# The problem of water renewal in swimming pool circuits 

Problemy odnowy wody w obiegach basenowych

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#### Abstract

The problem of water renewal in swimming pools is mainly related to the concentration of some contaminants (with the quality of swimming pool water) and to the need for water to supplement losses in the closed swimming pool circuit (volume of swimming pool water). This problem is presented on the basis of physicochemical analysis of pool water samples (taken every two hours during one day and taken daily during one week) and the amount of supplementary water demand (water metre reading) depending on attendance and in relation to rational water management for a sports-type pool. The results were compared with the guidelines of the Swimming Pool Water Quality Decree and the recommendations of DIN 19643. Pool water quality parameters, such as: absorbance, redox potential, combined chlorine, nitrates, and chlorides, could be considered as indicative for the daily assessment of water, and depending on their value, supplement the circuit with water from the water supply network. The amount of supplementary water used (an average of $40.6 \mathrm{~L} /$ bather day) exceeded the DIN 19643 recommendations by $26 \%$. To rationalise water management, a water quality analysis should be carried out with the consumption of supplementary water reduced to $30 \mathrm{~L} /$ bather day (that is, on average $11.5 \mathrm{~m}^{3}$ /day instead of $15.6 \mathrm{~m}^{3} /$ day). Keywords: water renewal, swimming pool, water closed circuit, swimming pool water quality, supplementary water

Problem odnowy wody w obiektach basenowych związany jest przede wszystkim z zatężaniem niektórych zanieczyszczeń (z jakościa wody basenowei) oraz z zapotrzebowaniem na wodę uzupełniaiqcą straty w zamkniętym obiegu basenowym (obiętością wody basenowej). Problem ten przedstawiono na podstawie analizy fizykochemicznej próbek wody basenowej (pobranych co dwie godziny w ciagu jednego dnia oraz pobranych codziennie w ciągu jednego tygodnia) i willkości zapotrzebowania na wodę uzupetniaiqcą (rejestr wskazańz wodomierza) w zależności od frekwencji oraz w odniesieniu do racjonalnei gospodarki wodnej dla basenu typu sportowego. Wyniki porównano z wyłycznymi rozporządzenia w sprawie jakości wody w pływalniach oraz zaleceniami normy DIN 19643. Parametry jakości wody basenowej, takie jak: absorbancja, potencjał redox, chlor związany, azołany i chlorki, można było uznać za wskaźnikowe do codziennej oceny jei jakości i w zależności od ich wartości uzupełniać obieg woda z sieci wodociagowej. Stosowana ilość wody uzupełniaiacej (średnio 40,6 L/os.d) przekraczała zalecenia normy DIN 19643 o $26 \%$. W celu racionalizacii gospodarowania wodą należałoby przeprowadzać analizę jakości wody przy zmniejszonym do $30 \mathrm{dm}^{3} /$ os. d zużyciu wody uzupetniaiqcej (czyli średnio $11,5 \mathrm{~m}^{3} / \mathrm{d}$ zamiast $15,6 \mathrm{~m}^{3} / \mathrm{d}$ ). Słowa kluczowe: odnowa wody, basen, zamknięty obieg wody, iakość wody basenowej, uzupetnianie wody


## Introduction

The problem of swimming pool water renewal is primarily related to the qualitative and quantitative characteristics of the water in the swimming pool circuit. The quality of swimming pool water depends on the water treatment technology used, the function of the swimming pool facility (sports, recreation, rehabilitation), the frequency and therefore the bathers' load, the type of chemicals used, the solution of the hydraulic system, the quality of the supply water, regulation and control of basic indicators of water quality and operating conditions of the swimming pool facility [1-3].

In turn, the amount of water in the swimming pool circuit depends on the capacity and equipment of the swimming pool (direct-
ly dependent on the function of the swimming pool), the capacity of the retention tanks, the required efficiency of the swimming pool circuit, the retention time of the water in the swimming pool, the length of filtration cycles and the demand for water for regular washing of filter beds, and to replenish water losses arising during the operation of the pool (as a result of evaporation, splashing and taking it out by bathers) [4-6].

Swimming pool water treatment technologies are based on processes carried out in a closed circuit with the use of an active overflow, which should ensure proper water circulation in the swimming pool and economical water management. Water is supplied to the pool with a system of bottom or side nozzles with adjustable flow. The water is discharged through overflow gutters and bottom outlets.

The water from the gutters drains to the retention tank, usually equipped with an automatic water volume control system. Circulation pumps integrated with fibre and hair catchers collect water from the retention tank and pump it to the filters. In the filter bed, impurities in the water are retained. This process is often supported by a predosed coagulant. The filtered water is heated to the correct temperature in heat exchangers and disinfected. Disinfection with a chlorine compound can be supported by an additional disinfectant agent, most often ultraviolet (UV) rays or ozone. It is important that the applied disinfection method ensures water protection against the development of pathogenic microorganisms [2,7-11].

The diagram of the swimming pool water treatment in a closed circuit is shown in Fig. 1.


Despite the use of modern swimming pool water treatment processes, a concentration of some impurities is observed in the swimming pool cycle, for example, combined chlorine, total organic carbon (TOC), nitrates, chlorides [2,12-14]. This aspect is a significant problem in the renewal of swimming pool water. The acceptable concentrafion of products that cannot be removed from the water in the treatment cycle can be obtained by ensuring the appropriate dilution with "fresh" tap water [15]. Therefore, the demand for tap water to supplement swimming pool circuits should take into account not only water losses, but also the results of control of parameters of decisive importance for the health safety of swimmers.

In Poland, the requirements to be met by water in swimming pools are regulated by the Regulation of the Minister of Health on the Journal U. 2015, item 2016 [16].

Recommendations related to swimming pool water treatment technology are provided by the German standard DIN 19643 ("Water treatment for swimming and bathing pools" from 2012), based on which manufacturers of water treatment devices specify their operating conditions (e.g., length of the filtration cycle, volume of water for washing filter beds, circulation efficiency and pump efficiency depending on the type of pool, water retention time, capacity of retention tanks). According to the provisions of DIN 19643, it is also assumed that the amount of supplementary water should be 30 litres per bather and day, and the maximum "age" of water (the time from filling the pool basin to its complete emptying) in sports type swimming pools should not exceed 12 months [17].

The problem of pool water renewal is presented on the basis of physicochemical analysis of pool water samples and analysis of the quantity of supplemental water demand (also depending on attendance) for an example sport swimming pool. A comprehensive qualitative and quantitative analysis is intended to present the problem of water renewal (or, in other words "aging" of pool water) in relation to rational water and wastewater management. This problem basically boils down to determining the time after which the pool water circuit should be par-
tially (replenish only water losses) or completely (empty the pool, clean, and refill) refreshed.

Research on rationalising the demand for water without the risk of deterioration of bathing water quality can contribute to changes in the operation of swimming pool water treatment plants and swimming pool facilifies, including the possibility of using flexible control of the operation of individual devices depending on the bathers load and the level of pool water contamination.

## Materials and methods

## Characteristics of the research object

Thematic research was carried out for an exemplary sport swimming pool (SP). The pool is supplied with water from the municipal water supply, which meets the quality requirements for drinking water $[18,19]$. The facility has a closed-circuit water treatment system, the principle of which is described in the "Introduction" chapter. The pool water treatment plant (WTP) has been equipped with: two pressure filters with multilayer beds, system of dosing a coagulant solution and an acid solution for pH adjustment, two-stage water disinfection system (irradiation with UV rays and stepwise dosing of sodium hypochlorite solution), automatic systems for dosing reagents, and controlling basic water quality parameters (temperature, pH , redox potential, free chlorine, and combined chlorine). Each filter worked for 2 days before washing its filter bed. The washing of the filtration beds is carried out with air (all filtration systems are equipped with air blowers) and water (taken from the retention tanks). About $6 \mathrm{~m}^{3}$ of water per $1 \mathrm{~m}^{2}$ of bed was used for washing. The filter bed washing process took place after the swimming pool facility was closed, and the washings were discharged to the sanitary sewage system. After washing the filter bed, the retention tank was refilled with fresh tap water (approx. $15 \mathrm{~m}^{3}$ ). The swimming pool was available to bathers 16 hours a day. During the day, an average of 384 swimmers use the swimming pool.

The technical parameters of the tested pool and the water treatment system are presented in Table 1.

Table 1. Technical parameters of the tested swimming pool (SP) and the water treatment system (WTS)
Tabela 1. Techniczne parametry badanego basenu (SP) oraz systemu oczyszczania wody (WTS)

| Pool dimensions (length $\times$ width $\times$ depth) | $\begin{aligned} & 25 \mathrm{~m} \times 12.5 \mathrm{~m} \times \\ & (1.3 \mathrm{~m}-1.8 \mathrm{~m}) \end{aligned}$ |
| :---: | :---: |
| Water surface area in the pool | $312.5 \mathrm{~m}^{2}$ |
| Volume of the pool basin | $485 \mathrm{~m}^{3}$ |
| Volume of the retention tank | $31 \mathrm{~m}^{3}$ |
| Hydraulic system | Vertical (inflow through two DN 160 channels located at the bottom of the pool basin) |
| Average attendance | 24 person/h |
| Bather loads | $20.2 \mathrm{~m}^{3} /$ person <br> ( $13.0 \mathrm{~m}^{2}$ /person) |
| Filtration | Filter type: pressure (closed) |
|  | Number of filters: 2 |
|  | Type and height of the filter bed: sand layer ( 0.7 m ) and activated carbon layer ( 0.5 m ) |
|  | Filter diameter: $1,800 \mathrm{~mm}$ |
|  | Filtration area of one filter: $2.54 \mathrm{~m}^{2}$ |
|  | Filtration velocity: $30 \mathrm{~m} / \mathrm{h}$ |
|  | Fillration flow: $152 \mathrm{~m}^{3} / \mathrm{h}$ |
| Coagulation | $5 \%$ solution of aluminum hydroxychloride (average dose: $\left.0.5-1.0 \mathrm{~mL} / \mathrm{m}^{3}\right)$ |
| Disinfection | UV irradiation (low-pressure UV lamp, $1.8 \mathrm{~kW}, 600 \mathrm{~J} / \mathrm{m}^{2}$ ) and final disinfection <br> ( $15 \%$ solution of NaOCl ) |
| pH correction | $50 \%$ solution of $\mathrm{H}_{2} \mathrm{SO}_{4}$ |

## Physicochemical indicator

 parameters of pool water quality and methods of analysisIn order to control and assess the quality of swimming pool water samples were collected in two time regimes. First, the variability of the values of the water parameters measured every two hours (from 8 am to 8 pm ) during one day (04.05.2022) was analysed. Then the values of the water parameters measured every day at 2 pm (MondaySunday) for a week (09.05-15.05.2022) were analysed.

In the collected samples, the indicator parameters specified in the regulation of the Minister of Health of 2015 [16] were analysed ( pH , rdox potential, temperature, turbidity, chemical oxygen demand - COD, total organic carbon - TOC, free and combined chlorine, and nitrates).

In studies on the quality of swimming pool water conducted by Wyczarska-Kokot et al. $[2,12,20]$ and Lempart-Rapacewicz et al. [13,21], attention was paid to increasing the content of some contaminants with increasing the length of filtration cycles and the time of water use in the swimming pool circuit (from the moment of filling the pool to its emptying). In these studies, it was found that in addition to nitrate and total organic carbon, chloride content and absorbance
value can also be a good indicator of water "ageing". Therefore, in the presented studies, chlorides and absorbance were also included in the analysis of pool water.

Table 2 presents the physical and chemical parameters analysed for swimming pool water, the method of determination, the measuring tool used, and the numbers of the standards on the basis of which the measurements were made.

The statistical analysis of the research results was based on the Microsoft Excel data analysis package. Each sample was analysed three times, and the presented results are the average values of these repetitions. The standard deviations of the repetitions did not exceed $5 \%$, indicating a high repeatability of results.

Table 2. Swimming pool water quality parameters and measurement methods Tabela 2. Parametry jakości wody basenowej i metody ich pomiaru

| Parameter | Determination method | Measuring tool | Standard No. |
| :---: | :---: | :---: | :---: |
| Absorbance $U V_{254 \mathrm{~nm}^{\prime}} \mathrm{m}^{-1}$ | Spectrophotometric | UV/VIS spectrophotometer CECIL model CE 1021 (Cecil Instruments Limited) | Method 415.3: Determination of total organic carbon and specific UV absorbance at 254 nm in source water and drinking water <br> (EPA/600/R-09/122) |
| Temperature, ${ }^{\circ} \mathrm{C}$ | Potentiometric | SensiON MM 150 DL (Hach) | PN-EN 872:2007 |
| Redox potential, mV | Potentiometric | SensiON MM 150 DL (Hach) | PB-247/P ed. 3 of April 20, 2017 ( $\mathrm{Ag} / \mathrm{AgCl}$ electrode measurement in 3.5 M KCl$)$; DIN 38404 part 6: Determination of the oxidation reduction (redox) potential |
| Turbidity, NTU | Nephelometric | Turbidimeter Eutech TN-100 (Thermo Scientific) | PN-EN 1484:1999 |
| Chemical Oxygen <br> Demand (COD), $\mathrm{mg} \mathrm{O}_{2} / \mathrm{L}$ | Spectrophotometric | Spectrophotometer DR3900 (Hach) | PN-ISO 6060:2006 |
| Free chlorine, $\mathrm{mg} \mathrm{Cl}_{2} / \mathrm{L}$ | Photometric | Pocket Colorimeter II (Hach) | PN-EN ISO 7393-2:2018-04 |
| Total chlorine, $\mathrm{mg} \mathrm{Cl}_{2} / \mathrm{L}$ | Photometric |  |  |
| Combined chlorine, $\mathrm{mg} \mathrm{Cl}_{2} / \mathrm{L}$ | Indirect, calculated (difference in total and free chlorine content) |  |  |
| Chlorides, $\mathrm{mg} \mathrm{Cl} / \mathrm{L}$ | Spectrophotometric method with iron thiocyanate III | Spectrophotometer DR3900 (Hach) | LCK311 Chloride cuvette test (Hach) |
| Nitrates, $\mathrm{mg} \mathrm{NO}_{3}{ }^{-} / \mathrm{L}$ | Spectrophotometric | Spectrophotometer DR3900 (Hach) | PN-EN ISO 13395:2001 |
| Total organic carbon (TOC), mg C/L | Catalytic combustion | Analyzer TOC-L (Shimadzu) | PN-EN 1484:1999 |
| pH, - | Potentiometric | SensiON MM 150 DL (Hach) | PN-EN ISO 10523:2012 |

## Measurement of the demand for supplementary tap water

To determine the real amount of tap water taken from the water supply system to supplement water losses in the swimming pool circuit, during the weekly water quality analysis, daily regular readings (at 2.00 pm ) were also taken from the water metre installed on the pipeline supplying water to the retention tank (Fig. 2). On the basis of the records of water metre and daily attendance, the amount of water supplementing the circulation was calculated per day for one bather. The obtained results allowed to compare it to

Figure 2.
Station of registration of demand for supplementary water with water metre on the pipeline supplying tap water to the retention tank
Rysunek 2. Stacia rejestracii zaporrzebowania na wodẹ uzupetniaiaca wraz z wodomierzem na rurociago doprowadzającym wodę wodociagowa do zbiornika retencyinego

water samples collected every two hours during one day, with the trend line, are presented in Fig. 3.

Similarly, Fig. 4 shows the results of the analysis performed daily for one week. In addition, Fig. 4 shows (with arrows) the dates of filter washing (at 10.00 pm on May 08. May 10, May 12 and May 14), after which the retention tank was filled with tap water in the amount used to wash the filter bed.

As the temperature of pool water was stable ( $27.2^{\circ} \mathrm{C}-27.8^{\circ} \mathrm{C}$ ) and regulated by heat exchangers, it was not included in the graphs.

Table 4, for comparison, presents the permissible values or recommended ranges of values of the tested parameters, their average values, and for the assessment of the variability of the values of individual parameters in the analysed time, the correlation coefficient $(r)$.

## Results of measuring the demand for supplementary tap water

The retention tank in the tested object was filled with tap water in an amount to ensure the supplementation of water losses arising during bathing (water splashed, evaporated, carried on the bodies and the swimwear of bathers) and water used to wash the filter bed, took place every day at about 10.00 pm after closing the pool . Table 5 shows the daily demand for supplementary water based on the readings of the water metre installed on the pipeline supplying water to the retention tank. To compare the recommended value of the demand for supplementary water for a bather ( $30 \mathrm{~L} /$ bather d), the daily and hourly attendance was also compared.

## Discussion

## pH

The value of the pH as an indicator of correct disinfection and coagulation process should be between 6.5-7.6 [16]. To ensure


Table 4. Permissible, average and $r$ - correlation coefficient values of pool water quality parameters during daily and weekly tests
Tabela 4. Dopuszczalne, średnie i r - wartości współczynnika korelacji parametrów jakości wody basenowej wyznaczone podczas badania w ciągu jednego dnia i jednego tygodnia

| Parameter | Unit | Permissible value [16] | Average value from samples taken every two hours during the day ( $8 \mathrm{am}-8 \mathrm{pm}$ ) | Pearson's r correlation coefficient | Average value from samples taken daily during the week (Monday-Sunday) | Pearson's r correlation coefficient |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Absorbance $\mathrm{UV}_{254 \mathrm{~nm}}$ | $\mathrm{m}^{-1}$ | - | 7.4 | 0.67 | 5.44 | 0.35 |
| Temperature | ${ }^{\circ} \mathrm{C}$ | - | 27.5 | - | 27.6 | - |
| Redox potential | mV | >750 | 655 | -0.71 | 655 | -0.04 |
| Turbidity | NTU | 0.30 | 0.16 | -0.33 | 0.17 | 0.60 |
| COD | $\mathrm{mg} \mathrm{O}_{2} / \mathrm{L}$ | 4.00 | 1.93 | 0.33 | 2.29 | 0.52 |
| Free chlorine | $\mathrm{mg} \mathrm{Cl} 2 / \mathrm{L}$ | 0.3-0.6 | 0.24 | - | 0.48 | -0.08 |
| Total chlorine | $\mathrm{mg} \mathrm{Cl}_{2} / \mathrm{L}$ | - | 0.70 | 0.59 | 0.93 | 0.34 |
| Combined chlorine | $\mathrm{mg} \mathrm{Cl}_{2} / \mathrm{L}$ | 0.30 | 0.46 | 0.67 | 0.45 | 0.46 |
| Chlorides | $\mathrm{mg} \mathrm{Cl} / \mathrm{L}$ | - | 227 | 0.84 | 213 | -0.37 |
| Nitrates | $\mathrm{mg} \mathrm{NO} 3{ }_{3} / \mathrm{L}$ | 20.00 | 3.57 | 0.89 | 3.73 | 0.50 |
| TOC | mg C/L | - | 6.679 | 0.65 | 5.771 | -0.22 |
| pH | - | 6.5-7.6 | 7.11 | 0.74 | 7.13 | 0.90 |

optimum effectiveness of sodium hypochlorite used for water disinfection and the lowest possible potential for the formation of disinfection by-products (DBPs), the pH of pool water required constant adjustment by automatic dosing of a $50 \%$ sulfuric acid solution. The pH adjustment was carried out in the range of 7.0 -7.2 , according to the indications of the measuring device. During the daily and weekly
analyses, there was an upward trend in pH values. In the daily cycle in the range of 6.96 - 7.24 (Fig. 3a) and in the weekly cycle in the range of 7.02-7.20 (Fig. 4a). Although the range of the increase in pH values during the day and week was small, the values of the correlation coefficients ( $r=0.74$ and $r=0.9$, respectively) indicate a strong dependence of pool water pH on the continuous dosing of
sodium hypochlorite and thus on the "age" of the water and confirm the need for constant pH correction.

## Turbidity

Turbidity as an indicator of aesthetic and the usable water quality and effectiveness of the coagulation process should not exceed 0.3 NTU [16]. Higher turbidity values can


Figure 4.
Swimming pool water quality parameters determined daily during one week (The arrow indicates the day of washing the filter bed - the 8, 10, 12, 14 of May after closing the pool for swimmers) Rysunek 4. Parametry jakości wody basenowej oznaczone codziennie w ciqgu jednego tygodnia (strzałka wskazuje dzień płukania złoża filłracyjnego - 8, 10, 12, 14 maj po zamknięciu basenu dla osób pływajqcych)

Table 5. Summary of the volume of tap water that supplements the pool circuit (based on readings of the water meter readings)
Tabela 5. Zestawienie obiętości wody wodociqgowej, uzupełniającej obieg basenu (na podstawie wskazań wodomierza)

| Date, 2022 |  | Indication of the <br> water meter, $\mathrm{m}^{3}$ | Quantity <br> of supplementary <br> water, $\mathrm{m}^{3} / \mathrm{d}$ | Daily attendance, <br> bather/d | Quantity of supplementary <br> water per bather and a day, <br> L/bather d |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 09.05. | Monday | 37333 | 16 | 384 | 41.7 |
| 10.05. | Tuesday | 37350 | 17 | 368 | 46.2 |
| 11.05. | Wednesday | 37364 | 14 | 384 | 36.5 |
| 12.05. | Thursday | 37381 | 17 | 384 | 44.3 |
| 13.05. | Friday | 37394 | 13 | 400 | 32.5 |
| 14.05. | Saturday | 37408 | 14 | 368 | 38.0 |
| 15.05. | Sunday | 37426 | 18 | 400 | 45.0 |
| The sum of |  |  | 109 | 2688 | 284.1 |
| Average |  |  | 15.6 | 384 | 40.6 |

cause an increased likelihood of the development of microorganisms, including pathogenic ones, in pool water [ $11,22,23$ ]. During the one-day analysis, there was no significant dependence of the turbidity value on the time of use of pool water, indicating a properly conducted filtration process, and the highest turbidity was measured during the highest load on the basin at 12:00 am (0.21 NTU, Fig. 3b), when a group of 26 children used the pool as part of school swimming lessons.

During the weekly analysis, despite the large variation in turbidity values from one day to the next, a general upward trend with a decrease in turbidity after daily replenishment of the circulation with tap water (Fig. 4b).

## Absorbance UV $2_{254 n m^{\prime}}$, TOC and COD

The absorbance in the ultraviolet (UV254) allows the identification of the fraction of dissolved organic carbon, characterised by a high content of aromatic components and thus a high potential for the forma-




tion of UPD [24-26]. In the work of, among others, Łaskawiec et al., it was shown that in practise, the measurement of absorbance, like TOC and COD, can be a method to quantify the total organic content of pool waters [27,28].

In the present study, the distribution of absorbance, TOC, and COD values was similar. There was an increasing trend for these parameters during the day ( $r=0.67, r$ $=0.65, r=0.33$, respectively) and their highest values were determined at 8 pm (Fig. 3c, $e, f)$. The swimming pool water quality regulation [16] only specifies a limit value for $\operatorname{COD}(4 \mathrm{mg} \mathrm{O} 2 / \mathrm{L})$ and TOC ( $4 \mathrm{mg} \mathrm{C} / \mathrm{L}$ ). Although the COD values in each sample did not exceed the limit value (Fig. 3e and Fig. $4 \mathrm{e})$, the TOC values in each sample were already much higher (Fig. 3 f and Fig. 4 f ).

In the case of the weekly analysis, despite the slight upward trend of the mentioned parameters with the time of pool water operation, there was a noticeable decrease in their values after refilling the circuit with tap water after washing the filter bed.

Taking into account the research of the results of the presented and previous studies, in the field of pool water quality, it seems
more reasonable (both in terms of precision and measurement methodology) to measure absorbance instead of COD and TOC [2]. Based on the results of studies on the quality of surface water, groundwater, infiltration water and water subjected to treatment processes, carried out by Nowacka et al. [26], Potter et al. [25], Shi et al. [24], among others, it is initially proposed to adopt the reference value of $6 \mathrm{~m}^{-1}$, after exceeding which the water in the swimming pool circuit should be renewed.

However, determining the exact absorbance limit for pool water requires continued testing of water samples collected from different types of pools.

## Redox potential

The redox potential allows to assess the course of the chlorination process and the rate of bacterial destruction. A high potential value indicates that bathers are well protected against the risk of infection while bathing. The water in pools requires a very high redox potential $\geq 750 \mathrm{mV}$ [16, 17].

During both the one-day and one-week analysis, the average value of the redox potential was 655 mV and was not 750 mV in any sample (Fig. 3d and Fig. 4d). Research experience on the modification of swimming pool water treatment systems to improve water quality shows that only WTS equipped with an ozonation system or in swimming pools where the chlorine concentration in the water is maintained at the level of 1 mg $\mathrm{Cl}_{2} / \mathrm{L}$ can be marked with a redox value greater than 750 mV [1,2,29].

The analysed pool is characterised by a high load of bathers, including swimming lessons for children. Therefore, only if more effective disinfection is introduced or the dose of hypochlorite is increased, it will be possible to obtain the required redox potential.

The significant decrease in redox, as seen in Fig. 3d, as the day progresses (from 724 mV at 8 am to 611 mV at 8 pm ) should be a signal for necessary replenishment of the pool circuit with tap water. Thus, regular monitoring of redox potential values can be a good indicator of "refreshing" pool water.

## Chlorides and nitrates

An increase in chlorides and nitrates in pool water indicates water contamination by products of bather metabolism, overloading of the pool, and insufficient water exchange in the pool circuit [15,30]. Regular monitoring of chloride and nitrate concentrations is a good indicator of pool water "ageing", and the nitrate limit value of $20 \mathrm{mg} \mathrm{NO}_{3} / \mathrm{L}$ [16] and the chloride limit value of 250 mg $\mathrm{Cl}^{-} / \mathrm{L}$ [19] should be considered as information about the state of the limit concentration of dissolved pollutants and the moment to
decide on complete or at least partial replacement of water in the pool circuit.

Analysis of pool water quality conducted over one day confirms the phenomenon of chloride (from $156 \mathrm{mg} \mathrm{Cl}^{-} / \mathrm{L}$ to 255 mg $\mathrm{Cl}^{-} / \mathrm{L}$, Fig. 3 g ) and nitrate (from 3.38 mg $\mathrm{NO}_{3}^{-} / \mathrm{L}$ to $4.02 \mathrm{mg} \mathrm{NO} \mathrm{N}_{3}^{-} / \mathrm{L}$, Fig. 3h) increases and the need to apply water renewal through daily replenishment with tap water. On the other hand, the analysis of chloride and nitrate content carried out during the week and the slight differences between days (Fig. 4 g and Fig. 4 h ) confirm the validity of replenishing the circulation after each wash of the filter bed.

It should be noted that when the water recovered from washings is used to replenish pool water losses (which is already a standard in many newly built swimming pool facilities), chlorides and nitrates in the pool water may concentrate much faster. Despite the undoubted advantage of such a system, i.e. much lower costs for the consumption of tap water and discharged sewage, it is necessary to determine the length of cycles in which the water from the washings can be safely used as water supplying the swimming pool circuit [31].

## Free chlorine and combined chlorine

Free chlorine and combined chlorine are indicators of the antiseptic effect of the disinfectant. Since free and combined chlorine can occur simultaneously, determining the form of residual chlorine is very important for the course and effect of water disinfection and for the organoleptic and health properties of water [32-34].

The concentration of free chlorine in the waters of sports-type swimming pools, to protect against secondary water contamination, should be in the range of $0.3-0.6 \mathrm{mg}$ $\mathrm{Cl}_{2} / \mathrm{L}$, with the possibility of decreasing the lower value to $0.2 \mathrm{mg} \mathrm{Cl} 2 / \mathrm{L}$, provided that an additional and effective disinfection step is used $[2,17]$.

The concentration of combined chlorine, a by-product of disinfection, responsible for the so-called irritation syndrome in swimmers, that is, dry skin, irritation of the mucous membranes of the nose and throat, the unpleasant smell of water and air in the swimming pool hall [20] - should not exceed $0.3 \mathrm{mg} \mathrm{Cl} 2 / \mathrm{L}[16,17,32]$.

The variable concentration of free chlorine during the day $-0.41 \mathrm{mg} \mathrm{Cl}_{2} / \mathrm{L}$ (at 8.00 am ), a sudden decrease to $0.04 \mathrm{mg} \mathrm{Cl} 2 / \mathrm{L}$ (at 10.00 am ) and then $0.21-0.29 \mathrm{mg} \mathrm{Cl}_{2} / \mathrm{L}$ in the afternoon and evening hours (Fig. 3i) shows that the use of automatic dosing of the disinfectant (sodium hypochlorite) is necessary to obtain a quick antiseptic response to changing load of bathers during the day. Simultane-
ous increase in combined chlorine during the day (from $0.34 \mathrm{mgCl}_{2} / \mathrm{L}$ to $0.57 \mathrm{mg} \mathrm{Cl} 2 / \mathrm{L}$, Fig. 3j) and the correlation coefficient ( $r=0.67$ ) confirm the daily need to renew the water in the swimming pool circuit.

The results of the weekly analysis of free chlorine indicate a stable protection of bathers against infection $\left(0.35-0.65 \mathrm{mg} \mathrm{Cl}_{2} / \mathrm{L}\right.$, Fig 4 i$)$. On the other hand, combined chlorine analysis, despite an upward trend ( $r=0.46$ ), but with clear decreases in concentration after the next "refreshing" of the circuit (Fig. 4 ) , again indicates the need to dilute the pool water with tap water.

## Water demand

Although the results of pool water the analysis of physicochemical parameters clearly indicate the need for renewal of water in the pool circuit, understood as its constant treatment and replenishment of losses with tap water that meets the requirements as for drinking water [19], the amount of water "refreshing" the pool circuit will have a significant impact on the variability of these parameters.

In the swimming pool tested, the average demand for supplementary water was 15.6 $\mathrm{m}^{3} /$ day and ranged from 13 to $18 \mathrm{~m}^{3} /$ day. After taking into account attendance, there was an average of $40.6 \mathrm{~L} /$ day per bather and it was the amount of supplementary water that ensured the renewal of water in the swimming pool circuit. However, compared to the recommended $30 \mathrm{~L} /$ bather day in DIN 19643, it was up to $26 \%$ higher.

Assuming that there is no effect of supplementing the swimming pool circuit with water in the amount of $30 \mathrm{~L} /$ bather day and with regard to rationalising the water and sewage management, the difference between the actual and recommended amount of supplementary water will have a significant impact on the amount of costs for water from the water supply network and sewage discharged to the sewage system.

An unequivocal statement to what extent the reduction of water demand will affect the quality of swimming pool water requires further analysis, taking into account the renewal of swimming pool water with various "doses" of tap water.

## Conclusions

The problem of water renewal in swimming pool circuits is typically due to the accumulation of contaminants, chemicals, and impurities in the pool water over time. To maintain a clean and safe swimming environment, regular water renewal and treatment are necessary.

Swimming pool water renewal should be understood as a set of processes and methods
of water treatment (filtration, chemical treatment, disinfection, and washing filter bed) linked to a system of water circulation (preventing stagnant areas where contaminants can accumulate) and partial water replacement (helps dilute accumulated impurities and maintain water quality).

In the case of the tested swimming pool, the quality parameters of the swimming pool water, such as absorbance, redox potential, combined chlorine, nitrates, and chlorides, can be considered indicative for the daily assessment of its quality and, depending on their size, actions can be taken to refresh/ replenish the circuit with water from the water supply network. The amount of supplementary water calculated during the tests (on average $40.6 \mathrm{~L} /$ bather day) significantly exceeds the recommendations of DIN 19643.

In order to rationalise water management in this pool, water quality analysis should be carried out with the use of supplementary water reduced to $30 \mathrm{~L} /$ bather day (i.e., on average $11.5 \mathrm{~m}^{3} / \mathrm{d}$ ) and taking into account the minimum required demand for water to wash the filter bed (i.e. $10.2 \mathrm{~m}^{3} / \mathrm{d}$ ).

On the other hand, the systematic daily analysis carried out during the week and the differences in the values of water quality parameters (absorbance, TOC, COD, redox, turbidity, combined chlorine) between subsequent washings of the filter bed confirmed the need to supplement a tap water circuit with the volume of approximately $15 \mathrm{~m}^{3}$ per day.

It is very important to note that each swimming pool is unique, and the specific approach to water renewal may vary depending on factors such as pool size, pool type, bathers load and local regulations.

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