# Assessment of the possibility of using flocculation to improve properties of ultrafiltration membranes used in the purification of swimming pool water system washings

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**Abstract.** The paper presents the possibility of using an in-line mode flocculation–ultrafiltration system for the purification of backwash water from flushing the beds of pressure filters used in the indoor swimming pool water treatment circulation. The effect of flocculation operational conditions (the flocculant dose in the range from 16 to 240 mg/dm$^3$ and the process temperature of 8–30°C) on the transport-separation properties of ultrafiltration membranes has been examined. To establish the effectiveness of the conducted processes, the contaminant retention coefficients, among others, were determined (based on the measurements of turbidity and UV254 ultraviolet absorbance). A significant influence of the flocculation process operational parameters on the performance of ultrafiltration was noted. With increasing flocculant dose, the efficiency of contaminant removal in the ultrafiltration process increased simultaneously. Moreover, the change in the temperature conditions of the flocculation process had a fundamental effect on the transport properties of the ultrafiltration membranes. The most advantageous temperature for conducting the processes was considered to be 21°C. Under those conditions, all flocculant doses contributed to a significant improvement in the transport properties of the ultrafiltration membranes. High values of the contamination retention coefficients and the permeate volumetric flux were obtained already at a flocculant dose of 80,160 and 240 mg/dm$^3$.

## 1 Introduction

The filtration process constitutes a basic element of water treatment systems in swimming pool facilities. During the flow of water through the bed, contaminant particles are retained in pores, which results in an increase in hydraulic losses. To prevent the bed breakthrough phenomenon and the contaminants passing on to the treated water, it is necessary to conduct bed washing with the reverse water and/or air stream at the

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appropriate frequency. In order to conduct the process in a correct manner, it is necessary to use 4–6 $m^3$ of water per each $m^2$, as a result of which a waste water stream, called backwash water, is formed. In the facility examined within the present study, the swimming pool circulation includes two 1800 mm-diameter filters which are washed every 48 hours, which generates a monthly water consumption from 245 to 365 $m^3$. The backwash water is discharged directly to the sewage system, which involves both wastage and high water drawing and waste water discharge costs [1–5]. Tests on the use of membrane pressure ultrafiltration for backwash water purification are being presently conducted [7]. It has been determined, though, that the chemical compounds and suspension present in the backwash water intensify membrane pore clogging. Hence, methods for supporting these processes are being searched for, which will increase the magnitude of the permeate volumetric flux, while maintaining the high separation abilities of the membranes.

The present investigation comprised the exploration of the possibility of using flocculation as an operation aiding the membrane ultrafiltration process. The purification system operated in an in-line batch mode, whereby the flocculant was introduced directly to the filtration cell. During the tests, an attempt was made to establish the operational parameters of the flocculation process (the flocculant dose and the process temperature), which contribute to an improvement in membrane transport–separation conditions, such as the permeate volumetric flow and the contaminant retention coefficient.

# 2 Materials and test methods

## 2.1 Characterization of backwash water tested

Backwash water used in the tests was a stream of waste water from washing multi-layered pressure filters constituting an element of an indoor swimming pool water treatment system. The facility under investigation is characterized by a high load with bathers, being the place of swimming lessons taken by children and young people of nearby schools and a form of recreation for adult city dwellers. A mixture of backwash water originating from the swimming pool circulation and a hot tub was used in the tests. The basic physicochemical parameters of the backwash water are given in Table 1.

**Table 1.** The physicochemical parameters of the backwash water.

| Parameter | Unit | Value |
|---|---|---|
| Reaction (pH) | - | 7.14 |
| Conductivity (PWC) | µS/cm | 960.00 |
| Turbidity | NTU | 26.60 |
| Colour ($C_{Pt}$) | mgPt-Co/l | 306.00 |
| Ultraviolet absorbance (UV254) | $m^{-1}$ | 23.50 |

## 2.2 Analytical procedures

The quality assessment of the test backwash water before and after the purification processes was made based on selected physicochemical properties. The measurement of the conductivity (PWC) and reaction (pH) of tested samples was done with an inoLab® 740 multi-parameter meter (WTW, Measuring and Analytical Technical Equipment). The ultraviolet absorbance at a wavelength of 254 nm was measured using a UV VIS Cecil 1000 supplied by Analytik Jena AG, with a cuvette optical pathlength of 1 cm. The $UV_{254}$ value was determined based on the measurement method presented by US EPA [6], and the final analysis result was expressed in $m^{-1}$. For the determination of the turbidity of samples, an EUTECH Instruments Turbidimeter, Model TN-100, was employed. The measurement of the colour was performed using a UV VIS Spectroquant® Pharo 300 spectrophotometer (Merck) using a wavelength of 340 nm.

### 2.3 Operational parameters of the purification process in the in-line flocculation–ultrafiltration system

For carrying out backwash water flocculation, a product under the commercial name of Flockfix (supplied by Chemoform AG), being a solution of dialuminium pentahydroxychloride, commonly used in swimming pool facilities, was used. The colourless liquid was characterized by density at a level of 1.024 $g/cm^3$ and active substance concentration in the range from 2.5% to 10%, as stated by the manufacturer. To assess the effectiveness of a single flocculation operation within preliminary testing, typical beaker tests were performed, which included: A one-minute fast mixing process (at 250 rpm), followed by 25 minutes' flocculation at a mixer rotational speed of 20 rpm conducted in a four-stand laboratory coagulator (Velp Scientifica). The process was conducted at different backwash water temperatures, namely 8, 21 and 30°C, for each of the assumed doses. The temperature conditions were assumed based the considered backwash water storage variants – in an external tank in spring–summer conditions or in a decanter located in the swimming pool understructure (21°C), in an external tank in winter conditions (8°C) and in a flow-through tank with the filtration process being conducted directly after washing the filters (30°C). Directly after the process of flocculation started the membrane filtration.

The tests of the in-line mode flocculation–membrane ultrafiltration process involved the determination of the relationship between the conditions of the conducted flocculation process and the transport–separation properties of the ultrafiltration membranes in a wide range of flocculant doses (16, 80, 160, 240 $mg/dm^3$) and the above-mentioned temperatures. In this process, the flocculant was fed directly to the membrane cell which, at the same time, played the role of a reaction chamber. Filtration was started after the fast mixing and flocculation processes.

For membrane filtration, an ultrafiltration membrane with the symbol MW supplied by GE Osmonics Inc. (USA), whose characteristics, along with the operational parameters of the ultrafiltration process, are given in Table 2.

**Table 2.** Characteristics of the ultrafiltration membrane and the operational parameters of the process.

| **Membrane-forming material** | **Cut-off molar mass, Da** | **Membrane active filtration surface area, $m^2$** | **Trans-membrane process pressure, MPa** | **Deionized water permeate volumetric flux, $Jw \cdot 10^{-5}$, $m^3/m^2s$** |
|---|---|---|---|---|
| Polyacrylonitrile | 50000 | 0.00385 | 0.2 | 2.60 |

The membrane was placed in a 380 $cm^3$ steel filtration cell equipped with a magnetic stirrer. Before starting filtration, the new membrane was conditioned by filtrating deionized water until the permeate volumetric flux stabilized. The proper filtration process was conducted in a dead-end unidirectional filtration system until the 50% of the feed volume was received. At the same time, selected physicochemical parameters were verified in successively received 25 $cm^3$-volume permeates and the magnitudes of the permeate volumetric flux were determined. Six measurements were taken at each cycle. After each cycle comprising the filtration of the post-flocculation solution under specified conditions, the membrane was washed with deionized water. This was aimed at removing any residues of the suspension deposited on the membrane surface. After that stage, the permeate volumetric flux was determined again for deionized water, which was used for determining the degree of membrane pore clogging.

### 2.4 Parameters of the assessment of the ultrafiltration membrane transport–separation properties

The assessment of the transport properties of membranes in filtration processes was made based on the volumetric flux of deionized water, $J_v$ (during conditioning the membrane with water), and the permeate, $J_w$ (the proper filtration process), from the following equation:

$$J_w = \frac{v}{F \cdot t}, \frac{m^3}{m^2 \cdot s} \tag{1}$$

where: V - volume of water of permeate, $m^3$; F- membrane active surface area, $m^2$; t - filtration time, s.
To assess the separation properties of membranes, the retention (R) was determined, whose value was determined based on the reduction in the values of respective contamination indices:

$$R = \left(1 - \frac{c_p}{c_n}\right), \% \tag{2}$$

where: $c_p$ - concentration (index value) of contaminants in the permeate stream, $c_n$ - concentration (index value) of contaminants in the feed.

The intensity of the reduction in membrane transport abilities (membrane pore clogging degree) was determined by calculating the value of the relative permeate volumetric flux:

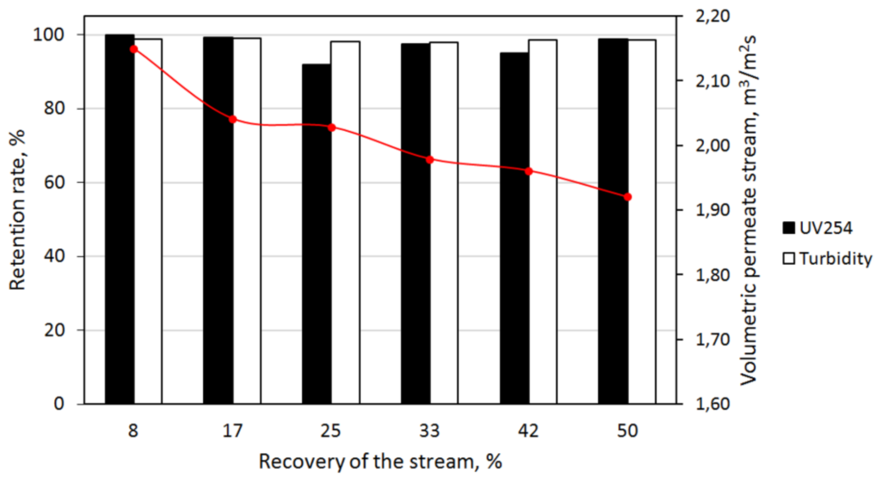
$$\alpha = \frac{J_w}{J_v} \tag{3}$$

where: $J_w$ – value of the permeate volumetric flux at the sixth measurement point, $m^3/m^2 \cdot s$; $J_v$ – value of the deionized water volumetric flux, $m^3/m^2 \cdot s$.

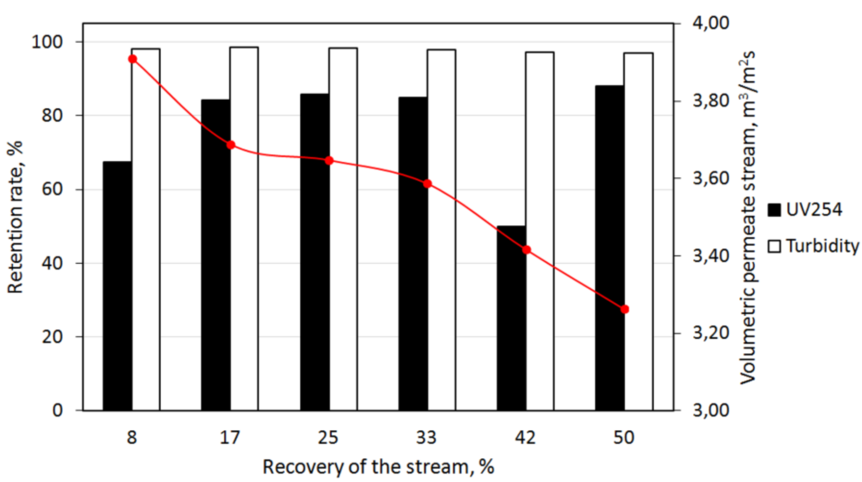
## 3 Test results

Figure 1 shows the transport–separation characteristics of membranes for the processes of filtering, respectively, raw backwash water and backwash water subjected to flocculation at a temperature of 21°C with a flocculant dose of 6, 160 and 240 $mg/dm^3$. A significant influence of the flocculation process operational parameters on the performance of ultrafiltration was noted. During the filtration of raw backwash water (with no flocculant), the average relative permeate volumetric flux was 0.74, which indicates a reduction in membrane efficiency by 26%. Whereas, the values of the contaminant retention coefficients, as determined by the measurement of turbidity or UV254 ultraviolet absorbance, amounted to approx. 98% and approx. 97%, respectively. The obtained results confirm the high effectiveness of the ultrafiltration process in removing the suspension present in the backwash water tested and part of the contaminants determined by the UV254 ultraviolet absorbance measurements. These results also document the fact of the occurrence of the membrane pore clogging phenomenon that reduces the values of the permeate volumetric flux. In turn, with increasing flocculant dose, a distinct increase in contaminant retention degree value was observed. By contrast, the relative permeate volumetric flux decreased in those conditions. With the increase in flocculant dose from 16 to 240 mg/dm$^3$, the average relative permeability of the membrane decreased from 1.26 to 0.97. Under the temperature conditions tested, all of the applied flocculant doses increased the membrane transport conditions. Moreover, already a flocculant dose of 80 mg/dm$^3$ allowed higher contaminant retention coefficient values to be obtained, compared to the results of raw backwash water filtration.

a)




b)



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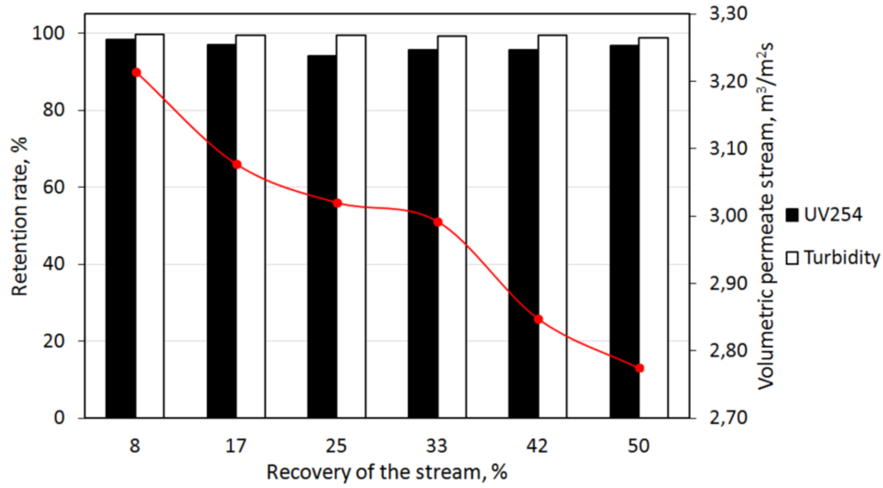
c)




d)

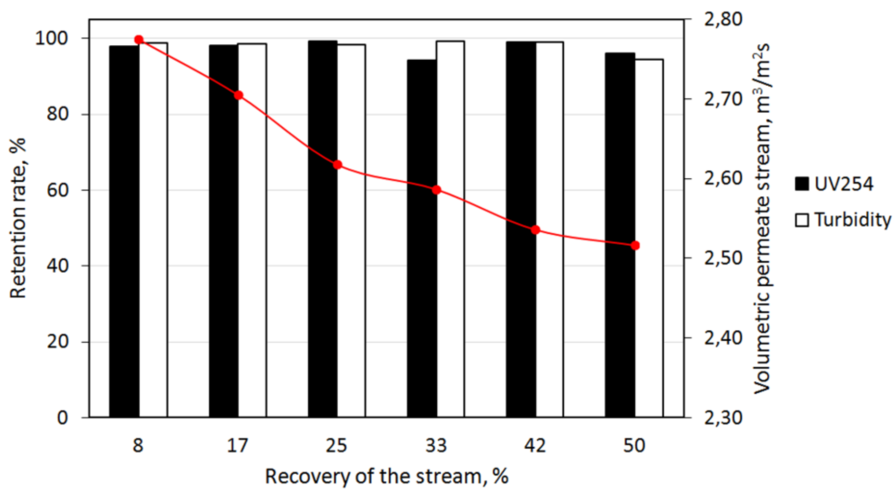



**Fig. 1.** The transport and separation properties of the ultrafiltration membrane during the filtration of a) raw backwash water, and backwash water with a flocculant dose of: b) 16 mg/dm$^3$ c) 160 mg/dm$^3$ d) 240 mg/dm$^3$, at a temperature of 21°C.

Figure 2 shows a comparison of the transport–separation abilities of the membrane for processes conducted at a temperature of 8 and 30°C with a flocculant dose of 16 mg/dm$^3$. Also for backwash water that underwent flocculation at temperatures of 8 and 30°C, an increase in the separation abilities of the ultrafiltration membrane was observed with increasing flocculant dose. Whereas, the values obtained at lower flocculant doses were higher for flocculation–ultrafiltration conducted at a lower temperature.

The change in the temperature conditions of the flocculation process had a fundamental effect on the transport properties of the ultrafiltration membrane. At a temperature of 8°C, an increase in the average relative permeate volumetric flux was noted only in the case of the filtration of backwash water with a flocculant dose of 160 mg/dm$^3$ ($\alpha$ = 0.76). In the remaining cases, the relative permeate volumetric flux value $\alpha$ was lower than that for the purification of raw backwash water. Furthermore, in spite of the high values of contamination retention coefficients for the flocculation–ultrafiltration process conducted at

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30°C with a flocculant dose of 160 and 240 mg/dm$^3$, much lower values of permeate volumetric fluxes were obtained (α at a level of approx. 0.50).

a)

b)

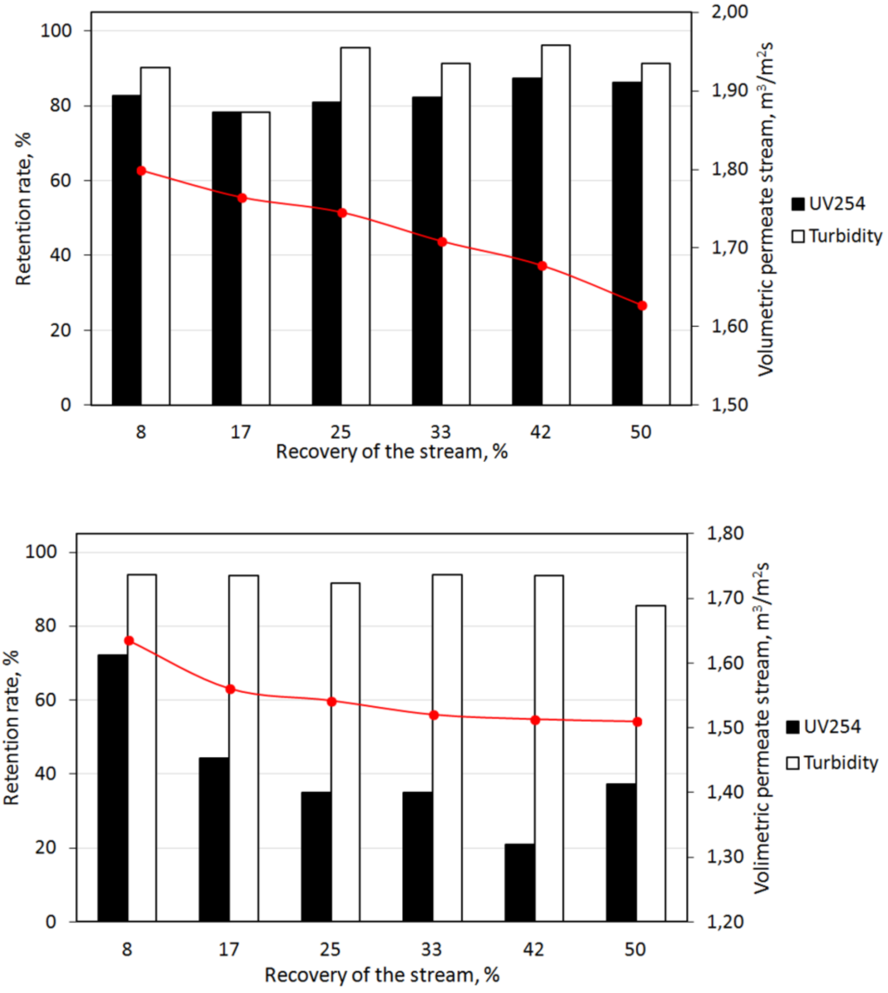


**Fig. 2.** The transport and separation properties of the ultrafiltration membrane – backwash water after flocculation with a flocculant dose of 16 mg/dm$^3$ at a process temperature of 8 (Fig. 2a) and 30°C (Fig 2b), respectively.

Among the presented backwash water purification systems, the most advantageous transport–separation conditions were shown by the variant with the flocculation process conducted at 21°C and with a flocculant dose of 80 mg/dm$^3$. Fig. 3 compares the effects of using the above-mentioned dose for three temperature variants.

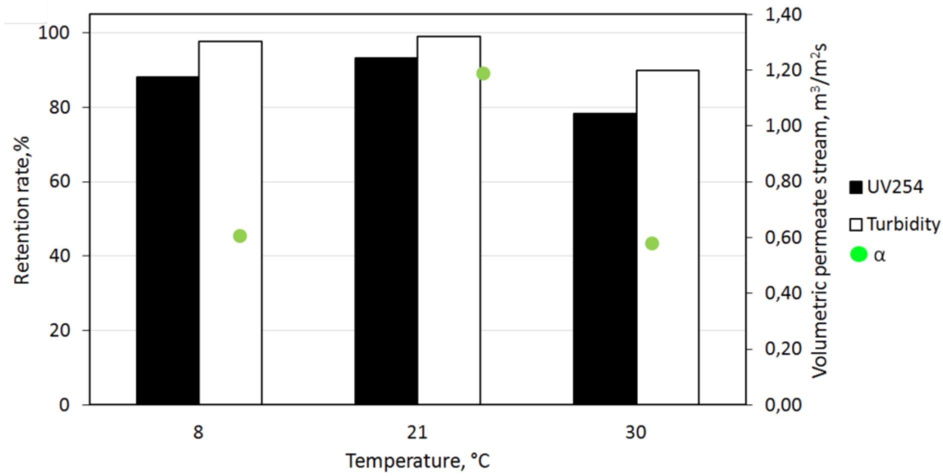


**Fig. 3.** The transport and separation properties of the ultrafiltration membrane – backwash water with 80 mg/dm$^3$ flocculant doses.

## 4 Summary

The investigation has confirmed the high effectiveness of pressure membrane systems in removing contaminations from backwash water coming from the swimming pool water circulation. The use of hybrid (flocculation–ultrafiltration) processes could improves the transport–separation properties of ultrafiltration membranes. The flocculation process has a particular importance in this case, as it increases the degree of removal of organic substances from the waste stream. It should be borne in mind, however, that the flocculant dose depend on the waste stream composition and concentration and on the nature of backwash water obtained in a given facility, including its physicochemical parameters. It is proposed that tests in a purification system with capillary immersed membranes should be carried out within further investigations on this subject.

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