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Application of pre-ozonation process in swimming pool water treatment technology

Joanna Wyczarska-Kokot*, Florian Piechurski

Department of Water and Wastewater Engineering, Faculty of Energy and Environmental Engineering, Silesian University of Technology, Konarskiego 18, 44-100 Gliwice, Poland, emails: joanna.wyczarska-kokot@polsl.pl (J. Wyczarska-Kokot), florian.piechurski@polsl.pl (F. Piechurski)

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ABSTRACT

The main objective of this research was to determine the possibility of using the highly ozonated water for the pre-ozonation process as a complementary process to the conventional pool water treatment method. In the tested facility, contamination with *P. aeruginosa*, accompanying over-normative colony-forming unit of total number of bacteria and a high content of combined chlorine (>0.3 mg Cl_2/L in pool water and >0.2 mg Cl_2/L in circulating water) and chloroform, was a basic problem related to water quality that caused the swimming pools to be excluded from an operation on several occasions. The research was divided into three parts. In each part, the quality of pool water was assessed in relation to the applicable requirements in this respect. In the first part, the quality of water treated in a conventional system was evaluated. In the second part, a mobile system for the production and dosage of highly ozonated water (SPID-WOFIL®) was included in the water treatment system (before the proper filtration system). In this part, several preliminary tasks were performed in order to prepare the ozonation system for operation on an everyday basis. In the third part, a sequential water pre-ozonation process was established. As a result of the pre-ozonation process (0.3–0.6 mg O_3/L dose), protection against microbiological water contamination and reduction of the content of selected DBP (chloramines: 12%–48%, trihalomethane: 35%–71%, and chloroform 4%–96%) was achieved.

Keywords: Pre-ozonation; Swimming pool water; Microbial contamination; Combined chlorine

1. Introduction

Swimming is one of the most popular aquatic activities. Swimming pools are used by millions of people seeking recreation, rehabilitation, wellness, and other health benefits. Just like natural and tap water, pool water may contain microbiological and chemical contaminants. Possible sources of these contaminants in swimming pools include contamination from swimmers (saliva, sweat, cosmetics, and urine), from the water supplied to the pool, from circulating water treatment and disinfection system [1–5].

Effective treatment of swimming pool water and constant control of its quality ensures the health of swimmers and staff, as well as protection against the spread of infections. A commonly used pool water treatment system is the so-called conventional system that consists of a filtration process (supported by coagulation) and a disinfection process, just as essential to the process of deactivation of pathogenic microorganisms [6,7].

The most frequently used disinfectant and oxidant for maintaining swimming pool water quality is chlorine. However, it reacts with organic matter, leading to the production of disinfection by-products (DBPs) which are a health risk for both swimmers and swimming pool staff [8–12].

Due to this awareness, among other things, the demand for alternatives to chlorine disinfection has increased. Such alternative processes include electrochemically generated mixed oxidants [13], ultraviolet irradiation (UV) and

* Corresponding author.

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UV-based advanced oxidation processes (AOPs), such as UV/H_2O_2 [14–17], ozone (O_3), and ozone-based AOPs, such as O_3/H_2O_2 and O_3/UV [18–20].

Despite the possibility of using highly efficient water disinfection systems and the ability to identify about 600 different DBPs [21–23], only combined chlorine, trihalomethane (THM), and chloroform are regulated by global (WHO [7]), American [24], and European (e.g., DIN 19643 [6], PWTAG [25], and Polish Ordinance of the Minister of Health [26]) documents pertaining to the quality of swimming pool water. Of these, combined chlorine (chloramines) is the most troublesome for bathers. It is responsible for the so-called "irritation syndrome" in swimmers, dry skin, and irritations of mucous membranes. It also causes an unpleasant odor of swimming pool water and has mutagenic properties [8,10,22,27].

The decisive role in the assessment of pool water quality is played by the results of microbiological tests and the assessment of the sanitary condition of the facility. Nevertheless, the results of physicochemical tests are the primary means of assessing the degree of its contamination.

In the case of the presence of *Pseudomonas aeruginosa* or *Escherichia coli* in pool water samples or in circulation water samples (water entering the pool), and if the total number of mesophilic bacteria found in the samples (grown at 36°C ± 2°C and after 44 ± 4 h) is above 100 CFU/mL in a pool or above 20 CFU/mL in a circulating water, the swimming pool has to be closed and the procedures provided for in the case of microbial contamination of water has to be implemented. Similar procedures are anticipated when *Legionella* sp. is found in water samples from pool circuits equipped with hydromassage devices, aerosol-generating devices or in water with water temperature above 30°C [6,7,26].

P. aeruginosa is an important opportunistic pathogen in recreational waters and the primary cause of hot tub folliculitis and otitis externa [28,29]. The water in swimming pools circulation systems is an important reservoir for *P. aeruginosa,* as it is a significant exposure pathway for bacterial transmission because wet skin and occlusion provide optimal conditions for *P. aeruginosa* to thrive. Water treatment installations supplying the swimming pools and hot tubs with water have complex piping systems which create opportunities for the biofilm development and make removal difficult. A place of especially high concentration of *P. aeruginosa* are beds of filters used in swimming pool water treatment systems. Additionally, the temperature range in indoor swimming pools and considerable aeration of hot tub water may cause the rapid spread of bacteria, and thus chlorine-based disinfectants may not be effective [4,29,30].

In the tested facility, contamination with *P. aeruginosa*, accompanying over-normative colony-forming unit (CFU) of a total number of bacteria and a high content of combined chlorine (>0.3 mg Cl_2/L in pool water and >0.2 mg Cl_2/L in circulating water [6,26]), was a basic problem related to water quality that caused the swimming pools to be excluded from an operation on several occasions. In order to solve this problem, an experiment was carried out involving the pre-ozonation process.

The aim of this study was an evaluation of the effectiveness of the pre-ozonation process by dosing highly ozonized water into the pool water purification system, to protect the water in the circulation and pool basins from bacterial contamination and reduce the combined chlorine content. Furthermore, the additional aim was to determine the possibility of sequential operation of the device for the production and dosing of ozone on the assumption that three swimming pool water circuits would be supplied from one device. It was also assumed that the pre-ozonation process would be used as a supplementary process for the conventional method of water treatment.

2. Methodology of the research

2.1. Tested pools and circulation systems

The tested facility includes: sports swimming pool (SP), recreational pool (RP), two hot tubs (HT1 and HT2) and toddlers' pool (TP). The facility has three closed circulations of water treatment: circuit 1 (*C*1) for SP, circuit 2 (*C*2) for an RP, hot tub 1 and hot tub 2 (RP+HT1+HT2) and circuit 3 (*C*3) for TP. The circuits are equipped with retention tanks and filtration systems. Two types of filtration systems are applied in this facility. In circuit 1 and 2 the water is filtered with the help of the open vacuum washed with diatomaceous earth filters. Circuit 3 uses the closed pressure filter with an activated glass AFM bed for filtration. Additionally, in this circuit, before the filter, a coagulant solution is applied (5% solution of aluminum hydroxide chloride). The water disinfection is carried out with 14% sodium hypochlorite solution (NaOCl). If the pH of the water needs adjustment, a 30% solution of sulfuric acid (H_2SO_4) is used. The basic technical parameters for the tested circuit and their pools are summarized in Table 1.

In January 2017, the authors carried out an internal audit of the facility taking into account the quality of the pool water, the quality of water flowing into the basins (after the treatment process was completed) and the efficiency of the water treatment installations and devices in particular circuits of swimming pools. This stage of the study was described in this paper and is listed as "Without O3."

On the basis of the analysis of the obtained results, it was deemed necessary to adapt the pool water treatment installation to the current requirements on the quality of water in swimming pools [7,26,31].

Based on literature research, analysis of studies regarding the increased effectiveness of pool water treatment [32–37], the authors' own experience in this area [27,31,38], audit results, and technical capabilities, a pre-ozonation system (supporting the conventional system) was chosen. It was installed to improve the water quality in the object in question, remove the microbiological hazard of water contamination and reduce the DBPs content.

Considering that ozone can simultaneously aggregate fine particles and break down large ones, making them more mineralized and easier to remove, and the results of research carried out, among others, by Sadrnourmohamadi and Gorczyca [39], Hua and Reckhow [40], Hansen et al. [19], and Chiang et al. [41], the main part of the experiment (i.e., after cleaning the walls of tanks and installations), consisted of dosing ozone water with a concentration of 0.3 mg O_3/L.

As part of experimental research, from May to July 2017, a mobile system for the production and dosing of highly ozonated water—SPID, WOFIL®—was introduced to the swimming pool water treatment system [42,43].

Table 1
Technical parameters of the tested swimming pools

Swimming pool	Circuit (*C*1)	Circuit (*C*2)			Circuit (*C*3)
	SP	RP	HT1	HT2	TP
Water surface area in the pool (m^2)	400.0	156.2	3.9	3.9	29.9
Depth of the pool basin (m)	1.2–1.8	1.0	1.0	1.0	0.35
Volume of the pool basin (m^3)	601.0	156.0	2.0	2.0	10.5
Average attendance (person/h)	25	23	6	6	6
Filter type	Vacuum, open, and washed with diatomaceous earth	Vacuum, open, and washed with diatomaceous earth			Pressure, closed
Filter size (m)	3.7 × 1.6 × 1.4	3.95 × 2.35 × 1.4			Ø 1.2
Type of filter bed	Diatomaceous earth F50	Diatomaceous earth F50			Activated glass AFM
Filtration flow (m^3/h)	178	281			34
Filtration velocity (m/h)	4	4			30
The time of one water change in the pool (h)	3.38	0.57			0.31

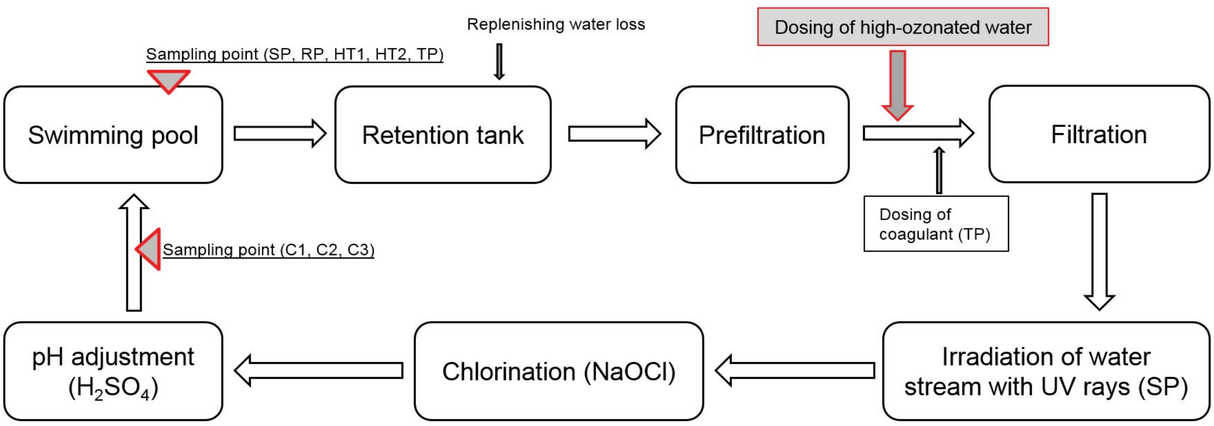


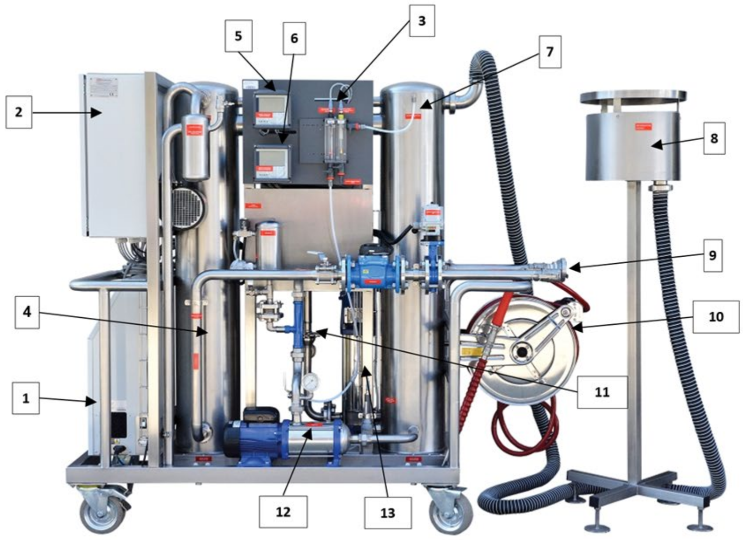
Fig. 1. Water treatment system in tested swimming pools.

The swimming pool technology diagram with the ozone dosing point and sampling points is shown in Fig. 1.

2.2. The applied pre-ozonation system

In order to remove the microbial threat of water contamination and to minimize the impact of DBPs on the health of people using the swimming pools SPID system has been introduced to the studied pool water treatment circuits—a mobile system for producing and dosing highly ozonated water. SPID system (blue series—Fig. 2) was provided by WOFIL® Company, Poland [42].

This system is an autonomous device for the preparation of a disinfectant solution based on ozone water, which operates on water and electricity supplied from the electricity grid or from a power generator. Monitoring the system operation parameters and their regulation is carried out by means of a control panel (HMI). Water inflow, the outflow of disinfectant, regulation of water saturation with ozone, and maintaining its set dose is automated. Ozone used for the preparation of ozone water is produced by an ozone generator with a capacity of 60 g O_3/h, equipped with an unloading module with an air-cooled aluminum plate. Ozone is produced from oxygen taken from the surrounding air. The nominal capacity of the entire system is 4 m^3/h of highly ozonated water (max 6 mg O_3/L), at a pressure of 4–12 bar. For operational safety, the contact columns are equipped with a water-gas trap with overflow, blow-through fan, on-line devices measuring the residual ozone in water, on-line devices measuring ozone in air, integrated with a sound alarm and ozone destructor connected with a flexible santoprene hose to the steel grounding spiral. The pumping system enables the dosing of highly ozonated water directly to the treated circulating water. The SPID system can also be



1	Oxygen generator
2	Ozone generator and HMI control panel
3	Ozone dose regulator
4	Contact column - a system of mixing ozone and water
5	Measurement of residual ozone in water
6	Measurement of ozone in the air
7	Contact column with a water-gas trap with overflow
8	Mobile ozone destructor
9	Port for connection to the circulating water
10	Spray lance for cleaning surfaces
11	Injector
12	Circulation pump
13	Pump with inverter

Fig. 2. SPID—the mobile system for production and dosage of highly ozonated water (blue series) [42].

used for safe cleaning and disinfection of various surfaces by means of a spray lance [43].

2.3. Process of research, materials, and methods

In the first week of the experiment, the overflow troughs along with the drain pipes and the walls of the retention tanks were cleaned, using the spray lance, with highly ozonated water (ozone dose of 1 mg O_3/L). Over the next days, water from the SPID device (ozone dose of 0.6 mg O_3/L) was mixed with water in expansion tanks. These activities were carried out during the night break while controlling the ozone content in water and air. After the cleaning operations, the ozone generator was alternately connected to *C*1, *C*2, and *C*3 circuit systems. Aiming not only to improve the bactericidal properties but also to increase the removal of organic matter, the dosing nozzles were installed into the pipeline section after the pumps with pre-filters and before the main filters. In this way, the water pre-ozonation process was carried out. Initially, ozone water (the concentration of residual ozone in water 0.6 mg O_3/L) was dosed for 8 h into the *C*1 circuit, then for 8 h into *C*2 circuit and, for the next 8 h, into *C*3 circuit. This stage of the study was described as "Experiment O3" (Ex. O3).

Finally (from September 2018 to March 2019), in order to ensure a bacteriologically and physicochemically stable swimming pool water, in the continuous operation of the swimming pool facility, it was established that pre-ozonation of water will be conducted sequentially with water with an ozone concentration of 0.3 mg O_3/L. This means that the ozone generator was included in the subsequent pool circuits (*C*1, *C*2, and *C*3) every 24 h, alternatingly. In addition, due to the large volume of SP basin (601 m^3) and the long time of water overflow (3.38 h), the circuit for this pool was equipped with a medium-pressure UV lamp (radiation dose 1,000–1,500 J/m^2). This stage of the study was described as "Sequential O3" (Seq. O3).

During the stage "Without O3" (from January to May 2017) water samples for physicochemical and bacteriological analyses were collected 9 times. During the stage "Experiment O3," using the device for ozone production (from May to July 2017), water samples were collected 7 times. During the stage "Sequential O3," after installation of the device and establishing its sequential integration into particular circuits (from September 2018 to March 2019), water samples were collected 11 times.

In order to assess the water quality in the tested swimming pools, the following parameters were analyzed: the pH of water, redox, and temperature (potentiometric method *in situ*, sensION meter + MM150 DL, Hach®), turbidity (nephelometric method, TN 100 turbidity meter, Eutech®), nitrates, and ozone content (spectrophotometric method; spectrophotometer DR 3900 with RFID technology, Hach®), oxidizability—chemical oxygen demand (COD; titrimetric method in an acid environment in accordance with PN-EN ISO 8467:2001), free chlorine and combined chlorine (colorimetric method *in situ*, Pocket ColorimeterTM II, Hach®), chloroform, and total THM (gas chromatography method, Agilent Technologies GC7890B chromatograph with MSD5977A mass detector), number of colony-forming units (CFU) *P. aeruginosa* (method according to PN-EN ISO 16266:2009), the *E. coli* CFU number (method according to PN-EN ISO 9308-1:2014-12/A1:2017-04) and the *Legionella* sp. CFU number (method according to PN-EN ISO 11731:2017).

Sampling took place in accordance with the guidelines of the Polish standard PN-ISO 5667-5:2003. Water samples were taken from swimming pools (SP, RP, HT1, HT2, and TP) and test cocks were installed on pipelines of circuits 1, 2, and 3 (*C*1, *C*2, and *C*3), supplying treated water to swimming pools. Samples were taken from a depth of about 30 cm below the water surface. The authors, guided by the experiments from previous studies, took samples at several characteristic basin points and used a mixed sample for analysis [44].

The samples were collected and marked in accordance with applicable standards and methods [6,45–48]. The statistical analysis of the analysis results was based on the Microsoft Excel data analysis package.

3. Results and discussion

Bacteriological, physical, and chemical research play a predominant part in the inspection process of swimming pool water quality. The main goal of the bacteriological research is an assessment of the risks from microorganisms. The main goal of the physical and chemical research is to determine the chemical composition of water, with special emphasis on substances hazardous to health (especially DBPs). Comparison of obtained results with admissible levels of pollutants is the basis for determining if the water is suitable for bathing. [6,7,26].

The main problem in the tested pool water turned out to be the content of combined chlorine exceeding 0.3 mg Cl_2/L in basins RP, HT1, and HT2 (circuit *C*2), combined chlorine in circulating water above 0.2 mg Cl_2/L (in all circuits), chloroform in RP basin and repeated contamination of the circulating water and pool basins with colonies of *P. aeruginosa* and the total number of mesophilic bacteria.

3.1. Microbiological research results and discussion

In the first stage of the research (Without O3), in each sample taken for microbiological tests (from SP, RP, HT1, HT2, and TP basins and from *C*1, *C*2, and *C*3 circulation systems), CFU of the total number of bacteria was determined. It was found that the limit value for swimming pool water (<100 CFU/mL) was exceeded in the basin of the RP (192 CFU/mL) and in hot tubs (185 CFU/mL in HT1 and 210 CFU/mL in HT2). The limit values in the water supplying the basins (<20 CFU/mL) were exceeded twice in *C*1 (141 CFU/mL), twice in *C*2 (106 CFU/mL and 193 CFU/mL) and three times in *C*3 (120 CFU/mL, 84 CFU/mL and 170 CFU/mL). The high level of contamination with mesophilic bacteria in *C*2 circuit was accompanied by high contamination with *P. aeruginosa*. In the same water samples, *P. aeruginosa* was determined at 83 CFU/100 mL and 104 CFU/100 mL, respectively. In addition, the presence of *P. aeruginosa* was detected in SP (5 CFU/100 mL), in RP (3 CFU/100 mL), and in TP (10 CFU/100 mL).

The high overall number of indicator bacteria (mesophilic) and repeated contamination with *P. aeruginosa* indicated favorable conditions for the development of bacteria in the installation of water treatment circuits. Usually, bacterial colonies accumulate in the filter beds (as a result of improper rinsing or lack of disinfection of filtration beds), in installation pipelines, and in pool basins (as a result of small overflows and the emergence of dead zones [4,31,44]).

Table 2 presents the results of bacteriological tests of water from pools (SP, RP, HT1, HT2, and TP) and water from circulation systems (*C*1, *C*2, and *C*3) carried out before the pre-ozonization process (Without O3) was applied.

As a result of the application of the device for the production and dosing of highly ozonated water, during both the second part of the research (Ex. O3) and in the sequential operation of the device (Seq. O3), no *P. aeruginosa* bacteria were found in the samples of water from the basins and from the circulation. The total number of bacteria at this time did not exceed 70 CFU/mL in water from basins and 19 CFU/mL in samples from *C*1, *C*2, and *C*3.

In all parts of the study, no *E. coli* and *Legionella* sp. were found.

A very unlikely cause of bacterial contamination is the pool load since the attendance rate did not reach even half of the maximum permissible for this facility. The permissible attendance for this facility is 155 person/h. The attendance at the analyzed pool facility was similar in particular study stages and ranged from 63 to 68 persons per hour (Table 1). However, it should be emphasized that the degree of contamination of pool water depends to a great extent on compliance with swimmers' personal hygiene rules [2,49,50].

3.2. Physicochemical research results and discussion

There were no great differences between the pH of water from pool basins and water from the circulation system. The average pH of the pool water was 6.7–7.2 (Fig. 3a), and circulating water 6.8–7.4 (Fig. 3b) and they were within the required range, that is, 6.5–7.6 [6,7,26].

Redox potential values in pool water samples averaged from 710 mV (TP) to 767 mV (RP). In the circulating water samples, the redox ranged from 697 mV (*C*3) to 746 mV (*C*1 and *C*2). The control of this parameter is important due to the rate of destruction of pathogenic microorganisms. With the increase in the redox potential, the risk of bacteriological contamination of the water decreases. In addition, high content of disinfectant and low content of contaminants translates into a high value of the redox potential [7,31]. According to the documents on the quality of swimming pool water, the redox value in TPs should not be less than 720 mV, and in other basin pools not <750 mV (at pH in the range 6.5–7.3) [6,26].

As a result of using the SPID device in the second (Ex. O3) and third (Seq. O3) stage of the research, the pool water redox values decreased in relation to the values from the first part of the research (Without O3) by ~2–6% (RP, HT1, and HT2) or remained at the same level (SP, TP). The average redox values of pool water treated in the pre-ozonation system met the requirements only in SP and TP. In RP, HT1, and HT2 they were, respectively: 724, 718, and 722 mV (Fig. 4a). There is no obligation to control the redox potential in the circulating water. However, determining this parameter also in the circulating water is important for the comparison of the oxidation-reduction properties of both types of pool water. In the circulating water, after a decrease (2–6%) as a result of cleaning the overflow troughs and retention tanks with highly ozonated water, there was a slight increase in the redox by ~3% in *C*1 and ~6% in *C*3, and a minimum decrease by ~1% in *C*2 (Fig. 4b). Finally, the redox of the circulating water was maintained at a slightly higher level (732–741 mV) in relation to the redox of water from the pool basins (718–724 mV), with the exception of the SP (758 mV).

The permissible turbidity value of pool water is 0.50 NTU, and water from the circulation system is 0.3 NTU [6,26]. In most of the analyzed samples the turbidity did not exceed the recommended values (Figs. 5a and b), with the exception of turbidity (Without O3) in water from *C*3 circuit, that is the one feeding the TP, for which the turbidity was, on average, 0.42 NTU. As a result of the use of the SPID device in all basins and in the feed water, a decrease in turbidity was noted. The greatest improvement in water turbidity was found in HT1 (by 31%), HT2 (by 41%), and in *C*3 (by 68%). In the case of water from the circuit, in which the solution of

Table 2
The results of bacteriological tests before installing the pre-ozonation system for pool and circulating water

Pool (Sampling period)	Sport swimming pool—SP (January–May 2017)																	
Place of sampling	SP	C1	SP	C1	SP	C1	SP	C1	SP	C1	SP	C1	SP	C1	SP	C1	SP	C1
E. coli (CFU/100 mL)	0	0	0	–	0	0	0	–	0	0	0	–	0	0	0	–	0	0
P. aeruginosa (CFU/100 mL)	0	0	0	–	0	0	0	–	0	0	0	–	0	0	0	–	5	0
Total number of bacteria, 36°C ± 2°C, and 44 ± 4 h (CFU/mL)	10	141	–	–	6	18	–	–	20	12	–	–	91	20	–	–	16	15
Pool (Sampling period)	Recreational swimming pool—RP (January–May 2017)																	
Place of sampling	RP	C2	RP	C2	RP	C2	RP	C2	RP	C2	RP	C2	RP	C2	RP	C2	RP	C2
E. coli (CFU/100 mL)	0	0	0	–	0	0	0	–	0	0	0	–	0	0	0	–	0	0
P. aeruginosa (CFU/100 mL)	0	83	0	–	0	0	0	–	0	0	0	–	0	0	0	–	3	140
Legionella sp. (CFU/100 mL)	0	0	–	–	–	–	–	–	–	–	–	–	0	0	–	–	–	–
Total number of bacteria, 36°C ± 2°C and 44 ± 4 h (CFU/mL)	2	106	–	–	80	16	–	–	92	19	–	–	73	19	–	–	192	193
Pool (Sampling period)	Hot tub 1—HT1 (January–May 2017)																	
Place of sampling	HT1	C2	HT1	C2	HT1	C2	HT1	C2	HT1	C2	HT1	C2	HT1	C2	HT1	C2	HT1	C2
E. coli (CFU/100 mL)	0	0	0	–	0	0	0	–	0	0	0	–	0	0	0	–	0	0
P. aeruginosa (CFU/100 mL)	0	83	0	–	0	0	0	–	0	0	0	–	0	0	0	–	0	140
Legionella sp. (CFU/100 mL)	0	0	–	–	–	–	–	–	–	–	–	–	0	0	–	–	–	–
Total number of bacteria, 36°C ± 2°C, and 44 ± 4 h (CFU/mL)	17	106	–	–	78	16	–	–	89	19	–	–	61	19	–	–	185	193
Pool (Sampling period)	Hot tub 2—HT2 (January–May 2017)																	
Place of sampling	HT2	C2	HT2	C2	HT2	C2	HT2	C2	HT2	C2	HT2	C2	HT2	C2	HT2	C2	HT2	C2
E. coli (CFU/100mL)	0	0	0	–	0	0	0	–	0	0	0	–	0	0	0	–	0	0
P. aeruginosa (CFU/100mL)	0	83	0	–	0	0	0	–	0	0	0	–	0	0	0	–	0	140
Legionella sp. (CFU/100mL)	0	0	–	–	–	–	–	–	–	–	–	–	0	0	–	–	–	–
Total number of bacteria, 36°C ± 2°C, and 44 ± 4 h (CFU/mL)	83	106	–	–	76	16	–	–	92	19	–	–	19	19	–	–	210	193
Pool (Sampling period)	Toddlers' swimming pool—TP (January–May 2017)																	
Place of sampling	TP	C3	TP	C3	TP	C3	TP	C3	TP	C3	TP	C3	TP	C3	TP	C3	TP	C3
E. coli (CFU/100 mL)	0	0	0	–	0	0	0	–	0	0	0	–	0	0	0	–	0	0
P. aeruginosa (CFU/100 mL)	0	0	0	–	0	0	0	–	0	0	0	–	0	0	0	–	10	0
Legionella sp. (CFU/100 mL)	0	0	–	–	–	–	–	–	–	–	–	–	0	0	–	–	–	–
Total number of bacteria, 36°C ± 2°C, and 44 ± 4 h (CFU/mL)	14	120			1	17			1	84			12	16			17	170

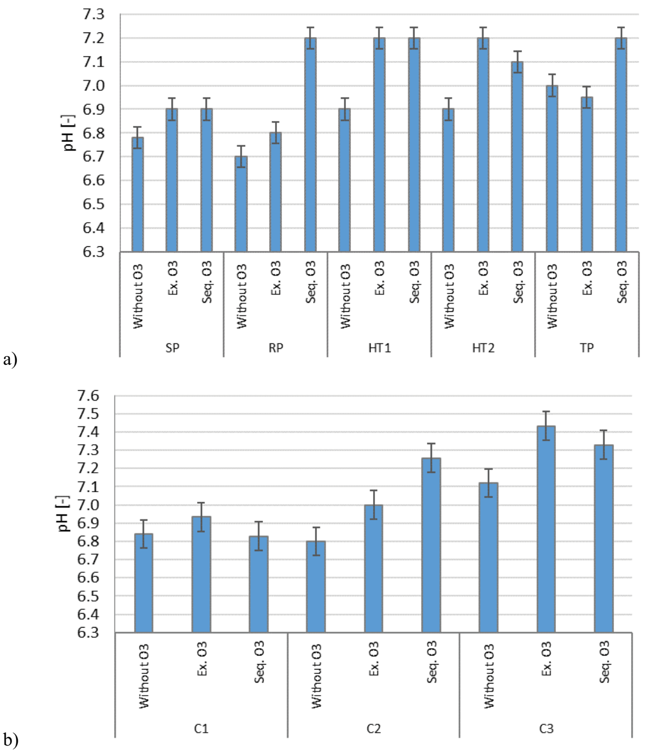


Fig. 3. The pH values of (a) swimming pool water and (b) circulating water.

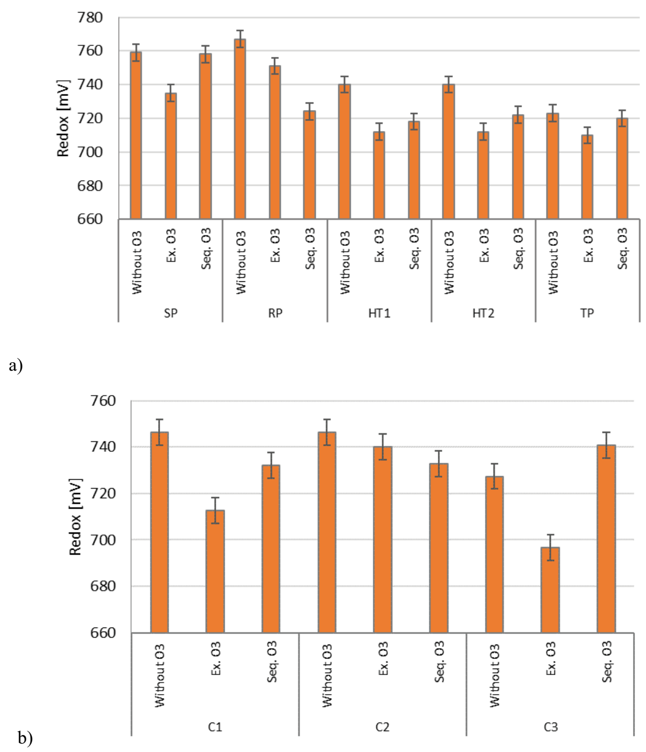


Fig. 4. The redox potential values of (a) swimming pool water and (b) circulating water.

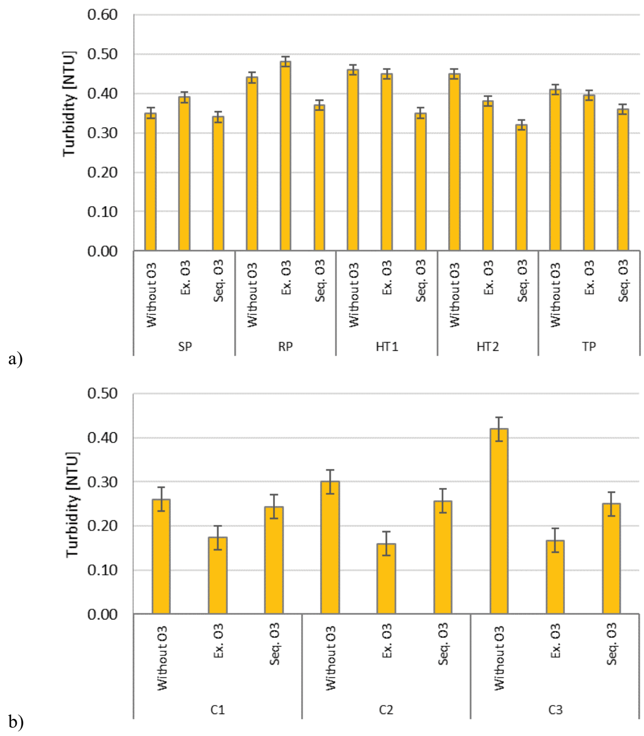


Fig. 5. The turbidity values of (a) swimming pool water and (b) circulating water.

coagulant (aluminum hydroxy chlorides) is dosed before the pressure filters with the glass bed, similarly as in the research conducted by Liu et al. [51] and Yan et al. [52], pre-ozonation had a significant effect on improving the coagulant flocculation capability.

Like the turbidity values, the COD (oxidizability, oxygen consumption demand) values also decreased in the subsequent stages of the study (Figs. 6a and b). After applying highly ozonated water to C2 circuit, feeding RP, HT1, and HT2 pools, just in C2 circuit the COD values decreased more than 2 times. In the basins, they decreased by 62%, 36%, and 63%, respectively. The strong oxidant also had a significant effect on the reduction of COD in C3 (82%) and SP (63%). The COD values throughout the test cycle were in the range of 1.6–4.4 mg O_2/L (water from pool basins) and 1.1–3.7 mg O_2/L (circulating water). According to the very restrictive guidelines of DIN 19643 [6], the COD values should not exceed the value of 4.0 mg O_2/L (in water from pool basins). Regular analysis of the content of organic compounds in pool waters (designated as COD) is necessary to control the content of DBPs.

In the case of nitrate content, the opposite situation was observed. The action of a strong oxidant on organic nitrogen compounds (urea, proteins), which are found in pool waters in a smaller or larger quantity [1,2,53] caused a significant increase in nitrate content. In the stage Ex. O3, when ozone water with 0.6 mg O_3/L residual ozone concentration was used, the nitrate content in water from the basins increased by an average of 50%, in C1 water by 18%, in C2 by 44%, and in C3 by 11%. Under the conditions of the stage Seq. O3 of the research - sequential operation with ozonated water

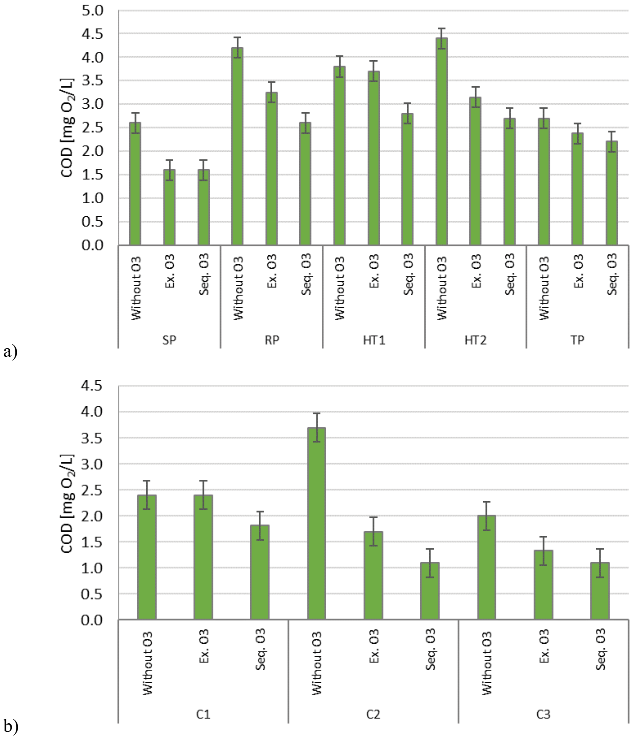


Fig. 6. The COD values of (a) swimming pool water and (b) circulating water.

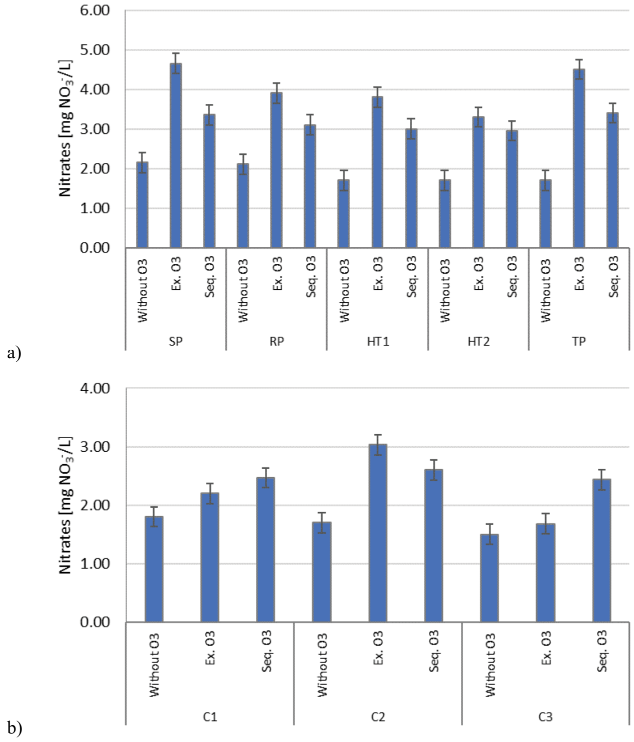


Fig. 7. The nitrate content in (a) swimming pool water and (b) circulating water.

(concentration of residual ozone 0.3 mg O_3/L), the content of nitrates in the water from the basins was reduced in relation to their content in the second part of the study by ~30%. In *C*1 and *C*3 circuit, the concentration of nitrates increased again. In *C*2 it decreased slightly by ~17%. Despite the increase in the nitrate content as a result of the pre-ozonation process, their concentration did not exceed the limit value, that is, 20 mg NO_3^-/L [6,26], and ranged from 1.50–4.64 mg NO_3^-/L (Figs. 7a and b).

The content of free chlorine in swimming pool water should amount to 0.3–0.6 mg Cl_2/L. In the basins equipped with devices producing water and air aerosol, the concentration of free chlorine should be 0.7–1.0 mg Cl_2/L, and in pools for children under 3 years old 0.3–0.4 mg Cl_2/L [6,26].

Throughout the test cycle, the final disinfection was carried out with a constant dose of 14% solution of sodium hypochlorite. In the first part of the research (Without O3) the concentration of free chlorine in water from SP basin was, on average, 0.68 mg Cl_2/L, 0.68 mg Cl_2/L in RP pool, 0.74 mg Cl_2/L in HT1, 0.76 mg Cl_2/L in HT2, and 0.62 mg Cl_2/L in TP. In the second part of the research (Ex. O3) the concentration of free chlorine in the majority of basins increased and amounted to 0.78 mg Cl_2/L in RP, 0.88 mg Cl_2/L in HT1, 0.96 mg Cl_2/L in HT2, and 0.71 mg Cl_2/L in TP. In the SP pool, the average concentration of free chlorine did not change. In the third part of the research (Seq. O3) there was another increase in the free chlorine content in RP pool (0.85 mg Cl_2/L) and TP (0.80 mg Cl_2/L), and a slight decrease in free chlorine in SP and HT2 (0.61 and 0.87 mg Cl_2/L, respectively). In HT1, the content of free chlorine has not changed. Finally, the process of dosing highly ozonated water in SP resulted in about 11% reduction in the free chlorine content and, in the remaining basins, in the increase in the free chlorine content from 13% in HT2 to 23% in TP (Fig. 8a). Similar results were obtained for circulating water (Fig. 8b). In *C*1, there was a decrease in free chlorine content, from 0.79 to 0.66 mg Cl_2/L, and an increase in *C*2 and *C*3. In *C*2 from 0.72 to 0.80 mg Cl_2/L and in *C*3 from 0.81 to 1.01 mg Cl_2/L.

With the unchanged dose of NaOCl, but with reduced organic matter content in the subsequent stages of the research (as shown by a comparison of turbidity, oxidizability, and nitrate parameters), the increase in free chlorine concentration was an expected occurrence, as was the reduction of combined chlorine (chloramines).

The concentration of combined chlorine in the water from pool basins (regardless of their type and function) should not exceed 0.3 mg Cl_2/L, and in the feed water from the circulation system, it should not exceed 0.2 mg Cl_2/L [6,26].

In the studied pool basins (in particular RP, HT1, and HT2), high variability (from 0.10 to 1.19 mg Cl_2/L), repeated contents of combined chlorine over the permissible values and bacteriological water contamination posed a health hazard to bathers [34,54–58].

As a result of a thorough cleaning of the installation with highly ozonated water followed by sequential pre-ozonation of water, the content of combined chlorine in the circulation circuits was decreased to the required level of 0.2 mg Cl_2/L (Fig. 9b). In pool waters, the combined chlorine content was decreased and stabilized to the required level of 0.3 mg Cl_2/L (Fig. 9a). In SP basin, it fell from 0.29 to 0.26 mg Cl_2/L, in RP a)

b)

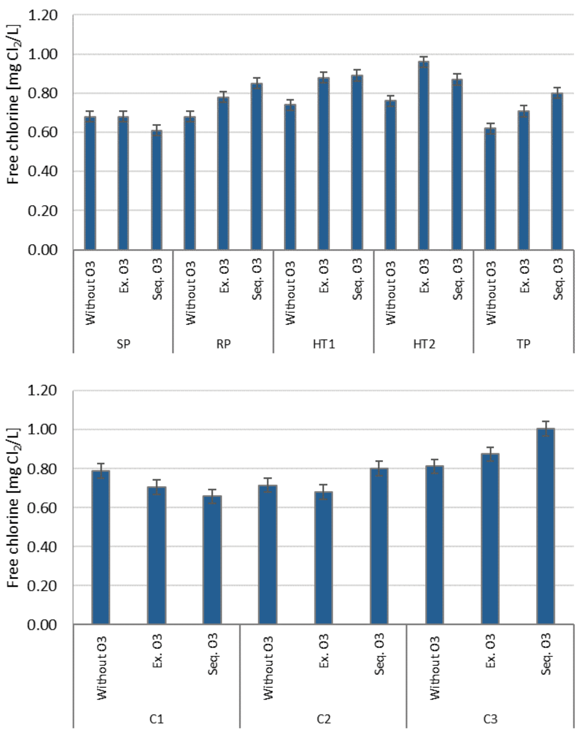


Fig. 8. The free chlorine content in (a) swimming pool water and (b) circulating water.

a)

b)

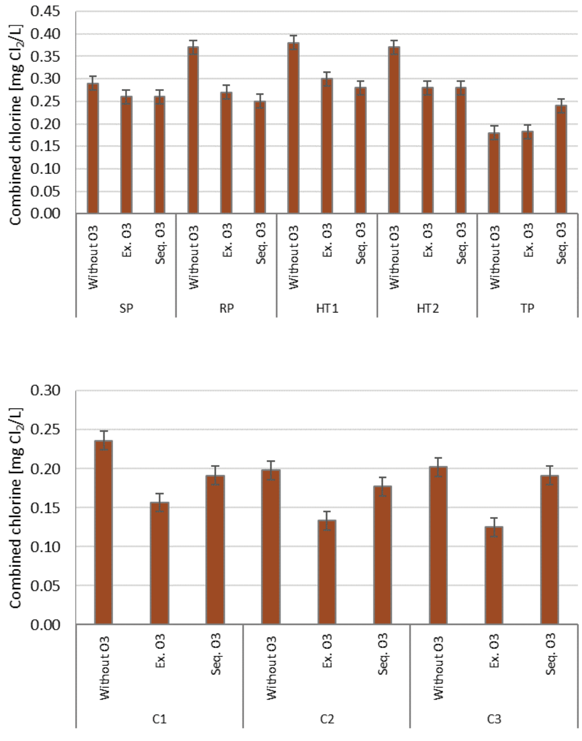


Fig. 9. The combined chlorine content in (a) swimming pool water and (b) circulating water.

from 0.37 to 0.25 mg Cl_2/L, in HT1 from 0.38 to 0.28 mg Cl_2/L, and in HT2 from 0.37 to 0.28 mg Cl_2/L. In turn, in water from the TP pool, the content of combined chlorine increased, from 0.18 to 0.25 mg Cl_2/L. In the case of young children, the principles of personal hygiene and proper behavior in swimming pool facilities may be difficult to enforce. In addition, children swallow water more often than adults. Therefore, it is important to strictly adhere to the recommendations regarding the permissible concentration of combined chlorine and strive to keep the concentration as low as possible [2,7,9,59,60].

Undoubtedly, the content of chloroform and THM is influenced by the type of pool water disinfection method that is used [19,23,32,42,58]. So far, these are the only DBPs, apart from the combined chlorine, whose limit values are strictly established for pool water [6,7,26]. In pools intended for young children, the concentration of chloroform in water should not exceed 0.02 mg/L. In other pools, it should not exceed 0.03 mg/L. The THM content, regardless of the type of pool, should not exceed 0.1 mg/L. Throughout the test cycle, the chloroform content only once exceeded the recommended value—in RP pool (Without O3) where 0.055 mg/L of chloroform was determined. The same sample contained 0.060 mg/L of THM. Ozonation of water, both in the Ex. O3 and Seq. O3 part, allowed to reduce chloroform concentrations in water from pool basins from 4% in HT2 to 96% in RP and decrease the THM concentrations from 35% in TP to 71% in RP (Fig. 10a). In water from *C*1, *C*2, and *C*3 circuit, the concentration of chloroform decreased by ~20%, which allowed to obtain concentrations from 0.021 to 0.026 mg/L. The decrease in THM concentrations in these circuits was more varied and amounted to 5% in *C*1, 38% in *C*2 and 21% in the *C*3 circuit, which resulted in THM concentrations in the range of 0.024–0.032 mg/L (Fig. 10b).

The dosage of ozonated water with a concentration of 0.6 mg O_3/L (in the stage Ex. O3) and with a concentration of 0.3 mg O_3/L (in the stage Seq. O3) and its effect on reducing the chloroform and THM content in the pool water confirms the effectiveness of this method, presented—for instance—in the research on the ozonation process as a complementary method to the chlorine disinfection method, aimed at reducing the potential for DBPs formation [19,33].

In all pool water samples, collected during the experiment and under the stated conditions of the sequential operation of the pre-ozonation system, the residual ozone content was below the limit of quantification (<0.05 mg O_3/L).

4. Summary and conclusions

The quality of the pool water depends on many different factors. These include the method of water treatment, type, and concentration of disinfectants, type, and concentration of contaminants introduced into the water by bathers, physicochemical properties of the treated water, time of contact with bathers, overflow intensity, number of bathers, compliance with hygiene rules, ventilation system, water and air temperature, plumbing of swimming pool installations, the possibility of creating dead zones in pool basins, filters, and installations, water circulation system, and many others.

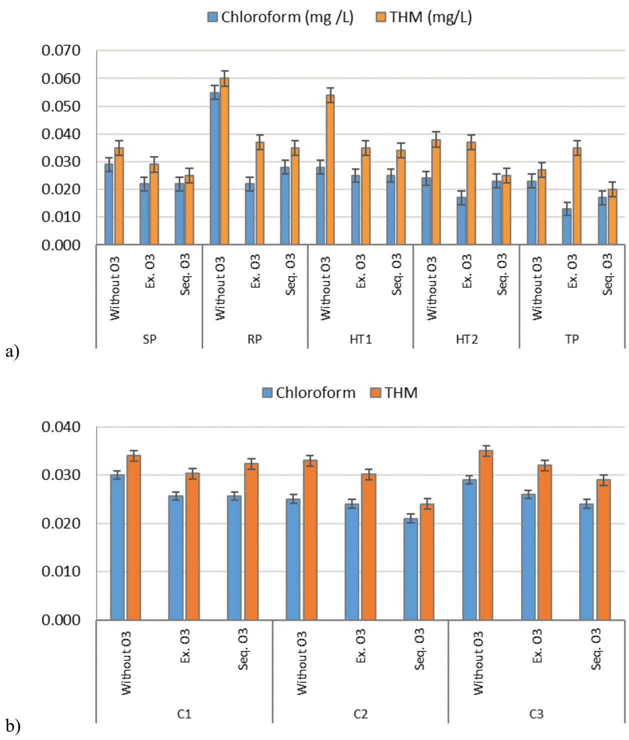


Fig. 10. The chloroform and THM content in (a) swimming pool water and (b) circulating water.

In the analyzed pool facility, in five pool basins fed from three circulation water treatment systems, there were repeated bacteriological contaminations (mainly *P. aeruginosa*), the significant exceedance of combined chlorine and, in the case of an RP, incidental exceedance of chloroform. Due to the very strict regulations regarding the quality of swimming pool water and the resulting limited possibilities of using chlorine compounds for disinfection and limited conditions for the modernization of water treatment circuits, a new mobile system for the production and dosing of ozone was used—SPID. As a result of dosing highly ozonated water to the pipelines before filters, during the sequential operation of this system, two basic goals were achieved. The bacteriological hazard of swimming pool water contamination was removed and concentrations of analyzed DBPs (combined chlorine, chloroform, and THM) were reduced to values well below the limit values.

Pre-ozonation of pool water resulted in:

- limiting the possibility of biofilm formation in the filter beds and in the circulation installation, and thus flushing the bacterial colonies to the filtrate and the circulating water flux,
- reduction of the pool water turbidity and its oxidizability (COD),
- increase in the nitrate content in the pool water indicating the rapid oxidation of organic compounds introduced into the water by its users,
- reduction of combined chlorine content depending on the type of pool, from 12% (in a SP) to 48% (in an RP),
- reduction of chloroform content depending on the type of pool, from 4% in a hot tub to 35% in a TP and as much as 96% in an RP,
- reduction of THM content depending on the type of pool, from 35% in the TP to 71% in the RP.

The problem of contamination of pool water with *P. aeruginosa* and large DBPs content discussed in the article is particularly important for multifunctional pool facilities. Facilities combining sports and RPs, which are made available to children for playing and swimming lessons, must be equipped with pool water disinfection systems based on multi-stage disinfection or with systems supporting chlorine disinfection, for example, pre-ozonation.

In modernized swimming pool facilities, if it is not possible to remove residual ozone in the filtration process through the activated carbon layer, the process of irradiation of the circulating water with a properly selected dose of UV radiation should be used.

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References

[1] W.L. Bradford, What bathers put into a pool: a critical review of body fluids and a body fluid analog, Int. J. Aquat. Res. Educ., 8 (2014) 168–181.
[2] Q. Zheng, L.K. Jmaiff Blackstock, W. Deng, H. Wang, X.C. Le, X.F. Li, Keep swimming but stop peeing in the pools, J. Environ. Sci., (China)., 53 (2017) 322–325.
[3] T.L.L. Teo, H.M. Coleman, S.J. Khan, Chemical contaminants in swimming pools: occurrence, implications and control, Environ. Int., 76 (2015) 16–31.
[4] M. Guida, V. Di Onofrio, F. Gallè, R. Gesuele, F. Valeriani, R. Liguori, V. Romano Spica, G. Liguori, *Pseudomonas aeruginosa* in swimming pool water: evidences and perspectives for a new control strategy, Int. J. Environ. Res. Public Health, 13 (2016) 919.
[5] M. Guida, F. Gallè, M.L. Mattei, D. Anastasi, G. Liguori, Microbiological quality of the water of recreational and rehabilitation pools: a 2-year survey in Naples, Italy, Public Health, 123 (2009) 448–451.
[6] DIN 19643, Water Treatment for Swimming and Bathing Pools, Beuth-Verlag, Berlin, 2012 (in German).
[7] Guidelines for Safe Recreational Water Environments, Vol. 2, Swimming Pools and Similar Environments, WHO, 2006.
[8] C.M. Villanueva, S. Cordier, L. Font-Ribera, L.A. Salas, P. Levallois, Overview of disinfection by-products and associated health effects, Curr. Environ. Heal. Rep., 2 (2015) 107–115.
[9] A. Florentin, A. Hautemanière, P. Hartemann, Health effects of disinfection by-products in chlorinated swimming pools, Int. J. Hyg. Environ. Health, 214 (2011) 461–469.
[10] A. Gomà, R. de Lluis, J. Roca-Ferrer, J. Lafuente, C. Picado, Respiratory, ocular and skin health in recreational and competitive swimmers: beneficial effect of a new method to reduce chlorine oxidant derivatives, Environ. Res., 152 (2017) 315–321.
[11] J.H. Li, Z.H. Wang, X.J. Zhu, Z.H. Deng, C.X. Cai, L.Q. Qiu, W. Chen, Y.J. Lin, Health effects from swimming training in chlorinated pools and the corresponding metabolic stress pathways, PLoS One, 10 (2015) 1–14.
[12] J. Westerlund, P. Graff, I.L. Bryngelsson, H. Westberg, K. Eriksson, H. Löfstedt, Occupational exposure to trichloramine and trihalomethanes in Swedish indoor swimming pools: evaluation of personal and stationary monitoring, Ann. Occup. Hyg., 59 (2015) 1074–1084.

[13] J. Lee, M.J. Jun, M.H. Lee, M.H. Lee, S.W. Eom, K.D. Zoh, Production of various disinfection byproducts in indoor swimming pool waters treated with different disinfection methods, Int. J. Hyg. Environ. Health, 213 (2010) 465–474.
[14] N. Cimetiere, J. De Laat, Effects of UV-dechloramination of swimming pool water on the formation of disinfection by-products: a lab-scale study, Microchem. J., 112 (2014) 34–41.
[15] M. Zare Afifi, E.R. Blatchley, Effects of UV-based treatment on volatile disinfection byproducts in a chlorinated, indoor swimming pool, Water Res., 105 (2016) 167–177, doi:10.1016/j.watres.2016.08.064.
[16] W.A. Cheema, T. Manasfi, K.M.S. Kaarsholm, H.R. Andersen, J.-L. Boudenne, Effect of medium-pressure UV-lamp treatment on disinfection by-products in chlorinated seawater swimming pool waters, Sci. Total Environ., 599–600 (2017) 910–917.
[17] A. Spiliotopoulou, K.M.S. Hansen, H.R. Andersen, Secondary formation of disinfection by-products by UV treatment of swimming pool water, Sci. Total Environ., 520 (2015) 96–105.
[18] Y. Ekowati, G. Ferrero, M.J. Farré, M.D. Kennedy, G. Buttiglieri, Application of UVOX Redox® for swimming pool water treatment: microbial inactivation, disinfection byproduct formation and micropollutant removal, Chemosphere, 220 (2019) 176–184.
[19] K.M.S. Hansen, A. Spiliotopoulou, W.A. Cheema, H.R. Andersen, Effect of ozonation of swimming pool water on formation of volatile disinfection by-products – a laboratory study, Chem. Eng. J., 289 (2016) 277–285.
[20] W.A. Cheema, K.M.S. Kaarsholm, H.R. Andersen, Combined UV treatment and ozonation for the removal of by-product precursors in swimming pool water, Water Res., 110 (2017) 141–149.
[21] S. Chowdhury, K. Alhooshani, T. Karanfil, Disinfection byproducts in swimming pool: occurrences, implications and future needs, Water Res., 53 (2014) 68–109.
[22] T. Manasfi, B. Coulomb, J.-L. Boudenne, Occurrence, origin, and toxicity of disinfection byproducts in chlorinated swimming pools: an overview, Int. J. Hyg. Environ. Health, 220 (2017) 591–603.
[23] R. Tardif, M. Rodriguez, C. Catto, G. Charest-Tardif, S. Simard, Concentrations of disinfection by-products in swimming pool following modifications of the water treatment process: an exploratory study, J. Environ. Sci., 58 (2017) 163–172.
[24] ANSI/APSP-11 2009, American National Standard for Water Quality in Public Pools and Spas, American National Standards Institute, Inc., Alexandria, VA 22314, 2009.
[25] H. Gosling, B. Guthrie, R. Riley, J. Calvert, G. Nichols, A. Elphick, P. Penny, D. Whittingham, Swimming Pool Water: Treatment and Quality Standards for Pools and Spas, 3rd ed., Pool Water Treatment Advisory Group (PWTAG), 2017.
[26] Decree of the Health Minister On the Requirements for Water in Swimming Pools, Dz. U. of 2015, item 2016 (in Polish).
[27] J. Wyczarska-Kokot, The problem of chloramines in swimming pool water - technological research experience, Desal. Water Treat., 134 (2018) 7–14.
[28] Z. Barna, M. Kádár, The risk of contracting infectious diseases in public swimming pools. A review, Ann. Ist. Super. Sanita., 48 (2012) 374–386.
[29] J.K. Lutz, J. Lee, Prevalence and antimicrobial-resistance of *Pseudomonas aeruginosa* in swimming pools and hot tubs, Int. J. Environ. Res. Public Health, 8 (2011) 554–564.
[30] T. Strateva, D. Yordanov, *Pseudomonas aeruginosa* - A phenomenon of bacterial resistance, J. Med. Microbiol., 58 (2009) 1133–1148.
[31] J. Wyczarska-Kokot, M. Dudziak, A. Lempart, Effects of modernization of the water treatment system in a selected swimming pool, Environ. Prot. Eng., 45 (2019) 31–43.
[32] H. Ilyas, I. Masih, J. van der Hoek, Disinfection methods for swimming pool water: byproduct formation and control, Water, 10 (2018) 797.
[33] W.A. Cheema, H.R. Andersen, K.M.S. Kaarsholm, Improved DBP elimination from swimming pool water by continuous combined UV and ozone treatment, Water Res., 147 (2018) 214–222.
[34] L. Yang, X. Chen, Q. She, G. Cao, Y. Liu, V.W.C. Chang and C.Y. Tang, Regulation, formation, exposure, and treatment of disinfection by-products (DBPs) in swimming pool waters: a critical review, Environ. Int., (2018) 1039–1057.
[35] X. Yang, W. Guo, W. Lee, Formation of disinfection byproducts upon chlorine dioxide preoxidation followed by chlorination or chloramination of natural organic matter, Chemosphere, 91 (2013) 1477–85.
[36] D.A. Reckhow, K.G. Linden, J. Kim, H. Shemer, G. Makdissy, Effect of UV treatment on DBP formation, J. Am. Water Works Assoc., 102 (2010) 100–113.
[37] A. Włodyka-Bergier, T. Bergier, Impact of UV disinfection on the potential of model organic-nitrogen precursors to form chlorination by-products in swimming pool water, Desalin. Water Treat., 57 (2016) 1499–1507.
[38] J. Wyczarska-Kokot, Wpływ metody dezynfekcji na zawartość chloramin w wodzie basenowej (Impact of disinfection method on chloramine content in swimming pool water), Ochr Srodow., 36 (2014) 37–42.
[39] M. Sadrnourmohamadi, B. Gorczyca, Effects of ozone as a stand-alone and coagulation-aid treatment on the reduction of trihalomethanes precursors from high DOC and hardness water, Water Res., 73 (2015) 171–180.
[40] G. Hua, D.A. Reckhow, Effect of pre-ozonation on the formation and speciation of DBPs, Water Res., 47 (2013) 4322–4330.
[41] P.C. Chiang, E.E. Chang, P.C. Chang, C.-P. Huang, Effects of pre-ozonation on the removal of THM precursors by coagulation, Sci. Total Environ., 407 (2009) 5735–5742.
[42] Available at: https://www.wofil.pl.
[43] R. Muszański, Application of Mobile Water Ozonation Systems to Reduce Combined Chlorine in Swimming Pools, K. Kuś, F. Piechurski, eds., Instal, Basenowe, Politechnika Śląska, 2017, pp. 157–169.
[44] J. Wyczarska-Kokot, A. Lempart, M. Dudziak, Chlorine contamination in different points of pool - risk analysis for bathers' health, Ecol. Chem. Eng. A, 24 (2017) 217–226.
[45] K. Kaul, Handbook of Water and Wastewater Analysis, Atlantic Publishers and Distributors, New Dehli, 2007.
[46] R.D. Down, J.H. Lehr, Environmental Instrumentation and Analysis Handbook, Wiley, New Jersey, 2005.
[47] P.R. Murray, K.S. Rosenthal, P.M. A., Mikrobiologia, Elsevier Urban and Partner, Wrocław, 2011.
[48] R.A. Harvey, C. Nau Cornelissen, B.D. Fisher, Microbiology, 3rd ed., Lippincott Williams and Wilkins, Philadelphia, 2013.
[49] C. Pasquarella, L. Veronesi, C. Napoli, S. Castaldi, M.L. Pasquarella, E. Saccani, M.E. Colucci, F. Auxilia, F. Gallè, V. Di Onofrio, S. Tafuri, C. Signorelli, G. Liguori, What about behaviours in swimming pools? Results of an Italian multicentre study, Microchem. J., 112 (2014) 190–195.
[50] F. Gallè, L. Dallolio, M. Marotta, A. Raggi, V. Di Onofrio, G. Liguori, F. Toni, E. Leoni, Health-related behaviors in swimming pool users: influence of knowledge of regulations and awareness of health risks, Int. J. Environ. Res. Public Health, 13 (2016) 513.
[51] H.L. Liu, D.S. Wang, B.Y. Shi, M. Wang, H.X. Tang, Effects of pre-ozonation on organic matter removal by coagulation with IPF-PACl., J. Environ. Sci. (China), 18 (2006) 453–458.
[52] M. Yan, D. Wang, B. Shi, M. Wang, Y. Yan, Effect of Pre-ozonation on optimized coagulation of a typical North-China source water, Chemosphere, 69 (2007) 1695–1702.
[53] S.D. Richardson, D.M. DeMarini, M. Kogevinas, P. Fernandez, E. Marco, C. Lourencetti, C. Ballesté, D. Heederik, K. Meliefste, A.B. McKague, R. Marcos, L. Font-Ribera, J.O. Grimalt, C.M. Villanueva, What's in the pool? A comprehensive identification of disinfection by-products and assessment of mutagenicity of chlorinated and brominated swimming pool water, Environ. Health Perspect., 118 (2010) 1523–1530.
[54] Z.T. How, I. Kristiana, F. Busetti, K.L. Linge, C.A. Joll, Organic chloramines in chlorine-based disinfected water systems: a critical review, J. Environ. Sci., 58 (2017) 2–18.
[55] K. van Veldhoven, P. Keski-Rahkonen, D.K. Barupal, C.M. Villanueva, L. Font-Ribera, A. Scalbert, B. Bodinier, J.O. Grimalt, C. Zwiener, J. Vlaanderen, L. Portengen,

R. Vermeulen, P. Vineis, M. Chadeau-Hyam, M. Kogevinas, Effects of exposure to water disinfection by-products in a swimming pool: a metabolome-wide association study, Environ. Int., 111 (2018) 60–70.

[56] T. Pándics, Á. Hofer, G. Dura, M. Vargha, T. Szigeti, E. Tóth, Health risk of swimming pool disinfection by-products: a regulatory perspective, J. Water Health, 16 (2018) 947–957.

[57] L. Font-Ribera, M. Kogevinas, C. Schmalz, C. Zwiener, E. Marco, J.O. Grimalt, J. Liu, X. Zhang, W. Mitch, R. Critelli, A. Naccarati, D. Heederik, J. Spithoven, L. Arjona, J. de Bont, E. Gracia-Lavedan, C.M. Villanueva, Environmental and personal determinants of the uptake of disinfection by-products during swimming, Environ. Res., 149 (2016) 206–215.

[58] S. Chowdhury, Predicting human exposure and risk from chlorinated indoor swimming pool: a case study, Environ. Monit. Assess., 187 (2015) 502.

[59] W. Nystad, S.E. Håberg, S.J. London, P. Nafstad, P. Magnus, Baby swimming and respiratory health., Acta Paediatr., 97 (2008) 657–662.

[60] Y. Schoefer, A. Zutavern, I. Brockow, T. Schäfer, U. Krämer, B. Schaaf, O. Herbarth, A. von Berg, H.-E. Wichmann, J. Heinrich, Health risks of early swimming pool attendance, Int. J. Hyg. Environ. Health, 211 (2008) 367–373.