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COMPARISON OF CHLORAMINE CONCENTRATION IN SWIMMING POOL WATER DEPENDING ON SWIMMING POOL INTENDED USE

PORÓWNANIE STĘŻEŃ CHLORAMIN W WODZIE BASENOWEJ W ZALEŻNOŚCI OD FUNKCJI BASENU

Abstract: Swimming pool water is a mixture of supplementary water added to a closed pool circuit (usually from water supply system) and water from a pool basin, constantly purified and disinfected because of its pollution caused by bathing people. In public swimming pools, in accordance with hygiene guidelines, disinfection by chlorine compounds is required. The most commonly used is sodium hypochlorite disinfectant. The disinfectant properties of chlorine are related to its ability to oxidize organic and inorganic compounds, and the result of water chlorination is the formation of disinfection by-products (DBP). Among the most troublesome DBPs for bathers and service facility of the swimming-pool are chloramines. Chloramines are responsible for the so-called syndrome of swimmers irritation, dry skin, irritation of the mucous membranes of the nose, throat and eyes. They give the pool water and the air in the pool hall a characteristic odor and have mutagenic properties. Therefore, analyzing chloramines concentrations and taking actions, in the field of pool water treatment, in order to reduce them are very important. The primary purpose of this paper is to present the distribution of chloramines concentrations (monochloramine and dichloramine) in the pool water, depending on the pool intended use (school training pool, sports pool, pool for children to play, pool with hydromassage and water tunnel). The analysis of the results of research takes into account the swimming pool water treatment systems, exploitation parameters and the number of people bathing. The comparison of parameters (physical, chemical and bacteriological) defining the quality of the pool water, with particular emphasis on the chloramines concentrations, allows to assess the efficiency of the treatment system and the usefulness of the water to swim and bathe in relation to DIN 19643 standards.

Keywords: swimming pool water, chloramines, disinfection

Introduction

Over the past 30 years there has been a continuous growth in the number of swimming pools and recreational pools.

In terms of the number of swimming pools, the European Union is in second place (approx. 4.5 million swimming pools). Almost half of these pools are new

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facilities, created as a result of growing health awareness and increasing recreational needs.

Swimming pool water is a mixture of supplementary water added to a closed pool circuit (usually from water supply system, meeting the requirements for drinking water) and water from a pool basin, constantly purified and disinfected because of its pollution caused by bathing people. The bathers bring into the water unwanted "biological matter" (*eg* epidermis particles, sweat, urine, feces) and micro-organisms. Each of the bathers may enter into the pool water even a billion bacteria, including pathogens that find it a suitable environment for development. With many people in the pool, the infection can be spread very rapidly.

In public swimming pools, in accordance with hygiene guidelines, disinfection by chlorine compounds is required [1–3]. The most commonly used is sodium hypochlorite disinfectant. The disinfectant properties of chlorine are related to its ability to oxidize organic and inorganic compounds, and the result of water chlorination is the formation of disinfection by-products (DBP). Among the most troublesome DBPs for bathers and service facility of the swimming-pool are chloramines. Chloramines are responsible for the so-called syndrome of swimmers irritation, dry skin, irritation of the mucous membranes of the nose, throat and eyes. They give the pool water and the air in the pool hall a characteristic odor and have mutagenic properties [4–9]. Therefore, analyzing chloramines concentrations and taking actions, in the field of pool water treatment, in order to reduce them are very important [10–15].

According to DIN 19643, chlorine concentration in water samples taken from a pool basin should not exceed 0.2 $mgCl_2/dm^3$. Practice, supported by numerous studies, shows that the pools in which the water is purified with the classic treatment method (pre-filtration + coagulation and filtration + disinfection by NaOCl + pH correction), maintaining such low concentrations of chlorine and keeping the recommended concentration of free chlorine at 0.3–0.6 $mgCl_2/dm^3$ is very difficult or even impossible [15, 16].

Chloramines are compounds formed during water disinfection with chlorine, containing: ammonia (NH_3), ammonia nitrogen ($N\text{-}NH_4$) or organic nitrogen compounds. One swimmer, after approx. 2 hours, can enter into the water from 20 to 80 cm^3 of urine and 0.1–1 dm^3 of sweat [17]. Both urine and sweat contain significant amounts of nitrogen which react with chlorine disinfectant and form undesirable disinfection products, including chloramines.

Depending on the proportion of chlorine to ammonia nitrogen, a pH value of water, alkalinity and temperature, monochloramine (NH_2Cl), dichloramine ($NHCl_2$) or trichloramine (NCl_3) as well as halogenated organic nitrogen compounds may be formed [18]. The formation of monochloramine and dichloramine is possible due to the specific quality of the swimming pool water (a degree of urine and sweat contamination, and a pH in the range of 7.0–7.6).

The aim of this study was to present the distribution of chloramines concentrations (monochloramine and dichloramine) in the pool water, depending on the pool intended use (sports pool, pool for children to play, pool with hydromassage and water tunnel). The pool facility selected for analysis is characterized by high number of bathers (approximately 650 people a day). The analyzed facility includes: sports pool (SP),

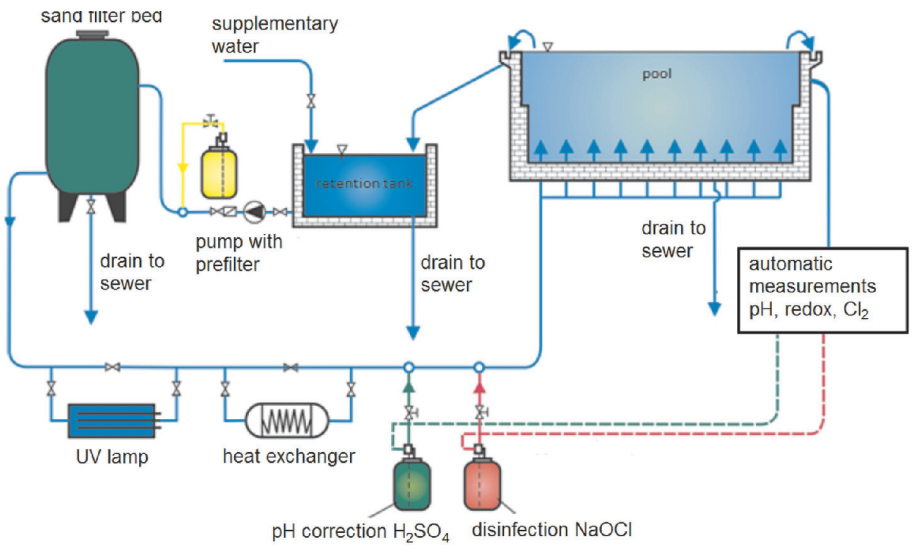

Fig. 1. Pool water treatment system in tested swimming pools

recreational pool (RP), 2 baths with hydromassage jets filled with fresh water (BF), 2 baths with hydromassage jets filled with salt water (BS) and the water tunnel (WT). The facility has five water treatment circuits, each for a different kind of pool. They are closed circuits with active overflow and retention tanks. The swimming pools are equipped with a vertical water flow system with nozzles placed at their bottoms. Figure 1 presents how the water treatment is performed: pre-filtration (to catch fibers and hairs) + coagulation and filtration (in pressure filters with multi-layered bed of sand and anthracite; coagulant: 5 % aluminum sulphate) + UV irradiation (low pressure lamps) + disinfection (sodium hypochlorite produced *in situ* in the membrane electrolysis process) + pH adjustment of water (50 % sulphuric acid).

Table 1

Characteristic parameters of tested swimming pools

Parameter	Unit	SP	RP	BF	BS	WT
Dimensions of the pool basin	m	25 × 12.5	12.5 × 6.0	Φ 2.3	Φ 2.3	—
Capacity of the pool basin	m^3	562	82	1.5	1.5	—
Circiut efficiency	m^3/h	152.6	152.6	46	30	46
Number of filters	—	2	2	1	1	1
Filter diameter	mm	1800	1800	1450	1450	1450
Filtration surface	m^2	2.54	2.54	1.54	1.54	1.54
The height of the filter layer	mm	1350		1250		
Type of filter bed	multilayer sand – anthracite					
Treatment system	pre-filtration, coagulation, filtration, heating pool water, disinfection using low-pressure UV lamps and sodium hypochlorite, pH correction					
Capacity of retention tank	m^3	37.4	17.4	7.48	14.34	36.2

The basic technical and technological parameters of tested swimming pools are summarized in Table 1.

Methods and results of research

In the period of time from 14.03.2014 to 22.04.2014, 8 water samples were collected from each of the tested pools and their physical and chemical parameters were determined with the use of a DR5000 UV/VIS spectrophotometer and in accordance with DIN 19643 (Table 2). The findings were compared with the requirements of DIN 19643, the sanitary and hygienic guidelines and recommendations of the Public Hygiene Institute of the National Institute of Public Health – National Institute of Hygiene (PHI NIPH-NIH) [1–3]. The water pH value, temperature, redox potential and the concentration of free chlorine were read directly from the control and measurement DINOTEC SCL compact DSC device.

Also were determined the bacteriological parameters (Table 3). It was done with the use of methods consistent with PN-EN ISO 9308-1:2004 (*Escherichia coli*), PN-EN ISO 622: 2004 (total number of bacteria at 36 ^{o}C after 48 h) and the National Institute of Hygiene (NIH) guidelines (coagulase-positive staphylococci).

Analysis of research results

On the basis of physical, chemical and bacteriological analysis of the water samples taken from the pools SP, RP, BF, BS and WT, the quality of the swimming pool water was compared with particular attention to the level of and changes in the concentration of chloramines (monochloramine, dichloramine) depending on the swimming pool intended use and the corresponding concentration of free chlorine.

The results of the pool water quality parameters, with the exception of chloramines, corresponded to the requirements of DIN 19643 and the guidelines of the Public Hygiene Institute of the National Institute of Public Health – National Institute of Hygiene (PHI NIPH-NIH) [1–3].

According to DIN 19643, chloramines concentration in water samples taken from the swimming pools should not exceed 0.2 $mgCl_2/dm^3$.

The limit value of chloramines in the SP pool was exceeded on average by 135 % (all samples exceeded the limit), in the RP on average by 25 % (6 out of 8 samples exceeded the limit), in the BF on average by 190 % (all samples exceeded the limit), in the BS on average by 95 % (all samples exceeded the limit) and in the WT on average by 10 % (5 out of 8 samples exceeded the limit).

The usage patterns of the pool basin, dictated by its intended use, operating parameters and the concentration of free chlorine had an influence on chloramines concentration in the water. In the sports pool (SP) – typical swimming pool, for which the time of full water exchange was 3.6 hours and the concentration of free chlorine was in the range of 0.31–0.52 $mgCl_2/dm^3$, the average content of chloramines was 0.47 $mgCl_2/dm^3$ and the percentage of monochloramine (39.9 %) was lower than dichloramine (60.1 %). In the recreational pool (RP), for which the time of full water

Table 2

Values of physical and chemical parameters of water from tested swimming pools

No.	Parameter	Unit	SP			RP			BF			BS			WT		
			Min.	Med.	Max.	Min.	Med.	Max.	Min.	Med.	Max.	Min.	Med.	Max.	Min.	Med.	Max.
1	Ammonia nitrogen	mgN-NH_4/dm^3	0.16	0.26	0.35	0.06	0.14	0.36	0.04	0.13	0.44	0.09	0.16	0.24	0.04	0.11	0.4
2	Nitrate nitrogen	mgN-NO_3/dm^3	10	18	26	10	27	37	10	22	37	10	22	34	13	21	33
3	Chlorine free	mgCl_2/dm^3	0.31	0.36	0.52	0.33	0.36	0.39	0.40	0.64	0.75	0.47	0.59	0.70	0.62	0.84	1.16
4	Chlorine total	mgCl_2/dm^3	0.74	0.83	0.93	0.54	0.61	0.76	0.92	1.22	1.49	0.84	0.98	1.16	0.83	1.06	1.47
5	Chlorine combined	mgCl_2/dm^3	0.22	0.47	0.60	0.15	0.25	0.43	0.36	0.58	0.79	0.33	0.39	0.49	0.12	0.22	0.31
6	Monochloramine	mgCl_2/dm^3	0.09	0.18	0.33	0.14	0.18	0.33	0.09	0.13	0.17	0.05	0.12	0.17	0.09	0.10	0.12
7	Dichloramine	mgCl_2/dm^3	0.08	0.29	0.44	0.01	0.07	0.1	0.23	0.43	0.70	0.20	0.29	0.37	0.10	0.13	0.17
8	Chlorides	mgCl^-/dm^3	113.0	126.6	144.0	216.0	228.6	247.5	68.5	218.1	270.0	1351.0	1427.8	1542.5	35.0	39.4	49.0
9	Phosphates	mgPO_4^{-3}/dm^3	0.11	0.19	0.33	0.30	0.35	0.41	0.04	0.19	0.31	0.04	0.18	0.30	0.02	0.22	0.39
10	Aluminum	mgAl^{+3}/dm^3	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.01	0.00	0.00	0.00
11	Acidity total	mval/dm^3	0.10	0.21	0.50	0.10	0.13	0.20	0.10	0.16	0.25	0.05	0.12	0.20	0.05	0.13	0.20
12	Turbidity	NTU	0.19	0.44	0.92	0.33	0.66	1.11	0.26	0.56	0.74	0.28	0.51	0.74	0.20	0.30	0.58
13	pH	—	7.24	7.32	7.60	7.19	7.30	7.60	7.18	7.33	7.73	7.22	7.27	7.33	6.80	7.07	7.30
14	Hardness total	mg$CaCO_3$/dm^3	103.4	112.7	123.2	125	139.7	158.9	132.1	147.5	175.0	137.5	156.5	173.2	114.3	134.0	151.8
15	Chemical oxygen demand ($KMnO_4$)	mgO_2/dm^3	2.60	3.86	5.05	3.00	4.54	6.10	2.10	4.11	5.70	6.35	7.89	9.40	1.30	2.74	6.60
16	Alkalinity total	mval/dm^3	0.3	0.46	0.55	0.3	0.4	0.55	0.25	0.36	0.5	0.2	0.36	0.55	0.3	0.44	0.80
17	Redox	mV	768	790	804	720	750	772	774	793	807	760	794	818	763	790	804

Table 3

Values of bacteriological parameters of water from tested swimming pools

Indicator	Unit	SP		RP		BF				BS				WT	
		March	April	March	April	March		April		March		April		March	April
						1	2	1	2	1	2	1	2		
Escherichia coli	CFU/ 100 cm^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total number of bacteria at 36 ± 2 ^oC/48 h	CFU/ 100 cm^3	1		0	0	0	0	0	2	0	1	1	1	0	0
Coagulase positive staphylococci	CFU/ 100 cm^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0

exchange was only 0.5 hours and the concentration of free chlorine was in the range of 0.33–0.39 $mgCl_2/dm^3$, the average content of chloramines was 0.25 $mgCl_2/dm^3$ and the percentage of monochloramine (74.3 %) was higher than dichloramine (25.7 %). In baths with fresh and salt water for which the time of full water exchange was approx. 15 minutes, and free chlorine concentration was in the range of 0.40–0.75 $mgCl_2/dm^3$, the percentage of monochloramine (26.0–28.7 %) was significantly lower than dichloramine (71.3–74.0 %) and the average content of chloramines in the BF was 0.58 $mgCl_2/dm^3$, and in BS was 0.39 $mgCl_2/dm^3$. In the water tunnel (WT) in which, due to its specific purpose (massage by water jets), the water was continuously exchanged and the concentration of free chlorine was in the range of 0.62–1.16 $mgCl_2/dm^3$, the average content of chloramines was: 0.22 $mgCl_2/dm^3$, and the percentage of monochloramine (44.1 %) was lower than dichloramine (55.9 %).

The distributions of free chlorine and chloramines concentrations in the tested pools are shown in Fig. 2 and Fig. 3. The percentage of monochloramine and dichloramine in the total content of chloramines, in the following days of research, are shown in Fig. 4.

The type of formed chloramines depends not only on pH, but also on the dose of chlorine. At a weight ratio of $Cl_2/N\text{-}NH_4 < 3/1$ monochloramine is formed and at values $Cl_2/N\text{-}NH_4 > 3/1$ dichloramine is formed [18].

For water in swimming pools, it is difficult to determine a fixed dose of chlorine, primarily due to the fact that the number of bathers is not constant.

The water in sports pools for swimmers (with large capacities and minimum required surface area per person of 4.5 m^2) and in recreational swimming pools for non-swimmers (with a much smaller capacity compared to sports-type pools and the minimum required surface area per person of 2.7 m^2) is disinfected with a dose of chlorine compound so that the content of free chlorine is in the range of 0.3–0.6

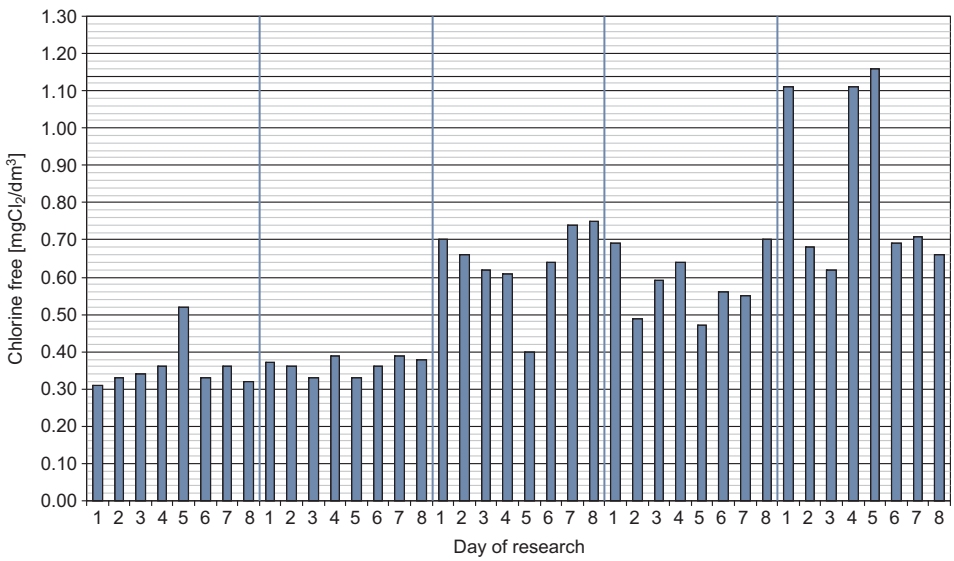

Fig. 2. Distribution of the free chlorine content

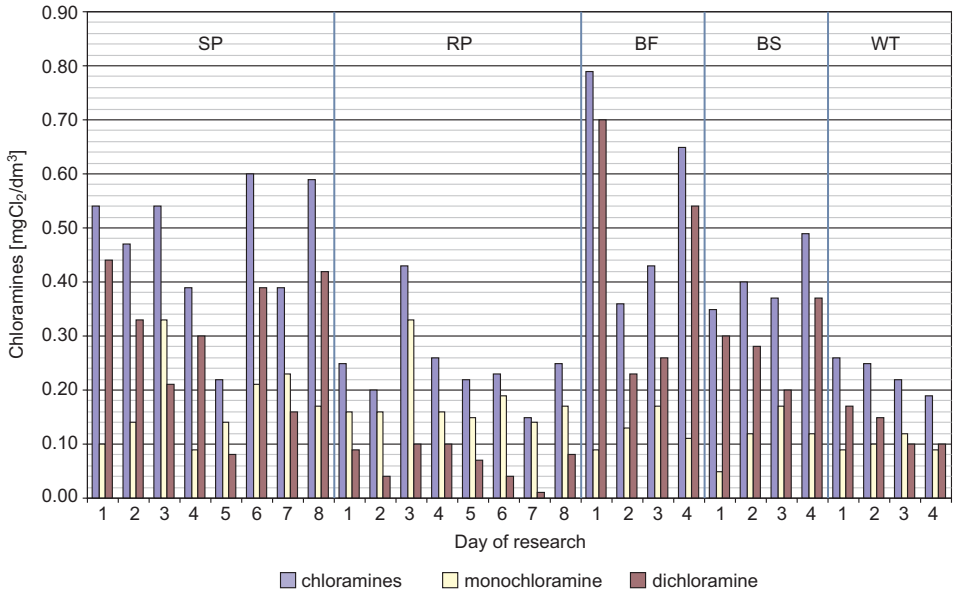

Fig. 3. Distribution of the chloramines content in tested swimming pools

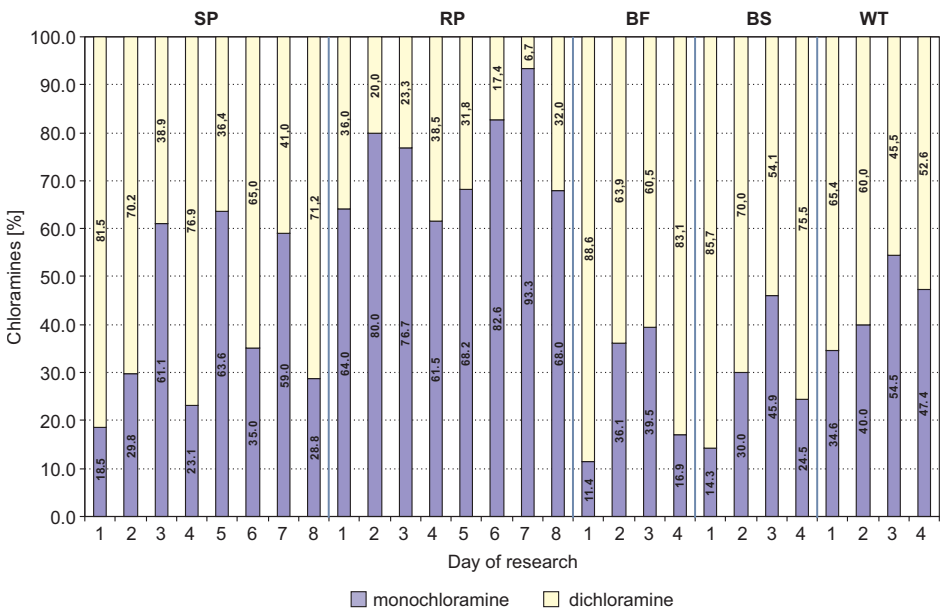

Fig. 4. Percentage of mono- and di-chloramine in the total content of chloramines

$mgCl_2/dm^3$. The water in baths with hydromassage or the one used by "water jet massagers" is disinfected with a dose of chlorine compound to achieve the content of

free chlorine in the range of 0.6–1.2 $mgCl_2/dm^3$. Considering the very small volume of water and the surface area taken by a person using the pool with hydromassage, such levels were determined in order to protect the water from bacteriological contamination (Fig. 2).

In the water from RP weight ratio of $Cl_2/N\text{-}NH_4 < 3/1$ and in the water from BF, BS and WT weight ratio of $Cl_2/N\text{-}NH_4 > 3/1$ results in a quantitative relation of monochloramine and dichloramine that is consistent with previous research [18]. In the case of RP, it is a predominance of monochloramine and, in the case of the BF, BS and WT, of dichloramine (Fig. 3 and Fig. 4).

In the water from SP the average weight ratio of $Cl_2/N\text{-}NH_4$ was 1.4 and the predominance of monochloramine was noted in 3 out of 8 water samples tested (Fig. 3 and Fig. 4).

Summary and conclusions

Providing swimming pool water that meets the sanitary and hygienic requirements, attending to safety and public health, in particular protecting against pathogens, obtaining water that is free from disinfection by-products (DBP), providing comfortable stay in the pool (no characteristic "chloral" smell in the hall pool) and the use of water treatment system adapted to the type and intended use of a pool, is of key value for any properly operated swimming pool facility.

In the swimming pool facilities that integrate sport (SP) with recreation (RP, BF, BS and WT) for both adults and small children, the contents of chloramines in the water should be under greater control.

The swimming pool water quality was compared on the basis of physical, chemical and bacteriological analyses of water samples taken from the examined swimming pools. Particular attention was directed to the content of chloramines (including mono- and di-chloramine) in reference to the free chlorine content, the pool intended use and DIN 19643.

It was found that the intended use of the pool – always associated with attendance factor, the surface of the water, the capacity of the pool and the intensity of its use – has an important impact on the content of chloramines in the water.

On the basis of the performed studies, the following conclusions were formulated:

– The comparison of the content of chloramines in tested swimming pool water showed that the used disinfection system (UV irradiation of circulating water flow + NaOCl dosing), the same for all the analyzed pools, does not guarantee the maintenance of chloramines at concentrations ≤ 0.2 $mgCl_2/dm^3$.

– The lowest concentration of chloramines (0.12–0.31 $mgCl_2/dm^3$) was found in the water from WT, where the contact of the bathers with water was the shortest (about 1 min), and the highest in the BF (0.36–0.79 $mgCl_2/dm^3$), and BS (0.33–0.49 $mgCl_2/dm^3$), where the bathers use relatively small volumes of water in a relatively short period of time, approx. 10–15 minutes.

– A wide variation in the content of chloramines was observed in pools SP and RP. In the sports pool with a large capacity (562 m^3) and time of the exchange of water at

approx. 3.6 hours, an average content of chloramines was 0.47 $mgCl_2/dm^3$. In the recreational pool with a small capacity (86.6 m^3) and time of the exchange of water at approx. 0.5 hours, an average content of chloramines was 0.25 $mgCl_2/dm^3$.

– Varied doses of sodium hypochlorite (Fig. 2) did not significantly reduce chloramines. For example, in pools BF and BS, despite high concentrations of free chlorine (0.40–0.75 $mgCl_2/dm^3$), in all the samples the content of chloramines was far above 0.2 $mgCl_2/dm^3$.

– In 28 samples of pool water concentrations of mono- and di-chloramine were analyzed. 12 samples showed higher concentrations of monochloramine and 16 samples higher concentrations of dichloramine. In the case of BF and BS, much higher concentrations of dichloramine than monochloramine was observed.

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PORÓWNANIE STĘŻEŃ CHLORAMIN W WODZIE BASENOWEJ W ZALEŻNOŚCI OD FUNKCJI BASENU

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Abstrakt: Woda basenowa to mieszanina wody uzupełniającej zamknięty obieg basenowy (najczęściej woda z sieci wodociągowej) oraz wody z niecki basenowej, podlegającej ciągłemu procesowi oczyszczania i dezynfekcji z powodu jej zanieczyszczania przez osoby kąpiące się. W basenach publicznych, zgodnie z obowiązującymi wytycznymi sanitarno-higienicznymi, wymagana jest dezynfekcja związkami chloru. Najczęściej stosowanym dezynfektantem jest podchloryn sodu. Właściwości dezynfekcyjne chloru związane są z jego zdolnością do utleniania związków organicznych i nieorganicznych, a wynikiem chlorowania wody jest powstawanie ubocznych produktów dezynfekcji (DBP). Spośród DBP najbardziej uciążliwymi dla osób kąpiących się i dla obsługi obiektu basenowego są chloraminy. Chloraminy odpowiedzialne są za tzw. zespół podrażnienia u pływaków, suchość skóry, podrażnienia śluzówki nosa, gardła i oczu, nadają wodzie basenowej i powietrzu w hali basenowej charakterystyczny nieprzyjemny zapach i mają właściwości mutagenne. W związku z powyższym analiza stężeń chloramin oraz podejmowanie działań z zakresu technologii wody basenowej, umożliwiających ich zmniejszenie są bardzo ważne. Podstawowym celem badań jest przedstawienie rozkładu stężeń chloramin (monochloraminy i dichloraminy) w wodzie basenowej w zależności od funkcji basenu (szkolny basen do nauki pływania, basen sportowy, basen do zabaw dla dzieci, basen z hydromasażem i tunel wodny). Analiza wyników badań uwzględnia układ oczyszczania wody basenowej, parametry eksploatacyjne oraz obciążenie niecek basenowych. Porównanie parametrów (fizyczno-chemicznych i bakteriologicznych) określających jakość wody basenowej, ze szczególnym uwzględnieniem stężeń chloramin, pozwoliło ocenić sprawność systemu jej oczyszczania i przydatność wody do kąpieli w odniesieniu do normy DIN 19643.

Słowa kluczowe: woda basenowa, chloraminy, dezynfekcja