DOI: 10.2428/ecea.2017.24(2)19 ECOL CHEM ENG A. 2017;24(2):227-236

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# SELECTION OF CONDITIONS OF WATER RECOVERY FROM THE STREAM OF WASHINGS FROM THE SWIMMING POOL WATER SYSTEM

## DOBÓR WARUNKÓW ODZYSKU WODY ZE STRUMIENIA POPŁUCZYN Z INSTALACJI WODY BASENOWEJ

**Abstract:** This study discusses the results of the preliminary tests use an integrated process coagulation-sedimentation-nanofiltration for the purification washings from swimming pool water treatment circulation. Studies included the effect of the terms and conditions of the preparatory process (coagulation where range of doses of coagulant 1.5–3.0 mgAl/dm$^3$ and sedimentation where the scope of duration 0.5–24 h) on the transport and separating properties nanofiltration membranes. Comparatively, the process of nanofiltration of raw washings has been performed. DK GE Osmonics membrane was used as a nanofiltration membrane.
A higher value of volumetric permeate flux was observed during the nanofiltration process for washings after coagulation process with dose 1.5 mgAl/dm$^3$. There has also been significant improvement in transport capacity of the membrane with increased sedimentation time (to 24 hours). The presence of sediment molecules, which contributed to the reduction of the process efficiency during filtration of washings after coagulation with dose 3.0 mgAl/dm$^3$, at the same time they caused a gradual increase in membrane separation capacity. A secondary membrane having a lower porosity than the primary membrane has been produced. The use of the integrated system has improved the transport conditions of the nanofiltration membranes, reduction of residual aluminium concentration, as well as significant improvements in other physicochemical parameters (inter alia reduction the amount of suspended solids and ultraviolet absorbance $UV_{254}$).

**Keywords:** integrated process, washings nanofiltration, coagulation, sedimentation, swimming pool water installation

## Introduction

Pressure membrane processes are differentiated in terms of substance separation mechanisms, thus allowing a separation of pollutants on a molecular level. Currently,

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they are widely used in both the ultra-clean water preparation processes, and to remove micropollutants from water streams [1–4]. The research conducted by the Authors of the paper [5, 6] on use of membrane techniques to remove pollutants from streams of washings removed from the swimming pool water filtration cleaning systems indicate a high effectiveness of such techniques. However, presence of a high amount of suspended solids in the washings significantly reduces the transport capacity of membranes as the membrane pores became blocked. Various variants of integrated systems have been considered that would allow minimizing the adverse effect of sludge during the membrane filtration and maintaining the high quality of received permeates.

The results of studies presented in this paper included the application of nanofiltration NF (main process) that would allow a high quality of cleaned washings and possibility of using them to make up for the losses in the swimming pool circuit. The nanofiltration membranes allow the total capture of particles of diameter 1 nm or greater, separation of ions with different valence, and elimination of disinfection by-products and their precursors present in swimming pool water, retention of coagulant residues, admixtures, residual aluminium, and microorganisms [1, 7–11]. The nanofiltration process is preceded by coagulation and sedimentation (preliminary processes) which aim at reducing the amount of suspended solids in the washings (turbidity), thus reducing some organic pollutants, and improving the transport capacity of membrane in comparison with nanofiltration as an individual process. The basic parameters of preliminary processes included the coagulant dose (1.5 or 3.0 $mgAl/dm^3$) and sedimentation time (from 0.5 to 24 hours).

## Materials and methodology of studies

### Physical and chemical analyses

Conductivity and pH of water samples was measured with the inoLab® 740 multi-parameter meter (WTW, Measurement and Analytical Equipment). Absorbance was measured using the UV VIS Cecil 1000 from Analytik Jena AG, at the cuvette optical path of 1 cm. The absorbance value at the 254 nm wavelength was determined using the method of absorbance measurement in $UV_{254}$ ultraviolet according to the standards accepted by US EPA [12]. The absorbance value in $UV_{254}$ is a substitute parameter for the analysis of total organic carbon (*TOC*), providing information about the potential to form disinfection by-products. It should be noted however that this measurement is not totally selective [13]. Concentrations of ammonia nitrogen and total phosphorus, the phenol index and the summary parameter of biological oxygen demand were determined using the UV VIS Spectroquant® Pharo 300 spectrophotometer (Merck) in standard cuvette tests. In addition, the colour and total suspended solids were measured using the photometric method on the UV VIS Spectroquant® Pharo 300 spectrophotometer (Merck). The samples turbidity was determined on the Turbidimeter TN-100 from EUTECH Instruments.

## Coagulation process methodology

The tested washings were coagulated (*Coag*) using polyaluminium chloride (*PAX* 16). The coagulant was added at doses (*DK*) 1.5 and 3.0 mgAl/dm$^3$. Standard beaker tests including fast mixing (1 minute) and flocculation (25 minutes) were performed to evaluate the process effectiveness and determine the coagulant dose. These tests were performed on a four-station laboratory coagulator (Velp Scientifica). Then, the sedimentation (*Sed*) process was performed for 0.5 to 24 h. The coagulation process was performed at the 7.8 ± 0.2 solution pH. The supernatant waster was decanted after sedimentation and transferred to the filtration cell in order to perform nanofiltration (*NF*).

## Nanofiltration methodology

Flat composite membranes DK from Osmonics Inc. (USA) were used in nanofiltration. The membrane skin layer is made of polyamide, and the molecular weight cut-off (*MWCO*) is from 200 to 400 Da. The membranes were placed in a 380 cm$^3$ steel filtration cell. The active membrane area was 38.5 cm$^2$. A new membrane was conditioned with deionized water before filtration in order to stabilize the volumetric permeate stream. The process was conducted in the unidirectional filtration system to receive 50% of the feed volume, at 2 MPa trans-membrane pressure ($\Delta P$).

In order to evaluate the membrane transport capacity, the equation (1) was used to determine volumetric flow of deionized water $J_w$ (membrane conditioning with water) and of permeate $J_v$ (proper filtration process):

$$J_v = \frac{v}{F \cdot t} \quad \left[\frac{\mathrm{m}^3}{\mathrm{m}^2 \cdot \mathrm{s}}\right] \tag{1}$$

where: $v$ – water or permeate volume [m$^3$];
$F$ – membrane active surface area [m$^2$];
$t$ – filtration time [s].

In order to evaluate the membrane separation capacity, the equation (2) was used to determine retention $R$ [–], which indicates the reduction of pollutants concentrations (indices):

$$R = \left(1 - \frac{c_p}{c_n}\right) \cdot 100\,[\%] \tag{2}$$

where: $c_p$ – concentration (index) of pollutants in the permeate stream;
$c_n$ – concentration (index) of pollutants in the feed.

### Integrated process methodology

The integrated process studies involved pre-cleaning of washings in coagulation and sedimentation (*Coag-Sed*), after which the nanofiltration was performed.

## Results of the studies

### Characteristics of the washings

The subject of the tests were samples of washings taken from water cleaning circuit at an indoor swimming pool. The washings were collected during the washing of sand-gravel beds of pressure filters which are the main components of swimming pool water treatment. The results of physical and chemical analysis are presented in Table 1.

Table 1

Physical and chemical parameters of raw washings

| Parameter | Unit | Value |
|---|---|---|
| pH | — | 7.28 |
| Electrical conductivity | μS/cm | 482.20 |
| Colour | $mgPt/dm^3$ | 24 |
| Turbidity | NTU | 19.24 |
| Absorbance in $UV_{254}$ | $m^{-1}$ | 14.00 |
| Total solids | $mg/dm^3$ | 84.00 |
| Total chlorine | $mgCl_2/dm^3$ | 0.82 |
| Total nitrogen | $mgN/dm^3$ | 11.50 |
| Total phosphorus | $mgP/dm^3$ | 0.60 |
| Ammonia nitrogen | $mgNH_4^+/dm^3$ | > 0.50 |
| Phenol index | $mgC_6H_5OH/dm^3$ | > 0.10 |
| Remaining aluminium | $mgAl/dm^3$ | 0.69 |
| Total hardness | $mgCaCO_3/dm^3$ | 136 |
| Chlorides | $mgCl^-/dm^3$ | 210 |
| Chemical Oxygen Demand COD | $mgO_2/dm^3$ | 101.00 |

The tested washings were characterized mainly by a high content of total solids with a poor sedimentation capacity. After three hours of sedimentation in the Imhoff cone the amount of sludge was 1.10 $cm^3$ and did not change until the completion of the sedimentation process (Fig. 1). The total solids content in the supernatant after sedimentation was 76 $mg/dm^3$. In addition, other parameters such as colour, turbidity, COD and remaining aluminium were also high The values of physical and chemical parameters of raw washings were evaluated in the context of municipal water [14] used to fill and replenish the swimming pool systems.

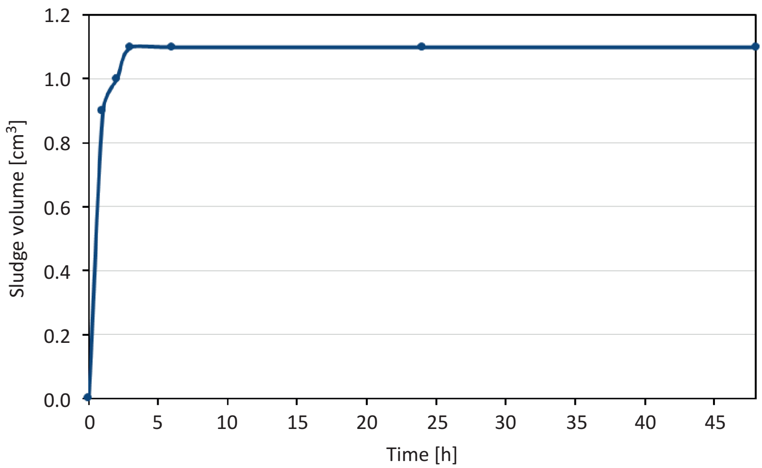


Fig. 1. Sedimentation capacity evaluation of tested washings

## Characteristics of the nanofiltration process of raw washings

The transport-separation properties of nanofiltration membranes in the individual process of filtration of raw washings were evaluated. Figure 2 presents the change of permeate volumetric flow during the process (total filtration time was 275 minutes). The membrane transport capacity worsened, and the reduction of the permeate volumetric flow $J_v$ was about 20% in comparison to the initial value. The process had a high capacity to remove pollutants. Figure 3 presents the range and the average values of pollutant retention for turbidity and absorbance in $UV_{254}$ ultraviolet, which were 95% and about 92%, respectively. The obtained permeate did not contain aluminium and had turbidity below 1 NTU. Coagulation and sedimentation as preliminary processes were

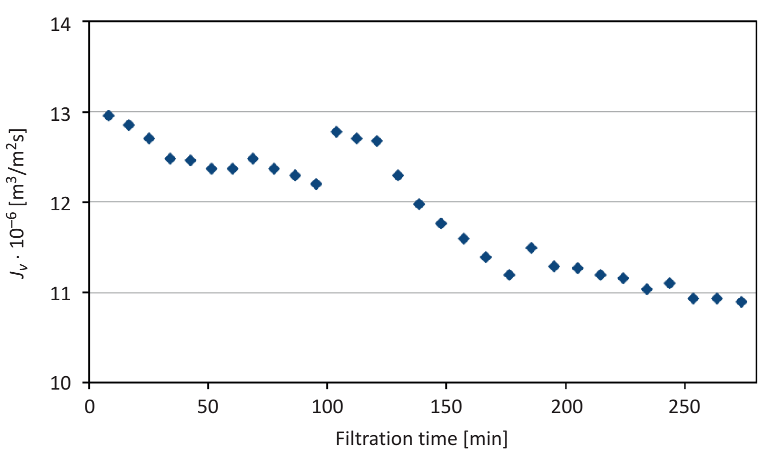


Fig. 2. Changes of volumetric permeate stream at the nanofiltration of raw washings ($\Delta P$ = 2.0 MPa)

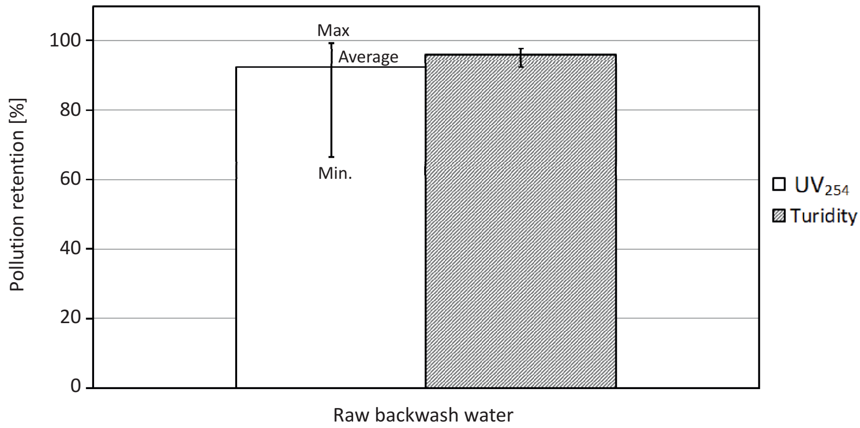


Fig. 3. The range of variation and average values of $R$ for $UV_{254}$ and turbidity during NF of raw washings

used in order to improve the transport properties on nanofiltration membrane and reduce the pores blocking by solid particles [7, 15–17].

## Effectiveness of the integrated washings cleaning system

The coagulation process was highly effective in elimination of pollutants from washings (Table 2). It also significantly improved the sedimentation capacity of the washings and allowed the turbidity reduction by 90%. However, there was a simultaneous accumulation of remaining aluminium which concentration in the tested samples after coagulation was from 0.83 to 1.20 mg/dm$^3$. In order to be reused in the swimming pool water circuit, the permeate must have the remaining aluminium concentration below 0.2 mg/dm$^3$ [14].

Table 2

Selected pollutants indices and their reduction in the coagulation process

| Coagulant dose [cm$^3$] | Sedimentation time [h] | $UV_{254}$ [m$^{-1}$] | $UV_{254}$ reduction [%] | Turbidity [NTU] | Turbidity reduction [%] |
|---|---|---|---|---|---|
| 1.0 | 0.5 | 5.60 | 60.00 | 1.53 | 92.05 |
| | 1 | 4.40 | 68.57 | 1.15 | 94.02 |
| | 4 | 5.40 | 61.43 | 1.10 | 94.28 |
| | 24 | 4.80 | 65.71 | 0.84 | 95.63 |
| 0.5 | 0.5 | 7.30 | 47.86 | 0.86 | 95.53 |
| | 1 | 4.70 | 66.43 | 0.76 | 96.05 |
| | 4 | 5.50 | 60.71 | 0.68 | 96.47 |
| | 24 | 7.00 | 48.57 | 0.86 | 96.97 |

Using coagulation and sedimentation before the nanofiltration process brought good results in terms of improving the membrane hydraulic properties, and the results depended on the coagulant dose and sedimentation time (Figs. 4 and 5). When a smaller coagulant dose was used, that is 1.5 mgAl/dm$^3$, the permeate volumetric flow $J_v$ was higher, and the reduction of this parameter value in time occurred at a significantly lower rate. The sedimentation time preceding the nanofiltration process was also important for the transport conditions. The $J_v$ value grew significantly when the process time was increased to 4 and 24 hours (Figs. 4 and 5).

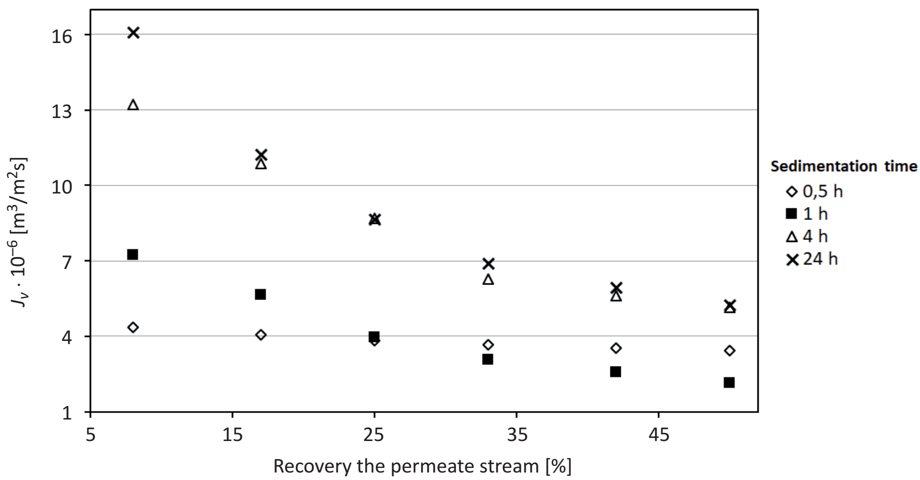


Fig. 4. The changes of $J_v$ in nanofiltration process of washings after coagulation with doses of 1.5 mgAl/dm$^3$

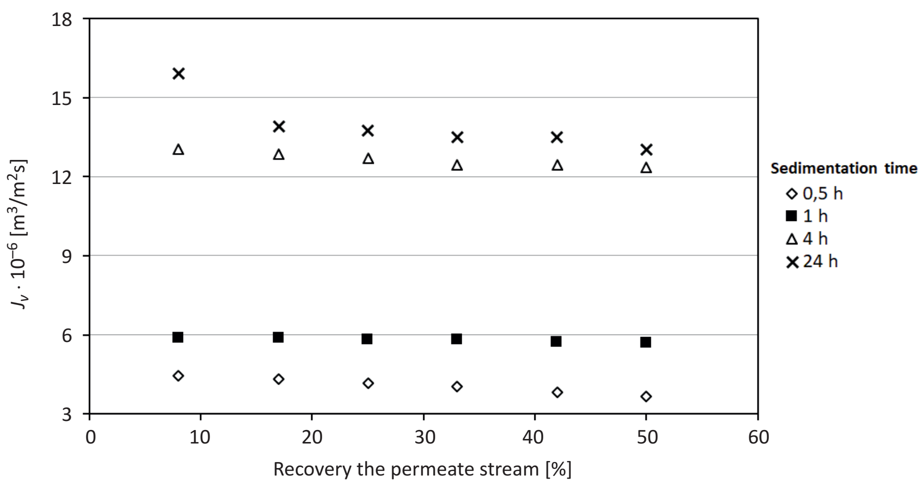


Fig. 5. The changes of $J_v$ in nanofiltration process of washings after coagulation with doses of 3.0 mgAl/dm$^3$

Figures 6 and 7 present retention properties of nanofiltration membranes in the integrated cleaning arrangement. In arrangement with coagulation at the 1.5 mgAl/dm$^3$

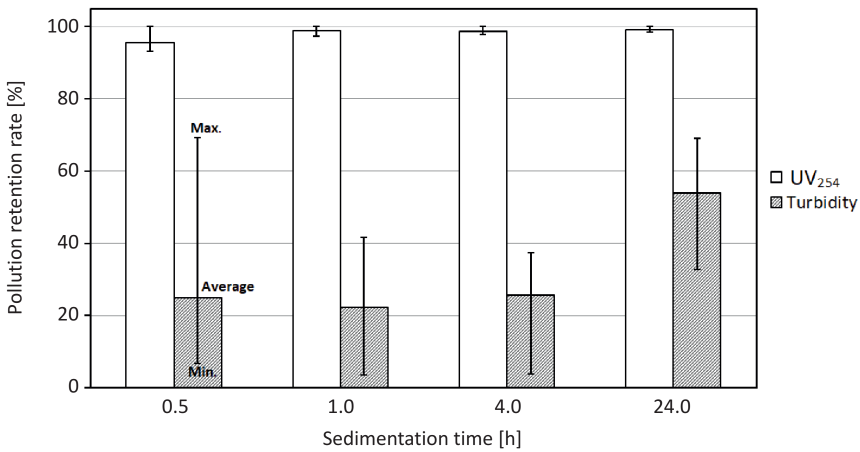


Fig. 6. The range of variation and average values of *R* after the *Coag-Sed-NF* process (*DK* = 1.5 mgAl/dm$^3$)

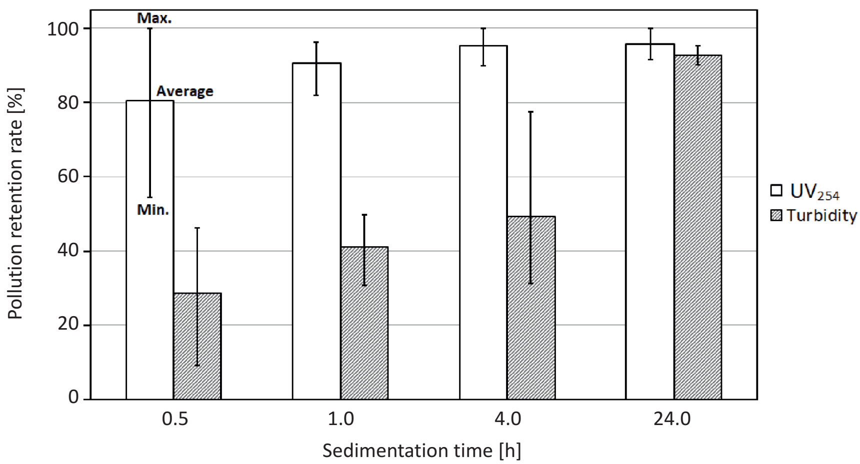


Fig. 7. The range of variation and average values of *R* after the *Coag-Sed-NF* process (*DK* = 3.0 mgAl/dm$^3$)

coagulant dose, high reduction of $UV_{254}$ absorbance were noticed (> 90%) regardless of the sedimentation time of post-coagulation sludge. In arrangement with coagulation at the 3.0 mgAl/dm$^3$ coagulation dose, the turbidity reduction indices were higher. In addition, the effectiveness of membrane process increased significantly as the sedimentation time was longer. For the cleaning arrangement: coagulation (*DK* = 3.0 mgAl/dm$^3$) – 24 h, sedimentation – nanofiltration, the average values of $UV_{254}$ absorbance and turbidity reduction were in excess of 96% and 90%, respectively. The increase of retention capability was related to formation of the so-called secondary membrane by the sludge left after the preliminary processes. The suspension particles could also penetrate the nanofiltration membrane structure, reducing it porosity.

## Summary and conclusions

1. The nanofiltration of raw washings allowed their significant purification. However, solid particles present in raw washings reduce the transport capacity of nanofiltration membranes. Although, paradoxically, by reducing the membrane porosity this increased its retention capabilities. The capacity increase of membrane filtration is possible by means of using preliminary purification processes, that is coagulation and sedimentation, however the parameters of these processes must be chosen.

2. In case of the coagulation-sedimentation-nanofiltration integrated arrangement, the quality of obtained permeate from washings allows it to be reused in the swimming pool water circulation, e.g. to make up for water loss in swimming pool basins.

### Acknowledgement

Study conducted within the departmental research grant for young scientists (BKM- 554/RIE-4/17) “Extended Evaluation of Swimming Pool Water.”

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## DOBÓR WARUNKÓW ODZYSKU WODY ZE STRUMIENIA POPŁUCZYN Z INSTALACJI WODY BASENOWEJ

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**Abstrakt:** W pracy przedstawiono wyniki badań dotyczących zastosowania zintegrowanego procesu koagulacji–sedymentacji–nanofiltracji do oczyszczania popłuczyn z obiegu uzdatniania wody basenowej. Badania obejmowały ocenę wpływu warunków prowadzenia procesów wstępnych, tj. koagulacji (zakres dawek koagulantu 1,5–3,0 mgAl/dm$^3$) oraz sedymentacji (czas trwania 0,5–24 h) na własności transportowo-separacyjne membran nanofiltracyjnych. Porównawczo przeprowadzono proces nanofiltracji surowych popłuczyn.

Obserwowano wyższą wartość objętościowego strumienia permeatu w trakcie procesu nanofiltracji dla popłuczyn po koagulacji (dawka koagulantu 1,5 mgAl/dm$^3$). Stwierdzono znaczącą poprawę zdolności transportowych membrany wraz z wydłużeniem czasu sedymentacji (do 24 h). Obecność cząsteczek osadów, które przyczyniały się do obniżenia wydajności filtracji popłuczyn po koagulacji, w której zastosowano wyższą dawkę koagulantu (3,0 mgAl/dm$^3$), równocześnie spowodowała stopniowy wzrost zdolności separacyjnych membrany – utworzyła się tzw. membrana wtórna charakteryzująca się mniejszą porowatością niż membrana pierwotna. W badanym przypadku zastosowanie układu zintegrowanego pozwoliło na poprawę warunków transportowych membran nanofiltracyjnych, zmniejszenie stężenia glinu pozostałego oraz znaczną poprawę pozostałych parametrów fizykochemicznych (m.in. zmniejszenie ilości zawiesin ogólnych i obniżenie absorbancji w nadfiolecie $UV_{254}$).

**Słowa kluczowe:** proces zintegrowany, popłuczyny, nanofiltracja, koagulacja, instalacja wody basenowej