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ASSESSMENT OF THE POSSIBILITY OF RECYCLING BACKWASHING WATER FROM THE SWIMMING POOL WATER TREATMENT SYSTEM

OCENA MOŻLIWOŚCI RECYKLINGU POPŁUCZYN Z SYSTEMU OCZYSZCZANIA WODY BASENOWEJ

Abstract: The paper presents the physicochemical analysis and toxicological assessment of backwashing samples taken after the process of washing filter beds in a raw condition after the process of their aeration and dechlorination. The backwash water under investigation originated from circulation systems existing in two indoor swimming pool facilities. The backwash water, as used at the preliminary and the main stages, was characterized by different physicochemical properties. For toxicological assessment, the Mictorox® bioluminescence inhibition test, the *Chaoborus sp.* insect larva survival test and the phyto test using *Lemna minor* fine cilium were involved. The investigation presented in the paper included a preliminary phase focusing on the ecotoxic characterization of backwash water subjected to aeration and dechlorination processes. In turn, at the main stage, the effect of aeration duration on the quality of backwash water in terms of its physicochemical parameters was analyzed. The results of the preliminary stage investigation indicate that backwash water, both in a raw condition and after 30 minutes' aeration, could not be discharged directly to the environment due to the threat to living organisms caused by its high toxicity. Whereas, using 160 minutes' aeration duration contributed to a significant improvement in the quality of the backwash water and elimination of its toxic properties with respect to the indicator organisms used. The chemical dechlorination process brought about varying effects. In the case of the Microtox® test, a stimulation of bacterial bioluminescence was noted, but, at the same time, the death of individual insect larva specimens was observed. In spite of the high biomass increase in the *Lemna minor* test, a gradual discolouration of fronds under the influence of backwash water was observed. Because of the presence of numerous compounds being disinfection by-products, as well as coagulant residues in backwash water deriving from swimming pool systems, it is necessary to seek further solutions that will allow them to be recycled, which will result in a reduction of water consumption and effluent discharges.

Keywords: swimming pool water, backwashing, toxicological assessment, physicochemical analysis, biotests

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Introduction

Conducting the process of washing swimming pool filters in the correct manner and at the proper frequency makes it possible to maintain the physicochemical and bacteriological standard of not only circulating water but also washings which, in terms of quality, corresponds to surface water in quality class three. The assurance of these requirements may contribute to a reduction of the discharge of backwash water as a waste stream to the sewage system and provide the possibility of reusing it [1]. The quality and quantity of backwash water is determined by numerous other factors, including: the intensity of conducted washing, the quality of water fed to the circulation system, the quantity and types of removed impurities, as well as the type and dose of chemicals used. To assure the correct bed washing process, it is necessary to use 4 to 6 m^3 of water per each square metre of the bed, which, in the case of large facilities, entails high water and energy consumption costs [2]. Backwash water is distinguished not only by a high content of suspension, but also by residues of coagulants and disinfectants. In particular, the presence of disinfection by-products, as well as admixtures and contaminants used in the surface coagulation process is problematic from the perspective of washing reuse [3, 4]. However, from the technological point of view, the recovery of water from the waste stream is possible.

The objective of the study was to carry out the physicochemical assessment (by the measurement of the conductivity, reaction, etc.) and toxicological assessment of backwash water obtained from the filter bed washing process, as well as the analysis of the parameters under investigation after the washing aeration and dechlorination process. The assessment of the toxicity was performed based on the Microtox® bacterial test, the *Chaoborus sp*. insect larva survival test, as well as the test using a water plant, *Lemna minor* fine cilium.

Materials and research methodology

Physicochemical analysis

Backwash water used at the preliminary investigation stage was taken from the circulation system of a sports swimming pool and then subjected to analysis for selected physicochemical properties, including the reaction (pH), conductivity and ultraviolet absorbance at a wavelength of 254 nm. For the extended stage, on the other hand, backwash water was taken from the common tank of the circulation systems of the sports and a leisure swimming pools. In that part, the concentration of (free and total) chlorine, chlorides, ammonium and nitrate nitrogen, colour, turbidity and total hardness were additionally measured.

The measurement of the conductivity and pH of water samples was done with an inoLab® 740 multi-parameter meter (WTW, Measuring and Analytical Technical Equipment). The absorbance was measured using a UV VIS Cecil 1000 supplied by Analytik Jena AG, with a cuvette optical pathlength of 1 cm. The absorbance value at the wavelength of 254 nm was determined based on the UV_{254} ultraviolet absorbance

measurement method in accordance with the standards adopted by US EPA [5]. The measurement of chlorine concentration by the colorimetric method was done using a Hach® Pocket Colorimeter™ II portable instrument. The concentration of nitrate and ammonium nitrogen was determined with a photolyser 400 (Dinotec) tester. The chloride concentrations were assayed by the Mohr method. 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). The total hardness, on the other hand, was determined by the titration method using sodium versenate.

Toxicological assessment

The Microtox® test enables the determination of the magnitude of the toxic effect based on the suppression of the natural metabolic processes of bacteria in the form of bioluminescence inhibition. The toxicity analysis was carried out in conformance with the *Screening Test*procedure of the MicrotoxOmni system in a Microtox analyzer, Model 500, manufactured by Tigret Sp. z. o.o., performing the function of both an incubator and a photometer. The percentage of inhibitions relative to the control sample not exposed to the potential toxicant was measured after 5 and 15 minutes' exposure time. The toxicity effect was determined as the percentage (%) of inhibition (I) according to Equation 1:

$$\%I = \frac{100 \cdot (E_K - E_T)}{E_K} \tag{1}$$

where: E_K – the value of bioluminescence in an attempt to control,
E_T – the value of the bioluminescence in the sample with a toxic substance.

The test of the survival of animal organisms, which were *Chaoborus sp.* larvae, was performed following the authors' own methodology. Acquired from an industrial culture, the larvae were taken to a laboratory, where their mobility was evaluated. Dead or immobilized specimens were rejected from the culture. After 24 hours, the review of the culture was repeated. 3 cm^3 washing samples, with 5 specimens being placed in each of them, were used in the test. The test plates were incubated in darkness at a temperature of 20°C. The reading of the number of immobilized or dead specimens was taken after 24 and 48 hours from the start of the test, respectively. The percentage value of the toxic effect was calculated from Equation 2:

$$\text{Effect} = \frac{100 - L_{24\,\text{h}}}{L_{0\,\text{h}}} \cdot 100\% \tag{2}$$

where: L_{24h} – number of alive specimens in the sample after 24 hrs of the test,
L_{0h} – number of specimens taken to the test.

For the classification of toxicity, a system commonly used by many researchers [6] was adopted, which is based on the size of the observable effect produced in the indicator organism used (Table 1).

Table 1

The toxicity classification system [6]

Effect [%]	Toxicity class
< 25	Non-toxic
25–50	Low toxic
50.1–75	Toxic
75.1–100	Highly toxic

A preliminary toxicological assessment of the backwash water under investigation was also made based on the growth inhibition of *Lemna minor* fine cilium according to the authors' methodology complying with the OECD recommendations [7]. The frond growth and inhibition coefficients, R_f and IR_f, were determined from Equations 3 and 4, respectively:

$$R_f = \frac{\ln f_2 \cdot \ln f_1}{\Delta t} \tag{3}$$

where: f_2 – number of fronds on the last testing day,
f_1 – number of fronds on the first testing day,
$\Delta t = t_2 - t_1$ – number of testing days.

$$IR_f = \frac{R_{fc} \cdot R_{ft}}{R_{fc}} \cdot 100\% \tag{4}$$

where: R_{fc} – coefficient of frond growth in the control sample,
R_{ft} – coefficient of frond growth for successive samples.

As the inhibition signal, positive growth inhibition coefficient values (> 0%) were taken. By contrast, the growth stimulation was indicated by negative values.

An attempt to determine the influence of washing components on the dye contents of plants was also made. The concentrations of chlorophyll and carotenoids were determined by the spectrophotometric method using an acetone extract from the plants. The chlorophyll determination was made by the method described by Blamowski and Borowski [8], while for determining the sum of carotenoids, Lichtenthaler's methodology [9] was used. The basic parameters of the influence of backwash water on the plant were determined based on the changes in 7 days' tests. All biotests were carried out in three repetitions, and the presented results constitute average values obtained from the analyses.

Washing aeration and dechlorination process

The aeration process was conducted in small laboratory reactors, each of a capacity of 400 cm^3. A HAGEN ELITE OPTIMA double discharge-port pump, with a delivery of 1500 cm^3/min for each discharge port, was used for aeration. The concentration of oxygen dissolved in backwash water was controlled during the aeration process using an immersible process probe operating based on an optical measurement method, equipped with an LDO sensor (HACH LANGE). The concentration of oxygen in the backwash water used at the preliminary testing stage was 7.61 mgO_2/dm^3 and the process was conducted for 30 minutes. At the next stage, on the other hand, the oxygen concentration was increased up to a maximum of 8.80 mgO_2/dm^3, and the physico-chemical parameters were determined after 40, 100 and 160 min after the start of the process.

The dechlorination process was carried out in compliance with the US EPA recommendations [10] using anhydrous sodium sulfite, Na_2SO_3 (Stanlab). Based on the stoichiometric equation for the reaction of sodium sulfite with hypochlorous acid, HOCl, it was determined that, in order to carry out the process, 1.775 mg of Na_2SO_3 had to be used per 1 mg of free chlorine. Dechlorination was carried out only at the preliminary testing stage for backwash water from the sports swimming pool circulation system using a single sodium sulfite dose.

Results and discussion

The physicochemical analysis of backwash water performed at the preliminary stage (Table 2) indicated variations in parameters under the influence of the processes carried out. A particularly marked increase in reaction, conductivity and ultraviolet absorbance was documented in the sample of backwash water subjected to chemical dechlorination. The processes carried out contributed to a change in the nature of the suspension, which underwent sedimentation more easily compared to backwash water not subjected to the cleaning processes.

Table 2

Physicochemical analysis of backwash water examined at the preliminary stage

No.	Backwash water	Reaction pH [-]	Conductivity [μS/cm]	UV_{254} ultraviolet absorbance [m^{-1}]
1	Raw	7.38	5526	15.60
2	Aerated (30 min)	7.31	5587	19.10
3	Dechlorinated	8.36	6604	37.70

During carrying out the main testing stages concerning the aeration effects, the scope of physicochemical analysis was increased (Table 3). With the increase in backwash water aeration time, an increase in the concentration of bonded chlorine (chloramines) and chlorides was noted. A similar relationship was observed for the reaction, total

hardness and turbidity. In contrast, the longer backwash water aeration time resulted in a lowering of the concentration of ammonium and nitrate nitrogen.

Table 3

Physicochemical analysis of backwash water

Parameter/Indicator	Unit	Aeration time [min]			
		0	40	100	160
Free chlorine	$mgCl_2/dm^3$	0.05	0.06	0.05	0.04
Bonded chlorine	$mgCl_2/dm^3$	0.34	0.52	0.45	0.44
Total chlorine	$mgCl_2/dm^3$	0.39	0.58	0.50	0.48
Reaction (pH)	—	7.28	7.49	8.08	8.19
Conductivity	µS/cm	1386	1389	1396	1389
Turbidity	NTU	9.05	10.80	10.40	10.58
Colour	m^{-1}	2.00	2.00	2.00	2.00
Ammonium nitrogen	$mgN\text{-}NH_4/dm^3$	2.37	2.32	0.29	0.12
Nitrate nitrogen	$mgN\text{-}NO_3/dm^3$	17.00	12.00	12.00	8.00
Chlorides	$mgCl^-/dm^3$	188.15	202.35	205.90	205.90
Total hardness	$mval/dm^3$	7.60	7.60	7.68	7.84
UV_{254} ultraviolet absorbance	1/m	5.40	6.30	6.90	7.40

The backwash water under investigation was distinguished primarily by varying values of UV_{254} ultraviolet absorbance and conductivity. The backwash water used at the preliminary stage exhibited much higher values of these parameters, which indicates a greater fraction of swimming pool water-contaminating substances of the sample taken.

The bioluminescence inhibition test of backwash water carried out at the preliminary investigation stage showed also its high toxicity towards bacteria. After 15 minutes of exposure, the value of inhibition for raw backwash water was over 99% (Fig. 1).

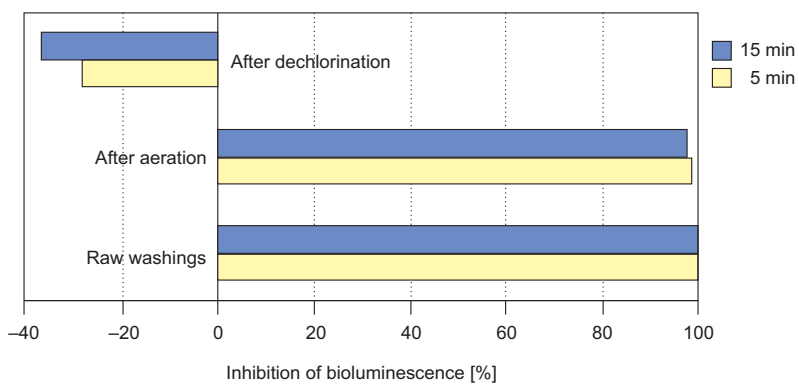

Fig. 1. The toxicity of backwash water samples in the Microtox® assay

Moreover, subjecting the backwash water to aeration did not bring about any significant reduction in inhibition value, and the bioluminescence inhibition after 15 minutes' exposure time was approx. 97%. By contrast, the dechlorination process not only completely deprived the sample of the toxic effect, but also stimulated the metabolic processes in the bacteria used in the test.

The backwash water used at the second investigation stage were characterized by a lower bioluminescence inhibition value. The bioluminescence inhibition value for the sample before the aeration process was about 78% (Fig. 2), which might have a great influence on the obtained results. Moreover, the backwash water was taken from two facilities that showed a different load with people bathing on the day preceding the sampling. The performed aeration contributed to a considerable reduction of the backwash water toxic effect on the indicator organism. Finally, the sample taken after 160 minutes of the process showed a bioluminescence stimulation at –54% of that after 15 minutes of exposure. Moreover, samples were also prepared for the sedimentation process, from which the supernatant liquid was taken after 24 hours. The fact interesting from the point of view of further research on this subject is that the bioluminescence stimulation in supernatant liquid samples was achieved already after 40 minutes' aeration time, with its value amounting to –14%.

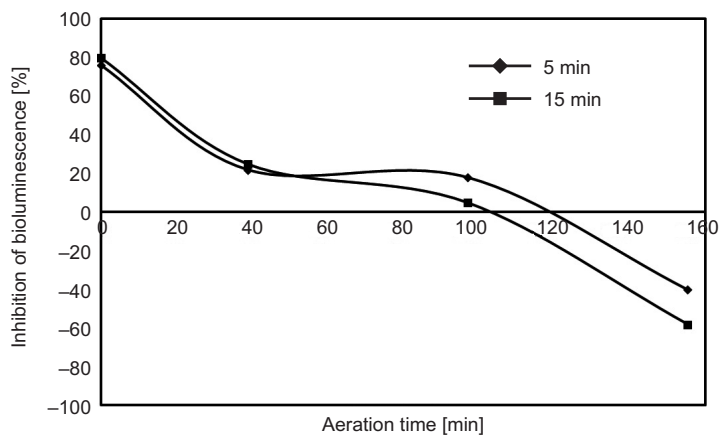

Fig. 2. Variations of bioluminescence inhibition in samples treated in the aeration process

The performed *Chaoborus* sp. insect larva survival test (Fig. 3) showed a high resistance of this organism to chemical compounds contained in the backwash water. The greatest mortality among the specimens was noted in the raw backwash water sample. The toxic effect was 27%, which classified the sample as toxic to the organisms used. Moreover, in the aerated backwash water sample the mortality of the specimens was 7%, while after the dechlorination process, 11%. The analyses were performed after 48 hours from the start of the test.

The *Lemna minor* phyto test showed a significant reduction in the content of chlorophyll-a in the fronds of plants grown both in raw backwash water and in preliminarily treated backwash water. At the same time, an increase in the concentration

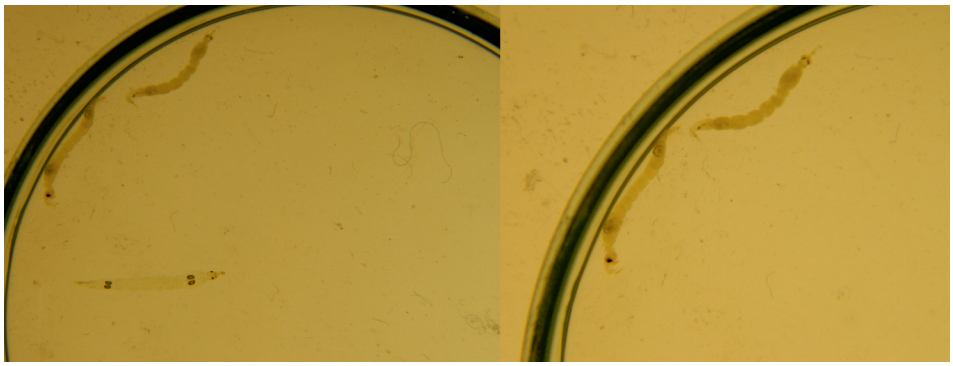

Fig. 3. The individuals of *Chaoborus* sp. – live (left photo, below one individual) and the dead (on the left and the right picture – two individuals)

of chlorophyll-b and carotenoids was noted. The increase in carotenoid contents might be caused by the activation of anti-oxidation mechanisms in the presence of impurities occurring in the test samples [11]. Whereas, the differences in values between chlorophyll-a and chlorophyll-b might be due to both the contamination of the samples and the development variations in the plants, which occur in individual phases of growth [12].

All samples taken during aeration exhibited high ability to stimulate the plant biomass increase, as indicated by the negative values of the growth inhibition coefficient (Fig. 4). The strongest stimulation was noted for raw backwash water, while the weakest stimulation, for backwash water aerated for 160 minutes. This suggests the occurrence of *Lemna minor* growth-promoting substances in the backwash water tested.

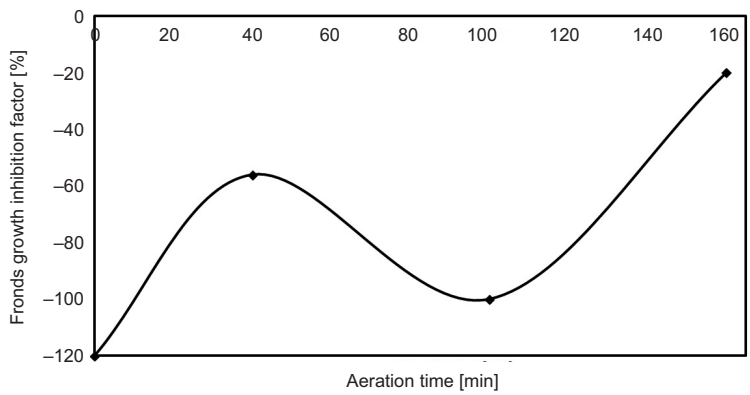

Fig. 4. Variations in the value of the growth inhibition coefficient for fronds in aerated samples

Conclusions

The performed pre-treatment processes changed the quality of the swimming pool system backwash water under investigation. The achieved final aeration results were

significantly influenced by the initial backwash water toxicity value noted in the biotests. Therefore, it is of particular importance to maintain the filter washing frequency standards. For toxicological tests, the susceptibility of particular indicator organisms is also very important, and the utmost care in their selection is necessary.

The application of the aeration or dechlorination process may bring about an improvement in the quality of the backwash water, which will allow it to be discharged directly to the soil or water. However, it is necessary to extend the research on the impact of backwash water-borne chemical compounds on the natural environment.

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OCENA MOŻLIWOŚCI RECYKLINGU POPŁUCZYN Z SYSTEMU OCZYSZCZANIA WODY BASENOWEJ

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Abstrakt: W pracy przedstawiono analizę fizykochemiczną oraz ocenę toksykologiczną próbek popłuczyn pobranych po procesie płukania złóż filtracyjnych w stanie surowym po procesie napowietrzania oraz dechlo-

racji. Badane popłuczyny pochodziły z obiegów zlokalizowanych w dwóch obiektach basenowych krytych. Do oceny toksykologicznej włączono test inhibicji bioluminescencji Mictorox®, przeżywalności larw owadów *Chaoborus* sp. oraz fitotest z wykorzystaniem rzęsy drobnej *Lemna minor*. Badania obejmowały fazę wstępną, skupiającą się na charakterystyce ekotoksykologicznej popłuczyn poddanych procesom dechloracji oraz napowietrzania. W etapie zasadniczym badań analizowano dodatkowo wpływ czasu napowietrzania na jakość popłuczyn pod względem parametrów fizykochemicznych. Wyniki wstępnego etapu badań sygnalizują, że popłuczyny zarówno w stanie surowym, jak i po 30-minutowym napowietrzaniu nie mogły zostać bezpośrednio odprowadzone do środowiska ze względu na zagrożenie dla organizmów żywych, spowodowane ich wysoką toksycznością. Natomiast zastosowane wydłużenie czasu napowietrzania (160 min) przyczyniło się do znaczącej poprawy jakości popłuczyn i pozbawienia ich właściwości toksycznych w stosunku do wykorzystanych organizmów wskaźnikowych. Zróżnicowane efekty przyniósł zabieg chemicznej dechloracji. W przypadku testu Microtox® odnotowano stymulację bioluminescencji bakterii, równocześnie zaobserwowano śmierć pojedynczych osobników larw owadów. Pomimo wysokiego przyrostu biomasy w teście z *Lemna minor*, zaobserwowano stopniowe odbarwienie frondów pod wpływem użytych popłuczyn. Niezbędne jest poszukiwanie dalszych rozwiązań umożliwiających ich recykling, co zapewni ograniczenie zużycia wody oraz odprowadzania ścieków.

Słowa kluczowe: wody basenowe, popłuczyny, ocena toksykologiczna, analiza fizykochemiczna, biotest