterion for their management or reuse in the circuit. The studied washings were characterized most of all by the presence of a large quantity of sludge that is hard to settle. The value of turbidity for the sample taken from the

Table 2
Physicochemical parameters of the studied washings

Indicator	Value in the circulation washings		Limit value acc. [23]	Limit value acc. [24]
	Children's pool	Swimming pool		
pH	7.20	6.85	6.5–9.5	6.5–7.6
Conductivity (μS/cm)	966.80	1,102.00	2,500	–
Redox (mV)	429.00	286.00	–	–
Turbidity (NTU)	10.64	35.75	1	0.30
Absorbance UVA254 (filtered samples[a]) (m^{-1})	5.40	12.60	–	–
Absorbance UVA254 (unfiltered samples) (m^{-1})	8.20	16.90	–	–
Free chlorine (mg Cl_2/L)	0.28	0.42	0.30	–
Combined chlorine (mg Cl_2/L)	0.41	0.54	0.50	0.20
Potassium (mg K/L)	4.10	4.80	–	–
Nitrates (mg NO_3^- /L[b])	2.80	3.50	–	20
Ammonium nitrogen (mg N-NH_4/L)	0.20	0.20	0.50	–
Total nitrogen (mg N/L)	8.00	8.20	–	–
Sulfides (mg S^{2-}/L)	0.10	0.10	–	–
Sulfur (mg SO_4^{2-} /L)	98.00	96.00	250	–
Cyanuric acid (mg $C_3H_3N_3O_3$/L)	4.00	4.10	–	–
Chlorides (mg Cl^-/L)	264.70	288.48	250	–
Aluminum (mg Al/L)	0.70	0.71	0.20	–
Phenol index (mg C_6H_6O/L)	0.42	0.48	–	–
Total hardness (mg $CaCO_3$/L)	91	90	60–500	–
Chemical oxygen demand (mg COD/L[c])	< 15.00	25.00	–	–
Total organic carbon (mg C/L)	5.95	8.15	No invalid changes	–
Dissolved organic carbon (mg C/L)	4.64	7.25	–	–
Total carbon (mg C/L)	10.76	15.54	–	–
Specific ultraviolet absorbance SUVA254 (m^3/g C m)	1.16	1.74	–	–
Adsorbable organic halogens (mg Cl/L)	2.17	2.92	–	–
Trichloromethane (∑THM)[d] (mg/L)	0.056	0.063	0.1	0.1
Chloroform[d] (mg/L)	0.056	0.063	0.03	0.03

[a]Filtered through a 0.45 μm membrane filter; [b]Method DIN 38405-9 with 2,6-dimethylphenol (DMP); [c]According to ISO 15705 method with potassium dichromate; [d]Average values from tests commissioned by the object.

children's pool circuit was equal to over 10 NTU and that for the sample taken from the swimming pool – to over 35 NTU. Moreover, the washings taken from the swimming pool filter circuit were characterized by a concentration of free and bound chlorine that was higher than the permitted values [23,24]. The values of the specific ultraviolet absorbance SUVA254 parameter were below 2 m^3/g C m, which proves the superiority of low-molecular-weight, nonhumic, and hydrophilic substances [22]. Also, increased concentration of chlorides and aluminum after the surface coagulation process was observed. The excessive values of those parameters that were observed do not enable reuse of the washings in the pool water circuit without their prior treatment.

3.2. Evaluation of the transport and separation abilities of membranes in the multistage system

Figs. 2–7 show the values of the volumetric permeate fluxes and of the pollutant retention coefficient at the different stages of the system. The changes that took place in the complete filtration cycles, including membrane flushing, were taken into account.

In the first ultrafiltration process, clear differences were observed in the transport abilities of the membranes depending on the filtered washing type (Fig. 2). In the case of filtration of the washings coming from the children's pool, the initial value of J_v was 1.99 × 10^{-5} m^3/m^2 s. In the initial four filtration cycles, the process of flushing with deionized water restored the effectiveness of the membrane. However, as the process became longer, the value of the volumetric permeate flux was gradually reduced and further flushing of the membrane did not restore the original value of J_w. The value of the relative volumetric permeate flux for the YMV53001 membrane in during filtration of the washings from the children's pool circuit changed from 0.94 (in the first minutes of the process) to 0.60 (in the 11th hour of the process). In an analogous process performed for the washings taken from the swimming pool circuit, the initial value of J_v was lower

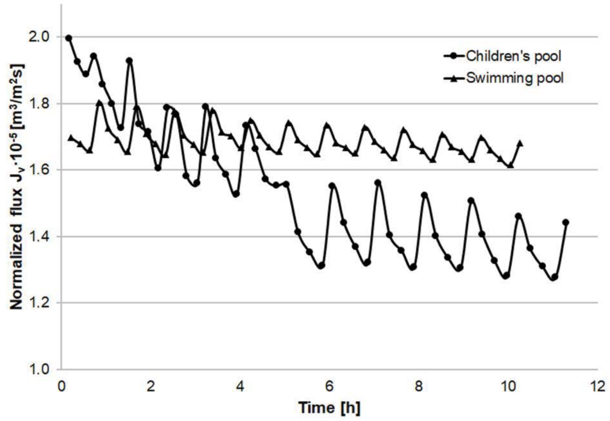

Fig. 2. A comparison of the transport characteristics of YMV53001 membranes (MWCO = 200 kDa; TMP = 0.2 MPa) in the process of ultrafiltration (UF I) of the washings.

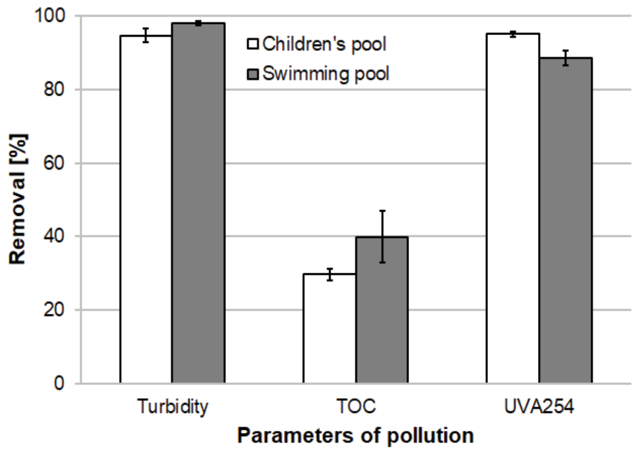

Fig. 3. Separation capacity (the indicator of pollutant reduction) of the YMV53001 membranes (MWCO = 200 kDa) in the process of ultrafiltration (UF I) of the washings.

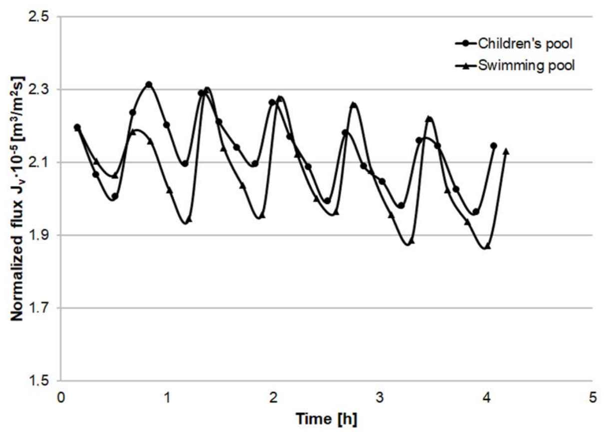

Fig. 4. A comparison of the transport characteristics of YMV33001 membranes (MWCO = 30 kDa; TMP = 0.2 MPa) in the process of ultrafiltration (UF II) of the washings.

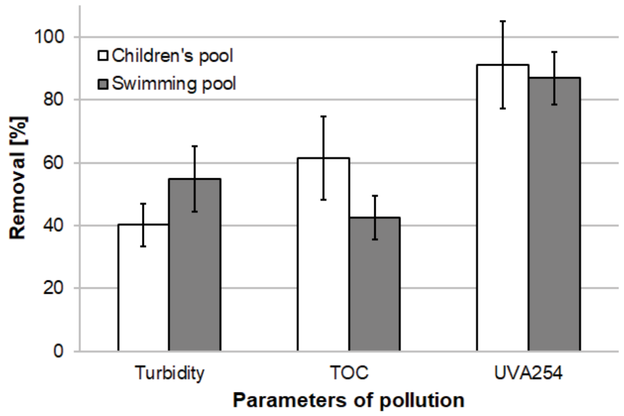

Fig. 5. Comparison of the separation capacities of YMV33001 membranes (MWCO = 30 kDa) in the process of ultrafiltration (UF II) of washings.

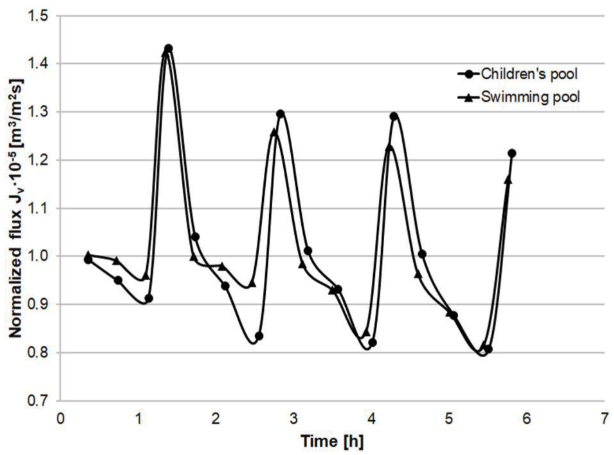

Fig. 6. The comparison of the transport capacity of the YMHLSP3001 membrane (MWCO = 150–300 Da; TMP = 1 MPa) during nanofiltration of washings.

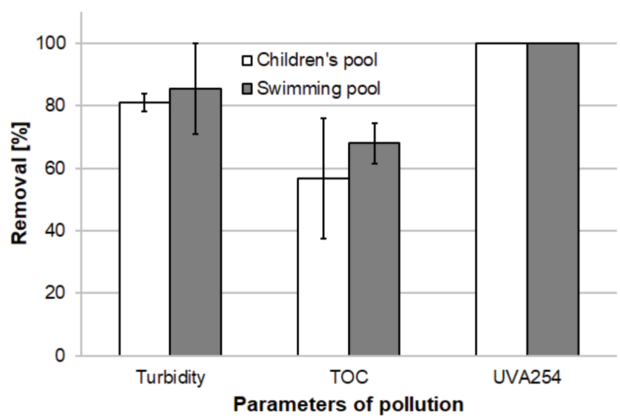

Fig. 7. The comparison of the separation capacities of YMHLSP3001 membranes (MWCO = 150–300 Da) in the process of nanofiltration of washings.

and equal to 1.70 × 10^{-5} m^3/m^2 s. The final value of the volumetric permeate flux was equal to 1.62 × 10^{-5} m^3/m^2 s. The relative volumetric permeate flux for the UF membrane in this series was in the range of 0.80–0.76.

The analyzed washings had different impact on the transport capacity of the UF membrane used in the first stage (type YMV53001). The washings from the swimming pool circuit, which were more turbid, demonstrated smaller affinity to block the pores of the membrane and to reduce its transport characteristics. Probably particles larger than the pores of the membrane did not penetrate into the structure of the membrane and did not block it but, instead, formed a layer on the surface of the membrane, which could be removed in during the flushing process [25–27]. It can be concluded that the intended use of the basin had a significant impact on the distribution of pollutants in the pool water circuit, including solids (suspensions).

Fig. 3 shows the average values of the pollution indicators reduction for all cycles of UF I. Slightly higher efficiency in reduction of turbidity was observed in the process of filtration of washings from the swimming pool circuit (97.14%–98.70%). In both cases, the average turbidity was below 1 NTU [23]; in the case of the washings from the swimming pool circuit it was equal to 0.76 NTU and in the case of the washings from the children's pool – 0.56 NTU. However, the reduction of the value of absorbance was higher in ultrafiltration of the washings from the children's pool, this reduction coefficient was in the range of 93.90%–96.46% (the average value was 0.40 m^{-1}). Much better reduction levels were observed in the case of concentration of TOC; in both cases the average concentration in the permeates was equal to approximately 4 mg C/L. Due to the significant reduction of the UVA254 value and the concentration of carbon compounds, there was a significant decrease in SUVA254 (approximately 0.11 m^3/g C m). At subsequent stages (UF II, NF), this value was 0 m^3/g C m. The use of the YMV53001 membrane with MCWO equal to 200 kDa as the first treatment stage enabled to remove a significant part of colloidal particles and suspended solids. The process allowed for a significant reduction of the levels of the studied parameters and an elimination of pollutants fed to the membrane used in UF II, which could significantly reduce its transport capacity.

The membrane used in the second ultrafiltration stage (type YMV33001) demonstrated higher values of the volumetric permeate flux during the treatment of the studied washings compared with the membrane used in the first ultrafiltration stage (YMV53001) (Fig. 4). Moreover, the values in both processes, according to the washing type, were similar. In the case of the washings from the children's pool and from the swimming pool, they were in the ranges of 2.19 ÷ 1.96 × 10^{-5} and 2.19 ÷ 1.87 × 10^{-5} m^3/m^2 s, respectively. The process of flushing with deionized water brought good results and enabled effective restoration of the initial transport characteristics. Moreover, the relative volumetric permeate flux was in the range of 1.10–0.99 in the case of the washings from the children's pool circuit and in the range of 1.01–0.86 in the case of the washings from the swimming pool circuit.

Moreover, the membrane used in UF II enabled to reduce the concentration of TOC by ca. 60% (with the average value in the permeate equal to 1.64 mg C/L) in the case of washings from the children's pool circuit. In the case of the washings from the swimming pool, the reduction was equal to approximately 40% (with the average value in the permeate equal to 2.89 mg C/L) (Fig. 5). The turbidity of the treated washings was reduced by 40% and 55%, respectively, in the washings from the children's pool circuit and in the washings from the swimming pool circuit (below 0.45 NTU). The value of absorbance in ultraviolet UVA254 in the permeates from both processes was below 0.30 m^{-1}.

The washings treated in the ultrafiltration processes were of good quality and, considering the analyzed parameters, could partially be added to the pool water circuit. Their addition would not result in a significant deterioration of the quality of water in the circuit. However, one must point at the need of aluminum removal, concentration of which could not be reduced in the ultrafiltration processes, and at the presence of fine particle compounds that constitute by-products of disinfection [28–30]. In order to prevent increased concentrations of harmful compounds in closed water circuits, it was justified to use a third treatment stage in the form of a NF process.

Due to the ultrafiltration processes, washings that initially had different values of physicochemical parameters (especially those related to turbidity) acquired similar characteristics that had comparable impact on the transport capacity of the NF membrane (YMHLSP3001) used in the third filtration stage (Fig. 6). The values of volumetric permeate flux for the washings from the children's pool circuit were in the range of 0.99–0.81 × 10^{-5} m^3/m^2 s, with the corresponding values of the relative flux in the range of 0.51–0.42. On the other hand, the values of the volumetric permeate flux for the swimming pool circuit were in the range of 1.00–0.82 × 10^{-5} m^3/m^2 s.

Fig. 7 shows the separation capacities of the studied NF membranes that enabled reduction of the value of absorbance in ultraviolet to 0 m^{-1} and reduction of turbidity of the washings to below 0.10 NTU. The concentration of TOC was also significantly lowered, the average values for the final permeates were below 0.10 mg C/L.

4. Conclusions

The article presents the high effectiveness of an integrated membrane system comprising of two stages of ultrafiltration combined with NF:

- The first ultrafiltration stage enabled to remove particles with molecular weights higher than 200 kDa. This resulted in a significant reduction of colloidal particles and suspended solids, a reduction of turbidity of the washings, and a reduction of their impact on the transport capacity of the ultrafiltration membrane in the second filtration stage.
- In the UF II process, the part of the pollutants, apparent molecular weight of which was in the range of 200–30 kDa was removed. This process clearly contributed to the reduction of the concentration of TOC in the permeate.
- The NF process was necessary in order to remove fine organic substances that could contribute to elevated concentrations of ca. by-products of disinfection in pool water circuits.

- This type of an integrated system guaranteed a quality of treated washings that enabled their recirculation to the circuit (at the overflow tank stage).
- In studies on the possibility to use washings from swimming pool facilities, one must always consider the size of the facility, its function (water park, recreational pool, sport pool, swimming lessons pool, etc.), the water treatment technology used, the type of filters and filtration beds, the duration of filtration cycles, and the daily and hourly load at the facility resulting of the number of swimming pool users.

Acknowledgment

The study was conducted within the department research grant for young scientists (BKM-554/RIE-4/17) "Extended Physicochemical Evaluation of Swimming Pool Water."

Symbols

V	—	Volume of water or permeate, m^3
F	—	Active surface area of the membrane, m^2
t	—	Filtration time, s
$J_{w/v}$	—	Volumetric flow rate of permeate, m^3/m^2 s
R	—	Retention coefficient, %
c_p	—	Concentration (indicator value) of pollutants in the permeate flux, –
c_n	—	Concentration (indicator value) of pollutants in the feed, –
α	—	Relative volumetric permeate flux, –

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