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The problem of chloramines in swimming pool water—technological research experience

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ABSTRACT

Chloramines in pool water are disinfection byproducts that are responsible for the unpleasant smell in the pool hall and the irritation syndrome in swimmers. The mandatory control of the concentration of chloramines in Polish pools came into force in June 2016. In some European countries, it was as early as 1997. The problem of their high concentrations and the ensuing adverse effect on bathers and pool employees has not yet been solved. The main objective of this research is comparing the presence of chloramines in a selected pool after every change in its treatment system. The special attention paid to the appropriate quality of the water is dictated by the intended use of the pool—for rehabilitation and for toddlers. The physicochemical and bacteriological tests of the pool water allowed to evaluate the quality of the water after six stages of tests. A special attention was paid to the changes in the concentration of chloramines with regard to the concentration of free chlorine and redox potential. The comparison allowed to determine that the value of chloramines did not exceed the limit of 0.2 mg Cl_2/L [23–25] and 0.3 mg Cl_2/L [20] due to the disinfection with sodium hypochlorite, irradiation with UV light, and application of a 1-d filtration cycle.

Keywords: Chloramines; Swimming pool technology; Rehabilitation pool

1. Introduction

Swimming pool water is a mixture of water supplementing a pool circuit system and water from a swimming pool basin that is constantly treated and disinfected. Swimming pool users introduce unwanted biological matter (fragments of epidermis, sweat, urine, and feces) and microorganisms into the water [1–3]. Both urine and sweat contain considerable amounts of nitrogen compounds which, by reaction with the chlorine disinfectant, turn into disinfection byproducts (DBPs), such as chloramines [4,5]. And it is chloramines that are the most inconvenient for the bathers. They are responsible for the so-called irritation syndrome, skin dryness, and mucous membrane irritation in swimmers, and they also give the water and air in the swimming pool hall an unpleasant smell. They are also mutagenic [6–8]. Due to their high volatility, they are dangerous not only for bathers, but also for swimming pool employees, especially those who spend a few hours in the swimming pool hall every day [9–11].

The amount and type of DBPs forming in the swimming pool water is influenced by many factors. The most important ones are the type of the disinfectant, method of water treatment, number of bathers (attendance), and the intensity and time of bathing [12–16].

In Poland, in accordance with the Act on Sports, legal and natural persons running businesses in the swimming pool industry are responsible for health and safety of the bathers [17]. As a result of that the individuals who are in charge of swimming pool facilities should control the swimming pool water and ascertain that it is of the best quality. The supervision over public swimming pool facilities is conducted by sanitary and epidemiological stations under the State

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Sanitary Inspection Act and the act regarding the prevention and elimination of infections and contagious diseases affecting people [18,19]. In 2015, the decree on the requirements regarding the quality of swimming pool water was published [20]. Before this decree came into force, the quality of the swimming pool water was determined on the basis of the following: Guidelines of the Chief Sanitary Inspectorate [21], recommendations of ZHK NIZP-PZH [22], DIN 19643 [23,24], and WHO from 2006 [25]. The guidelines defining the quality of swimming pool water in Poland specify the quality of water in pools intended for toddlers (babies and children up to 3 years old) [20,22].

All of these above documents specify rigorous, permissible values of basic concentrations of DBPs, including chloramines.

Practice supported by numerous studies shows that in the swimming pools using traditional treatment systems (prefiltration + surface coagulation + NaOCl disinfection + pH correction), maintaining the level of chloramines at a level of 0.2–0.3 mg Cl_2/L is very difficult or even impossible [6,8,10,13,26,27].

The main objective of this research is comparing the presence of chloramines in a selected swimming pool after every change in its treatment system. The special attention paid to the appropriate quality of the water in the analyzed facility is dictated by the intended use of the swimming pool. It is a rehabilitation pool that is also used as a pool for swimming lessons for toddlers. The physicochemical and bacteriological tests of the samples of the swimming pool water allowed to evaluate the quality of the water after six stages of tests. A special attention was paid to the changes in the concentration of chloramines with regard to the concentration of free chlorine and redox potential.

2. Characteristics of the tested swimming pool

In the tested swimming pool, during morning hours, there are physiotherapy sessions for patients suffering from various injuries. In the afternoon, there are swimming lessons for infants ("from baby to kindergartner") and their parents.

The swimming pool is equipped with a vertical water flow system with a capacity of 30 m^3/h and four stations with massage jets. The swimming pool dimensions (3.2 × 5.4 × 1.2) allow for a comfortable rehabilitation of six to eight persons. The swimming pool draws water from the municipal water supply system. Water deficits that are the result of evaporation, splashing, and the need to wash filter beds are replenished by drawing water into the expansion tank. The basic requirement for a correct circulation of swimming pool water is a closed circulation system with an active overflow (Fig. 1).

The treated water is introduced to the swimming pool through 14 jets located at the bottom of the pool basin. The water is drained through the top overflow troughs to the expansion tank. Then, the water is sucked by the circulation pump. Before the pump, there is a prefilter (mesh filter) whose aim is to capture large solid contaminants. The pump moves the water to the filter where, after the application of a disinfectant and a pH correction solution, it is directed to the swimming pool through heat exchangers. Before the filters, a coagulant solution is applied (2.5%–10% solution of aluminium hydroxide chloride). The swimming pool water treatment system uses a multilayered vacuum filter with sand and gravel bed with an area of 1 m^2 and height of 1.2 m. The filtrate pipe was supplemented, during Stage 2, with a low-pressure UV lamp and, during Stage 6, with a medium pressure one. Both in Stage 2 and Stage 6, a UV radiation dose of 600 J/m^2 was used. The treatment system is an automatic system controlled by an analyzer monitoring the quality indicators values of the water that is drained from the swimming pool basin.

3. Methodology and process of research

The analysis of the concentrations of chloramines in the swimming pool water was conducted in six stages. During Stage 1 (24 measuring days), the concentrations of chloramines in water from the swimming pool supplied with water treated by a traditional treatment system were tested. During Stage 2 (16 measuring days), the swimming pool treatment system was supplemented with a low-pressure amalgam UV lamp. During Stage 3 (20 measuring days), after the removal of a UV lamp, a "shock" swimming pool water disinfection was carried out during the night hours (between 11 pm and 5 am). The decision to disinfect the water with higher doses of NaOCl was

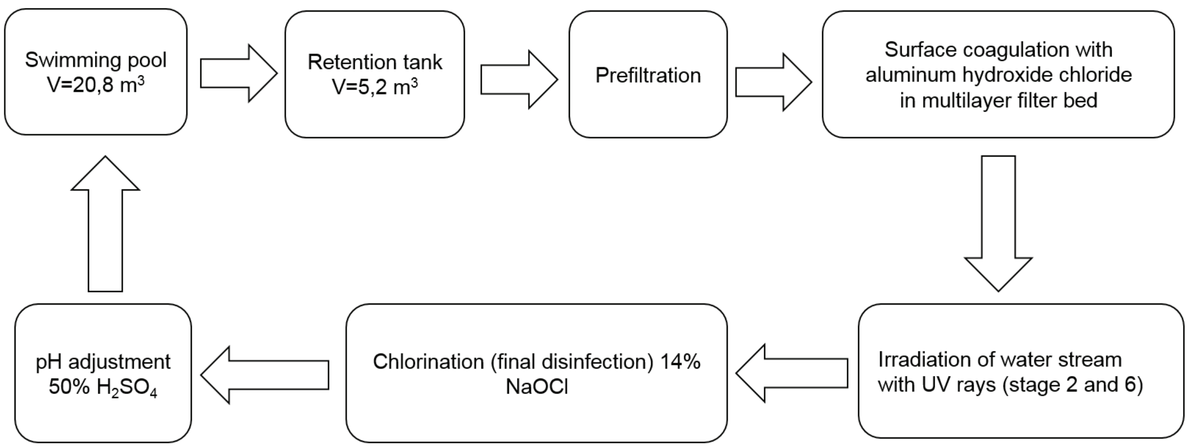

Fig. 1. Water treatment system in the tested swimming pool.

made primarily in order to protect the children, aged 1–3, attending swimming lessons against the adverse effects of chloramines on their health. Because the "shock" chlorination had not delivered the expected results, a decision was made to shorten the filtration cycle from 3to 1 d in accordance with the recommendations of ZHK NIZP-PZH, establishing the rules for the use of swimming pools for toddlers [22]. In this way, during Stage 4 (24 measuring days), it was analyzed whether the daily washings of the filtration bed improved the quality of the swimming pool water. The more frequent washing of the filtration bed significantly increased the cost of the supplementing water and wastewater that was not accepted by the person in charge of the swimming pool facility. As a result of that, Stage 5 was commenced (24 measuring days) this time with a filtration cycle of 2 d. Because during Stage 5, the quality of the water was still unsafe for bathers, according to the regulation of the health minister [20]; Stage 6 was started (21 measuring days) during which the treatment system was supplemented with a medium pressure UV lamp. The results from stages 1, 2, and 3 of research were partly presented by Wyczarska-Kokot [13].

The samples were collected and marked in accordance with applicable standards and methods [23,24,28,29]. The obtained test results were compared against the recommendations of DIN 19643 [23,24], ZHK NIZP-PZH [22], WHO [25], and the permissible values specified in the decree [20].

During each stage of tests, a sample of water from the swimming pool basin was taken in order to perform microbiological tests with the use of methods compliant with PN-EN ISO 9308-1:2004 (*Escherichia coli*), PN-EN ISO 622:2004 (total plate count in 36°C after 48 h), PN-ISO 11731-2:2006 (*Legionella* sp.), and research procedure KJ-I-5.4-44M ver. 01 of 11.06.2007 (coagulase positive staphylococci).

During the tests, the values of water pH, temperature, redox potential, and the concentration of free chlorine and combined chlorine were read every day, directly from the screen of control and measurement device SCL DINOTEC. Additionally, during each stage of tests, a spectrophotometer DR5000 UV/VIS (Hach, Poland, Wroclaw) was used to perform from six to eight control measurements of ammonia nitrogen, chlorides, free and combined chlorine, oxidizability (COD) and pH of the swimming pool water.

Because the concentration of chloramines in the swimming pool water is significantly influenced by the attendance, that is a usable area of water surface per every bather, the readings of water quality indicators were supplemented with the number of people present at the swimming pool.

4. Results and discussion

The physicochemical and bacteriological tests of samples of the swimming pool water allowed to evaluate the quality of the water with a special emphasis on the concentration of chloramines and its correlation with the concentration of free chlorine, redox potential value, water disinfection method, and the length of the filtration cycle.

During each stage of tests, the values of the control parameters of swimming pool water quality, that is, water pH, temperature, free chlorine, ammonia nitrogen, chlorides, oxidizability and colony forming unit (CFU), *E. coli*, *Legionella* sp., coagulase positive staphylococci, and the total number of microorganisms, in every water sample were compliant with the requirements in this regard [20–25].

Table 1 presents the results of the bacteriological tests, the minimal, maximal, and average values of physicochemical indicators, and the attendance during each stage of tests.

Table 1
Comparison of results from stages 1–6 of research

Parameter	Average values					
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
pH (–)	7.17	7.17	7.07	7.50	7.49	7.49
Redox (mV)	681	698	755	737	720	769
Temperature (°C)	34.7	33.8	34.5	34.8	34.7	34.9
Free chlorine (mg Cl_2/L)	0.34	0.36	0.48	0.33	0.32	0.35
Combined chlorine (mg Cl_2/L)	0.33	0.18	0.34	0.24	0.34	0.21
Ammonia nitrogen (mg $N–NH_4$/L)	0.15	0.08	0.12	0.10	0.18	0.16
Chlorides (mg Cl^-/L)	102	94	96	84	98	88
COD (mg O_2/L)	2.73	1.77	2.15	1.82	2.65	1.80
Escherichia coli (CFU/100 mL)	0	0	0	0	0	0
Legionella sp.(CFU/100 mL)	0	0	0	0	0	0
Total number of bacteria, 36 ± 2°C and 44 ± 4 h (CFU/1 mL)	0	1	0	0	0	0
Staphylococcus sp.(CFU/100 mL)	0	0	0	0	0	0
Attendance (person/h)	6.9	6.7	6.7	6.8	6.8	6.6

The number of people present at the swimming pool was similar. It was, on average, 6.6 persons/h in Stage 6 and 6.9 person/h in Stage 1. The usable area of water surface per every bather ranged, depending on the number of people present, from 1.75 m^2/person to 5.70 m^2/person (on average: 2.50 m^2/person, at the required minimum of 2.70 m^2/person according to DIN 19643 [23,24] and 2.2 m^2/person according to ZHK NIZP-PZH [22]).

During Stage 1, the concentrations of combined chlorine in the water from the swimming pool basin exceeded the permissible values (per DIN 19643 [23,24] and WHO [25]: 0.20 mg Cl_2/L and the decree [20]: 0.3 mg Cl_2/L) in all samples and ranged from 0.27 mg Cl_2/L to 0.42 mg Cl_2/L (on average: 0.33 mg Cl_2/L). Taking into consideration the intended use of the analyzed pool and the ensuing risk to the health of the bathers, the permissible concentration of chloramines should be 0.2 mg Cl_2/L. The permissible value was exceeded by approximately 65%. The concentrations of free chlorine at this stage ranged from 0.30 to 0.37 mg Cl_2/L (on average: 0.34 mg Cl_2/L). The values of redox potential in the majority of water samples were lower than the minimal required value, that is, 720 mV at pH = 6.5–7.3 (redox average value: 681 mV).

During Stage 2, with a low-pressure UV lamp supporting the disinfection process, the concentrations of chloramines ranged from 0.08 to 0.28 mg Cl_2/L (on average: 0.18 mg Cl_2/L), and only in 3 out of 24 samples, the values exceeded the permissible value, according to DIN 19643 [23,24], and all samples met the requirements of the decree [20]. The concentrations of free chlorine at this stage ranged from 0.30 to 0.39 mg Cl_2/L (on average: 0.36 mg Cl_2/L). Just as in Stage 1, the values of redox potential in the majority of water samples were lower than the required 720 mV at pH = 6.5–7.3 (redox average value: 698 mV).

During Stage 3, when the UV lamp was disassembled and a "shock" chlorination was applied, the concentrations of chloramines ranged from 0.05 to 0.51 mg Cl_2/L (on average: 0.34 mg Cl_2/L). Permissible concentrations of chloramines were reported only directly after the "shock" doses of NaOCl were applied when the concentrations of free chlorine significantly exceeded the permissible value (0.6 mg Cl_2/L) during the hours when such a situation was allowed, that is, between 9 pm and 7 am, and then they amounted to 0.75–1.51 mg Cl_2/L. During the rehabilitation sessions and swimming lessons for infants, the concentrations of chloramines exceeded the permissible value, on average, by 70% and amounted to 0.25–0.38 mg Cl_2/L. The concentrations of free chlorine at this stage ranged from 0.31 to 1.51 mg Cl_2/L (on average: 0.48 mg Cl_2/L). The values of redox potential, due to high doses of the disinfectant, were higher than the required minimum of 720 mV at pH = 6.5–7.3 (redox average value: 756 mV).

The "shock" chlorination did not significantly reduce the content of chloramines in the swimming pool water, and the reassembly of the UV lamp in the water treatment circuit was not possible due to investment and operational costs. Therefore, it was attempted (Stage 4 of tests) to lower the concentration of chloramines by washing the filtration bed daily (instead of once in 3 d, as it was previously done). Daily washings of the filtration bed in water circuits of swimming pools for children aged between 6 months and 3 years and equipped with hydromassage devices are recommended by ZHK NIZP-PZH [22] and DIN 19643 [23,24]. During Stage 4, the concentrations of chloramines ranged from 0.17 to 0.31 mg Cl_2/L (on average: 0.24 mg Cl_2/L). The permissible value of chloramines was exceeded by approximately 20%. The concentrations of free chlorine at this stage ranged from 0.30 to 0.36 mg Cl_2/L (on average: 0.33 mg Cl_2/L). The values of redox potential in the majority of samples were close to the minimal required value, that is, 750 mV at pH = 7.3–7.6 (redox average value: 737 mV).

Nevertheless, despite achieving lower concentrations of chloramines in the swimming pool water, as compared to Stage 1 and Stage 3, the significant increase of the operational costs resulting from the increased demand for supplementing water, as compared to stages 1–3—Table 2) was not approved by the person in charge of the facility and brought about further activities performed with the aim of checking the concentrations of chloramines while following a 2-d filtration cycle (Stage 5 of tests).

During Stage 5 of tests (filtration cycle of 2 d), the chloramines concentration in water from the swimming pool basin ranged from 0.28 to 0.44 mg Cl_2/L (on average: 0.34 mg Cl_2/L). Just as in Stage 3, the permissible value of chloramines was exceeded by approximately 70%. The concentrations of free chlorine at this stage ranged from 0.30 to 0.35 mg Cl_2/L (on average: 0.32 mg Cl_2/L). The values of redox potential in all water samples were lower than the required 750 mV at pH = 7.3–7.6 (average value: 720 mV). Shortening the filtration cycle by 1 d did not bring the required effects, both in terms of lowering the chloramines content and increasing the redox potential.

Table 2
Quantity of supplementary water in tested pool circuit depending on the length of the filtration cycle

Stage	Length of the filtration cycle (d)	Time of research (d)	Number of filter bed wash	Quantity of supplementary water		Average attendance (person/d)	Quantity of supplementary water (L/person·d)
				m^3	m^3/d		
1	3	24	8	26.00	1.08	63	17.2
2	3	16	6	19.50	1.22	62	19.7
3	3	20	7	22.75	1.14	60	19.0
4	1	24	24	78.00	3.25	61	53.3
5	2	24	12	39.00	1.63	62	26.2
6	2	21	10	32.50	1.55	59	26.2

Stage 6 consisted of tests of the swimming pool water quality after the reassembly of UV lamp in its treatment system—this time a medium-pressure one. The main reason for the use of UV disinfection, as an aid to the disinfection with sodium hypochlorite, was to guarantee the safety of the bathers in accordance with the obligatory conditions specified in the health minister decree [20]. The concentrations of chloramines in the swimming pool water ranged from 0.16 to 0.26 mg Cl_2/L (on average: 0.21 mg Cl_2/L). The permissible concentration of chloramines was exceeded in 11 out of 21 tested samples by 5%–30%. The concentrations of free chlorine at Stage 6 ranged from 0.32 to 0.42 mg Cl_2/L (on average: 0.35 mg Cl_2/L). The values of redox potential in all water samples were equal or higher than the required 750 mV at pH = 7.3–7.6 (redox average value: 769 mV).

Presently, UV lamps in swimming pool water treatment systems are widely used. Irradiation of the circulating water with ultraviolet rays is a process of physical disinfection preceding chemical disinfection with a chlorine compound. The ultraviolet light has disinfectant properties only when the stream of the circulating water is exposed to these rays. It is therefore necessary to combine UV technology with chemical disinfectants, which allow to protect the water against secondary contamination [30]. UV technology has many advantages, the most important of which are the lack of influence on the taste and smell of water and the high efficiency of destroying microorganisms resistant to chlorine [31].The results of scientific research on water irradiation systems with the use of low-pressure and medium-pressure lamps do not give a definite answer to the question which one should be used in swimming pool technology. Although the impact of this process on the formation of DBPs remains a controversial issue, it is stated that UV-based systems improve the quality of pool and pool water, and UV dechlorination is a popular process for reducing chloramines in swimming pool water [15,32,33].

In the case of the analyzed pool, the water disinfection applied in stages 2 and 6 of the tests, that is irradiation of the circuit water flux with UV light and then the dosage of sodium hypochlorite, reduced the concentration of chloramines to 0.2–0.3 mg Cl_2/L, while maintaining the concentrations of free chlorine within the range of 0.30–0.42 mg Cl_2/L and the values of redox potential ranging widely from 590 to 800 mV.

A similar relationship was observed during Stage 4, when the filtration cycle was reduced to 1 d. It is water filtration that is the most popular and easy to use technological process in water treatment systems. Its efficiency may be controlled by the intensity and frequency of the washings of the filter beds [34]. Because the swimming pool water is being constantly contaminated with dissolved and suspended pollutants, among others with pre-DBPs, the filtration is supported with coagulants. It is only due to surface coagulation that they are stopped in the filter bed and then removed from the swimming pool circuit by means of filter bed washing [35]. Thus, effective filtration, adherence to proper procedures of filter beds washings (in the tested system, one washing per day), and replenishing the water losses in the swimming pool circuit (at least 30 L/person day) significantly influenced the content of chloramines in the analyzed swimming pool.

The disinfection methods based only on the dosage of sodium hypochlorite, used in stages 1, 3, and 5, did not bring the expected results. Using stable doses of NaOCl (in Stage 1) and "shock" doses (in Stage 3) and a considerably long filtration cycle (in stages 1, 3, and 5) did not allow for the concentrations of chloramines to fall below 0.3 mg Cl_2/L.

In accordance with the recommendations of ZHK NIZP-PZH [22], disinfection of water in swimming pools for toddlers and their caretakers should be based on chlorine preparations with the concentration of free chlorine not exceeding 0.3 mg Cl_2/L. The use of UV irradiation is acceptable but it has to be combined with water chlorination. In this case, the concentration of free chlorine may be lowered even to 0.1 mg Cl_2/L on the condition that the microbiological quality of the water is maintained. Additionally, every person participating in the classes must have not less than 2.2 m^2 of water surface area, the swimming pool must have a separate circulation system and the so-called water recirculation, that is, a full replacement of water in the swimming pool should take 1–1.5 h [22–24].

The basin of the swimming pool has its own circulation and treatment system. The water recirculation time during the tests was approximately 1 h and every bather had an average 2.5 m^2 of water surface area.

It may raise doubts that the application of a 3-d filtration cycle in stages 1–3 of the tests resulted in a demand for supplementing water to reach, per every bather, 17.2–19.7 L/person·d, at the recommended by DIN 19643 [23,24] 30 L/person·d. Shortening the filtration cycle caused the amount of the supplementing water to raise to 26.2 L/person·d, when the cycle was shortened to 2 d, and to 53.3 L/person·d, when it was shortened to 1 d (Table 2).

Because in this type of pools, the risk of contaminating the water with pathogenic bacteria coming from the rehabilitated and immunosuppressed persons is especially high; it was decided not to lower the concentration of free chlorine to 0.1 mg Cl_2/L and ascertain that during the classes with children this concentration does not fall below 0.3 mg Cl_2/L (Table 1).

Figs. 2–4 present the distribution of the concentration of chloramines, free chlorine, and the value of redox potential in particular test stages.

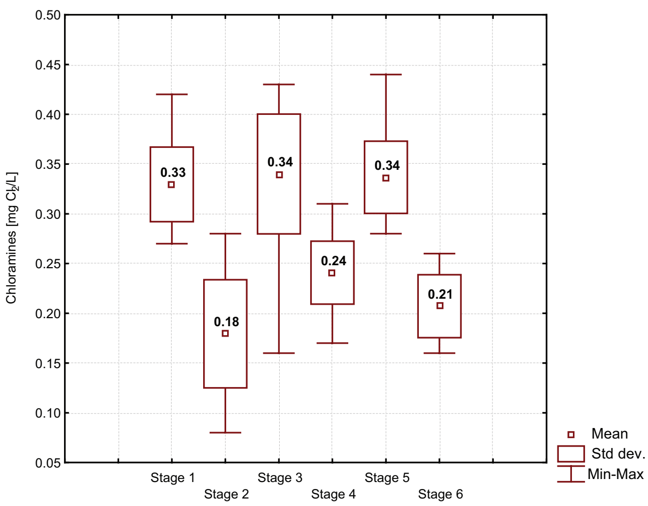

Fig. 2. Concentration of chloramines in stage 1–6 of research.

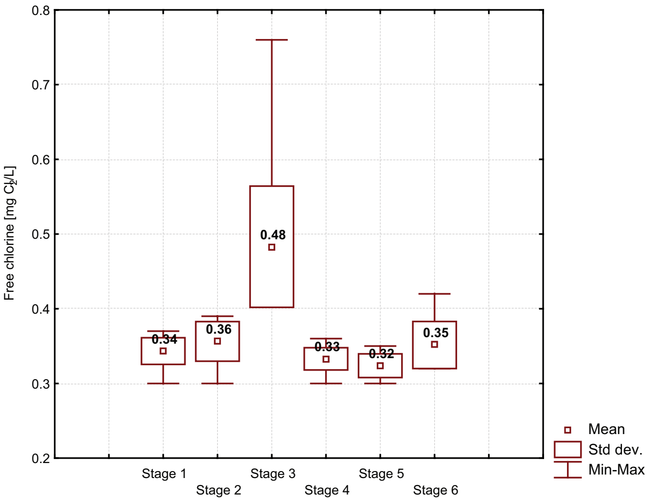

Fig. 3. Concentration of free chlorine in stage 1–6 of research.

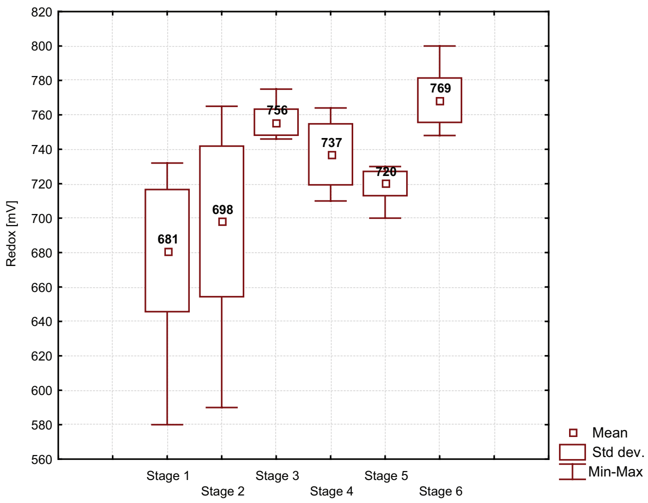

Fig. 4. Values of redox potential in stages 1–6 of research.

No significant dependency between the concentrations of chloramines and free chlorine was determined. In stages 2, 4, and 6, in which the concentrations of chloramines fell below 0.2 mg Cl_2/L, and in stages 1, 3, and 5, in which the concentrations of chloramines exceeded 0.3 mg Cl_2/L the content of free chlorine ranged from 0.32 to 0.36 mg Cl_2/L. Even with relatively large concentrations of free chlorine in Stage 3 (on average: 0.48 mg Cl_2/L), no significant decrease in the chloramines content was observed (Fig. 5(a)).

The analysis of the effect of the redox potential on the content of chloramines allowed to determine that high oxidizability of swimming pool water (redox > 720 mV) boosted the decrease of chloramines content (Fig. 5(b))

During research, other parameters of water quality which were proven to have an effect on the formation of various groups of DBPs, including chloramines, were also noted. [36,37].

Within the specified pH values of swimming pool water (on average: pH = 7.5) in Stage 4 (1-d filtration cycle), Stage 5 (2-d filtration cycle), and Stage 6 (2-d cycle and medium-pressure UV lamp), a considerable difference in the concentrations of chloramines was detected (Fig. 5(c)). However, the analysis of all pH measurement results (6.89–7.50) in relation to the content of chloramines (0.05–0.51 mg Cl_2/L) showed that lowered pH resulted in a higher concentration of chloramines.

Between subsequent washings of the filter bed in the swimming pool water circuit, the dissolved substances, and primarily chloride compounds, were being concentrated, influencing the formation of DBP. Although the concentrations of chlorides fluctuated only mildly (from 76 mg Cl^-/L in Stage 4 to 112 mg Cl^-/L in Stage 1), it was determined that the concentrations of chloramines were rising with the concentrations of chlorides (Fig. 5(d)).

The results of research conducted by many authors, compared in WHO document from 2006, indicate that one person swimming in a pool for 2 h may introduce to the water 20–80 mL of urine and 0.1–1.0 L of sweat [25]. These substances contain considerable amounts of nitrogen compounds which, by reaction with the chlorine disinfectant, turn into DBPs, including chloramines. The relationship between the concentration of chloramines and ammonia nitrogen is presented in Fig. 5(e). With the exception of Stage 6, it was determined that heightened concentrations of chloramines were coinciding with heightened concentrations of ammonia nitrogen.

This dependency is proved by the results of the analysis of oxidizability index, a parameter which allows to assess in a quick and straightforward manner, the content of fresh organic matter in samples of swimming pool water (Fig. 5(f)).

5. Conclusions

Adhering to rigorous guidelines regarding the requirements for swimming pool water makes it necessary to incorporate new devices into the treatment systems that facilitate their operation.

The rehabilitation pools, due to the high risk of contaminating the water with pathogenic bacteria, hydromassage pools, due to a higher load of organic matter, and swimming pools for infants, due to a higher water temperature (30°C–36°C) should have their circulation systems supplemented with an additional disinfection method, for instance, by irradiating the water flux with UV light or its ozonization. It is also important to comply with the operational conditions regarding the frequency of filtration beds washings and the amount of water supplementing the water treatment system.

The problem of exposing bathers to adverse effects of the DBPs, discussed in this paper, is especially important in the case of rehabilitation pools and pools for swimming lessons for toddlers. As the requirements for swimming pool water became more rigorous, it was of vital importance to lower the amount of combined chlorine.

It needs to be remembered that testing swimming pool water quality for the content of chloramines should be connected not only with the control of free chlorine and redox potential, but also with the control of water pH, chlorides content, ammonia nitrogen, and oxidizability index.

In the analyzed swimming pool facility, all stages of research were undertaken with an aim to protect the bathers from microbiological contamination and the adverse effects of disinfection.

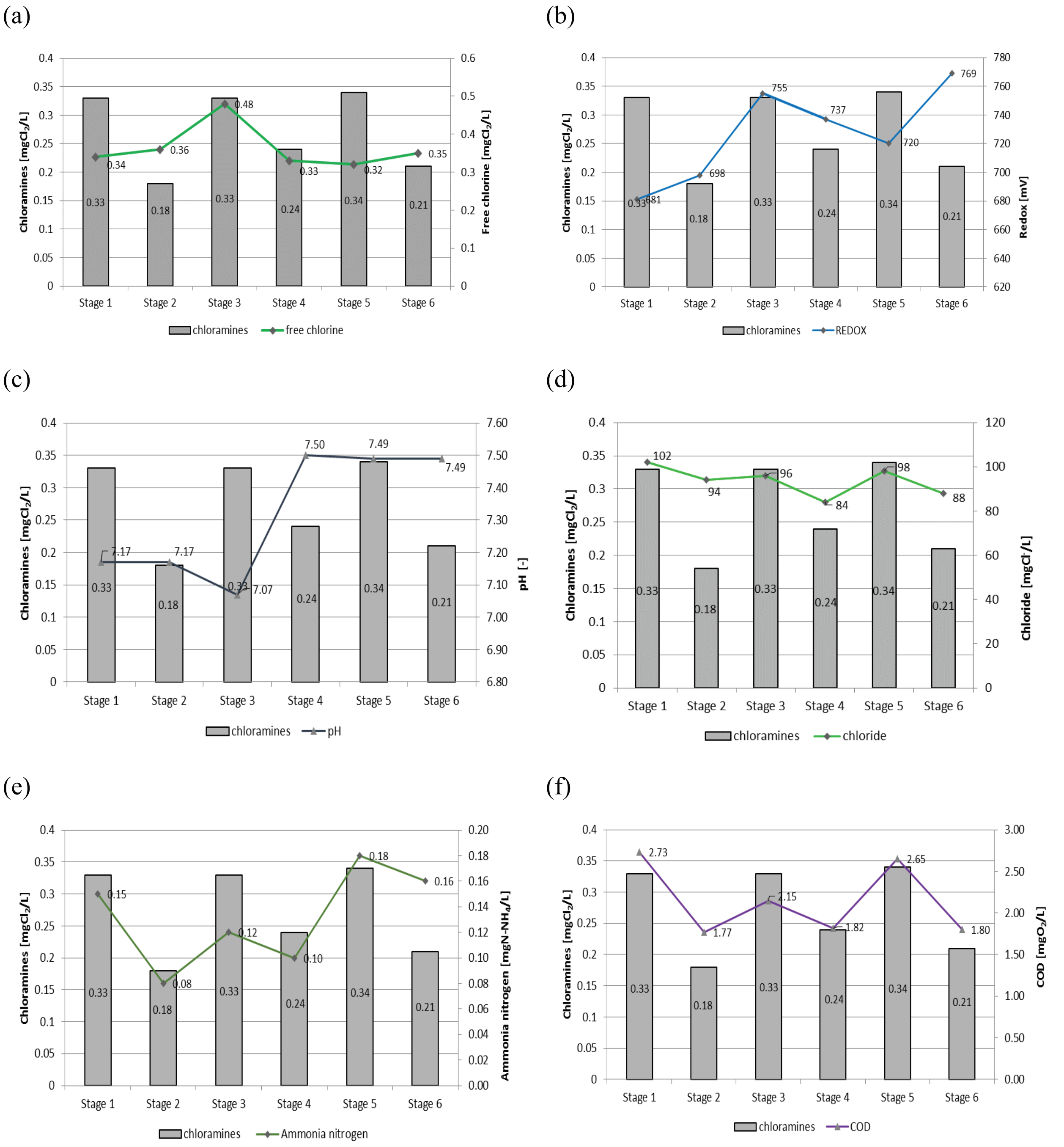

Fig. 5. Effect of pool water quality parameters on the content of chloramines in stages 1–6 of research: (a) free chlorine, (b) redox, (c) pH, (d) chloride, (e) ammonia nitrogen, and (d) COD.

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References

[1] A. Kanan, T. Karanfil, Formation of disinfection by-products in indoor swimming pool water: the contribution from filling water natural organic matter and swimmer body fluids, Water Res., 45 (2011) 926–932.

[2] J. Wyczarska-Kokot, Effect of disinfection methods on microbiological water quality in indoor swimming pools, Archit. Civil Eng. Environ., 4 (2009) 145–152.

[3] V. Bessonneau, M. Derbez, M. Clement, O. Thomas, Determinants of chlorination by-products in indoor swimming pools, Int. J. Hyg. Environ. Health, 215 (2011) 76–85.

[4] L.E.Y. Lian, J. Li, E.R. Blatchley, III, Volatile disinfection byproducts resulting from chlorination of uric acid: implications for swimming pools, Environ. Sci. Technol., 48 (2014) 3210–3217.

[5] J. Li, E.R. Blatchley, III, Volatile disinfection byproduct formation resulting from chlorination of organic-nitrogen

precursors in swimming pools, Environ. Sci. Technol., 41 (2007) 6732–6739.

[6] A. Florentin, A. Hautemaniere, P. Hartemann, Health effects of disinfection by-products in chlorinated swimming pools, Int. J. Hyg. Environ. Health, 214 (2011) 461–469.

[7] S. Simard, R. Tardif, M. Rodriguez, Variability of chlorination by-products occurrence in water of indoor and outdoor swimming pools, Water Res., 47 (2013) 1763–1772.

[8] S. Chowdhury, K. Alhooshani, T. Karanfil, Disinfection by-products in swimming pool: occurrences, implications and future needs, Water Res., 53 (2014) 68–109.

[9] J.H. Jacobs, S. Spaan, G.B.G.J. van Rooy, C. Meliefste, V.A.C. Zaat, J.M. Rooyackers, D. Heederik, Exposure to trichloramine and respiratory symptoms in indoor swimming pool workers, Eur. Respir. J., 29 (2007) 690–698.

[10] C. Voisin, A. Sardella, F. Marcucci, A. Bernard, Infant swimming in chlorinated pools and the risk of bronchiolitis, astma and allergy, Eur. Respir. J., 36 (2010) 41–47.

[11] C. Catto, S. Simard, G. Charest-Tardif, M. Rodriguez, R. Tardif, Occurrence and spatial and temporal variations of disinfection by-products in the water and air of two indoor swimming pools, Int. J. Hyg. Environ. Health, 9 (2012) 2562–2586.

[12] J. Lee, M.J. Jun, 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.

[13] J. Wyczarska-Kokot, Impact of disinfection method on chloramine content in swimming pool water, Ochr. Środow., 36 (2014) 37–42 (in Polish).

[14] J. Wyczarska-Kokot, Comparison of chloramine concentration in swimmingpool water depending on swimming pool intended use, Ecol. Chem. Eng. A, 22 (2015) 27–37.

[15] A. Włodyka-Bergier, T. Bergier, Impact of UV disinfection on the potential of model organic-nitrogen precursors to form chlorination byproducts in swimming pool water, Desal. Wat. Treat., 57 (2016) 1499–1507.

[16] 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.

[17] Act on Sports of 25 June 2010, Dz. U. of 2010, No. 127, Item 857 (in Polish).

[18] Act of 14 March 1985 on the State Sanitary Inspection, Dz. U. of 2011, No. 212, Item 1263 of 2012, Item 460, Item 892 of 2013, Item 2 (in Polish).

[19] Act of 5 December 2008 on Preventing and Combating Infectious Diseases in Humans, Dz. U. No. 234, Item 1570 (in Polish).

[20] Decree of the Health Minister on the Requirements for Water in Swimming Pools, Dz. U. of 2015, Item 2016 (in Polish).

[21] Guide on Water Quality Requirements and Sanitary and Hygienic Conditions in Swimming Pools, 2014 (in Polish).

[22] ZHK NIZP-PZH: Recommendations on Sanitary and Hygienic Requirements for Swimming Pools and Water Quality in Pools for Babies and Children from 6 Months to 3 Years Old, 2012 (in Polish).

[23] DIN 19643, Water Treatment for Swimming and Bathing Pools, Beuth-Verlag, Düsseldorf, Berlin, 1997 (in German).

[24] DIN 19643, Water Treatment for Swimming and Bathing Pools, Beuth-Verlag, Berlin, 2012 (in German).

[25] WHO, Guidelines for Safe Recreational Water Environments, Vol.2: Swimming Pools and Similar Environments, 2006.

[26] A. Bernard, S. Carbonnelle, C. de Burbure, O. Michel, M. Nickmilder, Chlorinated pool attendance, atopy, and the risk of asthma during childhood, Environ. Health Perspect., 114 (2006) 1567–1573.

[27] C.M. Villanueva, L. Font-Ribera, Health impact of disinfection by-products in swimming pools, Ann. Ist. Super Sanita, 48 (2012) 387–396.

[28] R.D. Down, J.H. Lehr, Environmental Instrumentation and Analysis Handbook, John Wiley & Sons, New Jersey, 2005.

[29] K. Kaul, Handbook of Water and Wastewater Analysis, Atlantic Publishers and Distributors, New Delhi, 2007.

[30] W. Liu, L. Cheung, X. Yang, C. Shang, THM, HAA and CNCl formation from UV irradiation and chlor(am)ination of selected organic waters, Water Res., 40 (2006) 2033–2043.

[31] B. Lyon, A. Dotson, K. Linden, H. Weinberg, The effect of inorganic precursors on disinfection byproduct formation during UV-chlorine/chloramines drinking water treatment, Water Res., 46 (2012) 4653–4664.

[32] M. Zare Afifi, E.R. Blatchley, III, Effects of UV-based treatment on volatile disinfection byproducts in a chlorinated, indoor swimming pool, Water Res., 105 (2016) 167–177.

[33] 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.

[34] I. Skoczko, E. Szatyłowicz, The analysis of physico-chemical properties of two unknown filter materials, J. Ecol. Eng., 17 (2016) 148–154.

[35] A. Korkosz, M. Janczarek, R. Aranowski, J. Rzechuła, J. Hupka, Efficiency of deep bed filtration in treatment of swimming pool water, Physicochem. Prob. Miner. Process., 44 (2010) 103–113.

[36] K.M.S. Hansen, S. Willach, M.G. Antoniou, H. Mosbæk, H.J. Albrechtsen, H.R. Andersen, Effect of pH on the formation of disinfection byproducts in swimming pool water—is less THM better? Water Res., 46 (2012) 6399–6409.

[37] Y.E.H. Baia, L. Lian, J. Li, E.R. Blatchley, III, Effect of chloride on the formation of volatile disinfection byproducts in chlorinated swimming pools, Water Res., 105 (2016) 413–420.