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Disinfection By-Products in Swimming Pool Water and Possibilities of Limiting Their Impact on Health of Swimmers

Abstract: The presence of water disinfection by-products (DBPs) in the pool environment is a threat to the health of the users of swimming pools. Due to the mechanism of DBP formation, we are not able to prevent their presence. However, there are several ways to prevent the harmful effects of DBPs on the health of pool users; among these, various kinds of methods that result in the reduction of combined chlorine and DBPs precursors should be mentioned. And last but not least, a new approach to the design of the ventilation system for indoor swimming pools seems to be crucial for the above-mentioned purpose.

Keywords: treatment of swimming pool water, THM, DBPs, ventilation

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1. Introduction

Pool water disinfection is the last stage of water treatment and is necessary for the protection of pool users against harmful micro-organisms such as bacteria and viruses. Due to its high efficiency and economic cost, the basic disinfection agent is chlorine.

The reaction between water and the chlorine introduced to it can be presented as Equation (1):

$$Cl_2 + H_2O \rightleftarrows H^+ + HClO + Cl^- \tag{1}$$

At the next stage, the weak pre-chloric acid (I) reacts with organic substances, producing chloramines (2)–(4):

$$NH_4^+ + HClO \rightleftarrows NH_2Cl + H_2O + H^+ \tag{2}$$

$$NH_2Cl + HClO \rightleftarrows NHCl_2 + H_2O \tag{3}$$

$$NHCl_2 + HClO \rightleftarrows NCl_3 + H_2O \tag{4}$$

The type of the emerging chloramines depends mainly on the proportion of the concentration between the chlorine concentration and the ammoniacal nitrogen, which results in the dose of chorine and the water's pH. In a swimming pool, the water's pH level is kept within a range of 6.5–7.6 in accordance with the regulation of the Ministry of Health [1]. Such a range promotes the arising of both mono-chloramines and dichloramines.

The quantity of water disinfection by-products depends on a few factors; among these, the following shall be listed [2]:
– volume of organic substances present in water,
– dose of chlorine,
– water pH,
– water temperature,
– contact time between chlorine and THM precursors.

In the first stage of chlorine disinfection, the chlorine binds with the ammonia- and methane-based contaminations introduced to the water by the users, forming DBPs such as chloramine and trichloromethane; i.e., the compounds of combined chlorine. Hence, the concentration of the combined chlorine indirectly provides information about the quantity of the DBPs.

In the next stage, the free chlorine participates in bacteriological disinfection.

According to the valid regulations (the regulation of the Minister of Health dated November 9, 2015 – the requirements for swimming pool water), managers of swimming pools are obligated to introduce the new requirements regarding the observation and control of the water, meaning the control over the micro-biological and physicochemical parameters of the water.

The swimming pool manager shall control the water regularly on a current basis, checking the following:

– transparency, visible contaminations, repair activities, irregularities, and the undertaken actions connected to them;
– systematic control over equipment for registration of water quality measurement in terms of the parameters indicated in Table 1.

Table 1. Physical and chemical parameters related to water quality and their maximum values according to regulation of Minister of Health

Parameter	Comments		Swimming pool for general use	Swimming pool for children under 3 years old	Sampling
Redox potential	$6.5 \le pH \le 7.3$	[mV]	750	720	4/day
	$7.3 < pH \le 7.6$	[mV]	770	750	
pH	–	[–]	6.5–7.6		4/day
Turbidity	–	[NTU]	0.5	0.5	3/quarter
Combined chlorine	Strive to achieve lowest possible concentration	[mg/dm^3]	0.3		1/day
Free chlorine	Possible short-term increases of 0.6 or 0.4 with heavy load of pool basin	[mg/dm^3]	0.3–0.6	0.3–0.4	4/day
Chloroform	–	[mg/dm^3]	0.03	0.02	1/quarter
ΣTHM	Sum of trichloromethane, bromodichloromethane, dibromochloromethane, tribromomethane	[mg/dm^3]	0.1		1/quarter

Source: [1]

The regulation also defines the guidelines regarding the methodology of the analyses in terms of their correctness, precision, and LOD (limit of detection), which are as follows:

– for the free and combined chlorine: 10%/10%/10% of the values of the parameters;
– for pH: 2.5%/2.5%/not applicable;
– for THM: 25/25/10% of the values of the parameters.

As both the combined and free chlorine define the status of the pool water quality, it is necessary to consider the reasons for exceeding those parameters.

1.1. Pool Water Disinfection By-Products in Indoor Swimming Pools

The scientific research regarding DBP (the origins, presence in swimming pools, and their impact on users) began in 1922 [3]. The main areas of this research (regarding DBP) included the following:

- origins of DBPs,
- properties of DPBs,
- limitation of precursors of DBPs,
- testing DBP concentration in water and air,
- impact on swimming pool users' health,
- routes of human body penetration,
- testing filtration methods impact of DBP presence,
- prevention methods against negative impact of DBPs on users' health.

The organic substances present in potable or pool water react when in contact with disinfected water (which is saturated with chlorine); this reaction results in the origin of DBPs. More than 600 compounds with such a character have been identified. A few groups of them are described by the scientific research:

- trihalomethane (THM); among this, the greatest share is chloroform ($CHCl_3$),
- chloramines (NH_2Cl, $NHCl_2$, NCl_3);
- haloacetic acids (HAAs),
- haloacetonitriles (HANs).

The graphs present the percentage of the individual compound shares in organochlorine DBPs (Fig. 1) and division of THM groups into individual components (Fig. 2).

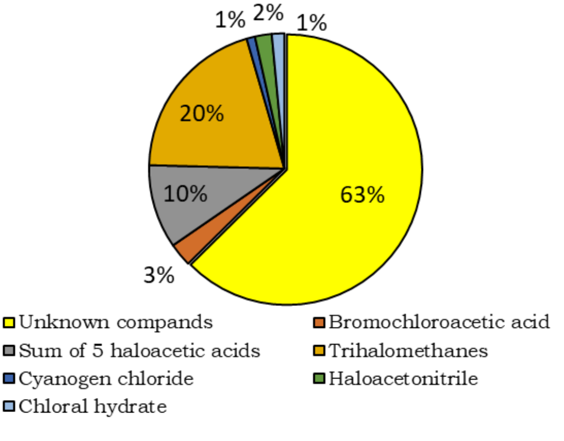

Fig. 1. Chlororganic by-products of disinfection

Source: [2]

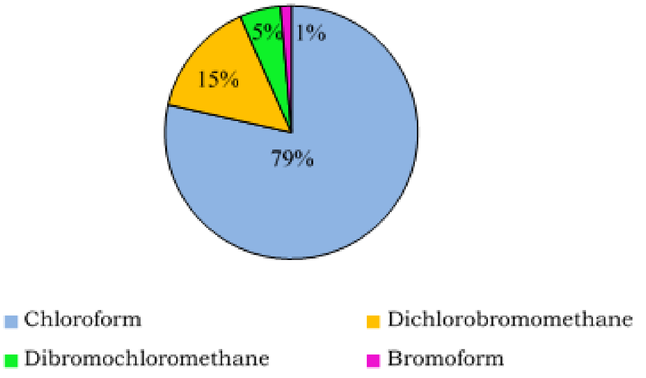

Fig. 2. Trihalomethane (THM) breakdown into four basic components

Source: [4]

One of the main physical features of these compounds that is connected to their harmful character is their volatility. They easily transfer from the water to the air [5–7]. Their concentration in the air depends on their concentration in the water [8–10] as well as on the intensity of the water turbulence; i.e., the activity of the swimmers [11] and the intensity of the water works of the recreation devices (waterfalls, geysers, hydro-massage devices, etc.). Most of these compounds are heavier than air, so they tend to gather just above the water surface.

Equation (5) presents the simplified reaction of the compound's formation [2]:

$$\text{THM precursors} + \text{chlorine} \leftrightarrow \text{THM} + \text{other compounds} \quad (5)$$

The chlorine is present in the equation due to the fact that it is used in the disinfection process, while the THM precursors are the organic compounds present in the raw water or those introduced to the pool water by the users.

In potable water, the organic substances are represented by TOC (total organic carbon), which includes humic acids, fulvic acids, and hydrophilic acids. Meanwhile, we must deal with the additional external organic substances in the pool water; the users of the swimming pools are the most significant source of these substances. The list of these substances consists of the organic components of cosmetics and suntan creams and human body substances (sweat, urine, mucus, epidermis, hair), among others [6].

1.2. Impact of Disinfection By-Products on Health of Pool Users

Due to the DBP properties, there are three ways for the compounds to penetrate the human body:

- dermal contact,
- ingestion,
- inhalation.

There is much research regarding the methods of DBP penetration into the human body. There, one can find information pointing to the fact that the concentration of THM in the exhaled air is strictly connected with the concentration of these compounds in the swimming pool's air [4, 8]. In the other tests, it was found that checking the concentration of the chloroform in the exhaled air and comparing the results of the people walking around a pool or swimming in an aqualung (or without one) that inhalation is the most efficient way of chloroform penetration into the human body. However, dermal contact can also be important [12]. Other researchers have found that 40% of DBP penetration into the human body is caused by dermal contact; the remaining part is by inhalation [10].

Similar tests were carried out for haloacetic acids (HAAs). The concentration of HAAs was tested in the urine in three phases: sitting next to a pool, standing in a pool, and swimming for one hour. The results confirm that there are three ways for these compounds to penetrate the human body [13]. The other results clearly show that the concentration of harmful compounds in the inhaled air has a significant importance. Often, it is stressed that there is a correlation between the concentration of DBPs in the water and the air [14] and between the concentrations in the water, air, and the human body [9].

In their analyses, the researchers also paid attention to the impact of DBPs on human health. A few diseases and symptoms were identified that can be connected to a stay at a swimming pool (particular with long-term stays). One such disease is asthma. It has been noticed that, in the case of recreational swimming (once or twice per week), there is no high risk of asthma; however, those who regularly and often stay at a swimming pool (mainly the coaches and competitive swimmers) are prone to significant asthma risk [15]. Other tests carried out in Denmark confirm that swimming pool employees can have the health problems (particularly regarding the respiratory tract) more often that the rest of the population [16]. The tests also confirmed that trichloroamine is the main cause of eye and skin irritation about which pools users typically complain [17]. The next disease whose cause might be DBPs is bladder cancer [18–20]. There were also tests carried out that indicated that the inhalation of air containing DBPs as a cause of infertility [21, 22].

An analysis of the quoted tests and research leads to the conclusion that it is necessary to control DBP emission in indoor swimming pools; hence, proposing solutions regarding the methods of human body penetration and its impact on users' health must be taken into consideration.

2. Method and Subject of Research

Knowing the mechanism of DBP formation in the water and being aware of its properties (such as volatility, which is most important for the transfer to the air and human body penetration by these compounds), it is possible to propose a few methods of limiting DBP impact in users' health. The following are among them:

- limitation of precursors of DBP formation (mainly organic compounds),
- securing proper ventilation of swimming pool,
- selection of proper method of water disinfection and water-treatment system.

This work presents and describes the three methods above for protecting users from the harmful effects of DBPs. Due to the difficulties in measuring the concentration of DBPs in the air and water, the first two methods will be presented on the basis of the state of the art and a literature review. The experimental part of this work consists of an analysis of the third method – selecting of the proper method of water treatment. The concentration of free chlorine and combined chlorine was measured. The tests were carried out at three indoor swimming pools equipped with standard water-treatment systems, which included the following processes: pre-filtration, coagulation, filtration on a multilayer bed, UV lamp irradiation, pH correction, and chlorination.

The water samples were taken from the basins available for swimming lessons for children that were held twice a day from spots located at the pool's water circulation system. In the samples, the free chlorine, total chlorine, and combined chlorine were indicated. Total chlorine is the sum of the free and combined chlorine, so the quantity of the combined chlorine was calculated as the difference of the measured total and free chlorine. The analyses were carried out by the pool's POOLTEST 3 SPH photo-meter produced by PALINTEST. Additionally, the pH and temperature were measured. Within the period of time from April to June 2016, the measurements were carried out on the standard water-treatment systems. During the period of September-November 2016, measurements were taken for the systems equipped with the additional segments of the water-treatment system.

It was recognized that the concentration of combined chlorine is related to the presence of DBPs in the water. The higher its concentration, the greater the problem is with the quality of the water.

The concentration of free and combined chlorine in pools was the subject of evaluation; first, when the pools were used as the standard, and then after the introduction of additional sections in the pools' water-treatment sections.

3. Limiting Impact of DBPs on Users' Health

3.1. Limiting DBPs Precursors

According to the literature, as the high concentration of DBPs in the water and air results from the high number of the precursors [23, 24], it can be assumed that a limitation of the organic compounds in the pool's water introduced by the users can significantly improve the situation [11, 25]. A simple thing that can be done for this is to recommend taking a shower before entering a swimming pool. The usage of swimming caps should be recommended as well, as human hair is considered to be a source of pollution [26]. Special attention must be paid to the users' and managers' education in terms of the recommended shower-taking, as this is an important factor that influences the limitation of DBP concentrations inside a swimming pool's building [27].

The pool's environs are premises for a special purpose. Inside, there is a special climate – water is evaporating, and pollutions are emitted into the air. The source of pollution is the pool's water. Taking into account the volatility and density of DBPs, it can be stated that their highest concentration is located in the vicinity of the water's surface. The problem is that the swimmers are taking breaths just above the water's surface – therefore, they inhale air with high concentrations of the harmful chemical compounds. As mentioned above, DBPs most often penetrate the human body through the respiratory tract.

3.2. Proper Ventilation of the Swimming Pool

The concentration of DBPs in water can be limited by shortening the number of their precursors and/or properly disinfecting the water, but passing into the volatile phase cannot be stopped. DBP concentrations in the air will be lower if their concentrations in the water are low.

Different tests indicate the necessity for the proper ventilation of a swimming pool, but the authors did not provide any details on how exactly the proper ventilation should look like [9, 12, 24]. These suggestions are the results of the awareness regarding the ways DBPs penetrate the human body, among which inhalation plays the most important part.

As a response to the recommendation regarding proper ventilation, an appropriate installation system can be proposed – a system that will facilitate the removal of the harmful compounds. For this purpose, it should be a ventilation system. In facilities where the harmful substances are present, the most popular is spot ventilation. The best example of such a system is a production hall. At the working stands where the emission of harmful chemical compounds occurs, ventilation hoods or ventilation nozzle are installed (i.e., local solutions). The harmful chemical compounds are removed at the place of their origin; thanks to this solution, they do not migrate to other places in the hall.

The premises of a swimming pool is a spacious area. However, special conditions are required inside for the purpose of providing temperature control for the users – the air temperature for general purposes is 30–32°C, and the relative humidity should be 60–70%. due to the water evaporation and risk of condensation on the external partitions' surfaces. A pool's environs can be divided into three zones depending on the relative humidity of each of these zones.

Moisture is emitted in the swimming pool basin. Here, the volatile water DBPs are also emitted. It must be considered that the swimming pool users are present in this particular zone – swimmers, coaches, and lifeguards. Therefore, they are exposed to the inhalation of moist air consisting of DBPs. The remaining part of the swimming pool is not occupied by humans except for the facilities where the stands are is built. It might be assumed that swimming pools are the huge premises where only a small part of the surface is used for human needs as with sports venues, for example – therefore, the solution for ventilation can be the same as in a sports hall.

Taking humans' needs and requirements connected to the building's structure under consideration, a swimming pool can be divided into three zones with different thermal and humidity requirements (as shown in Figure 3).

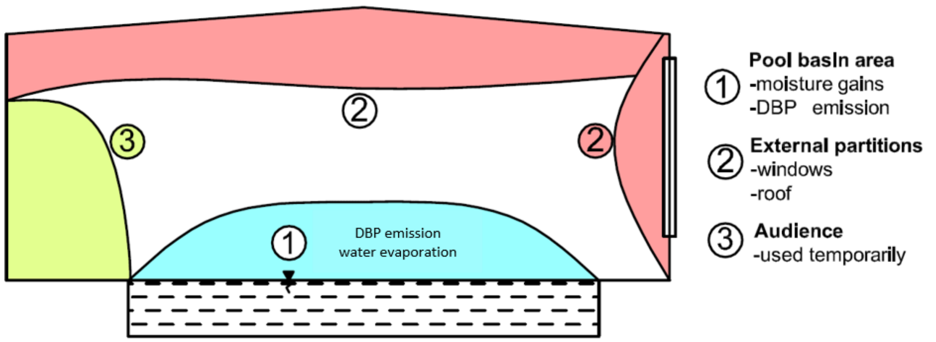

Fig. 3. Zones in swimming pool with different thermal and humidity requirements

Source: [28]

Zone 1 is a place where people are present, so the correct temperature must be secured – not giving the impression of being cool. Also, fresh air must be supplied here – as has resulted from hygiene-related needs. Moreover, all moisture gains and harmful chemical compounds must be removed from here.

Zone 2 is a zone of external partitions. It is located near the external walls and the slab/roof. In this zone, it is necessary to provide such conditions to exterminate the risk of condensation on the building's cladding surface. This is difficult due to the fact that the requirements regarding indoor air parameters cause a the relatively high dew point (21.4°C); i.e., the surface temperature at which condensation occurs.

In the case of low outdoor temperatures, the risk of condensation is significant. The traditional protection of the external partitions consists of the application of air flow directed towards them [29, 30].

A traditional air distribution system used in a pool's facilities is presented in Figure 4.

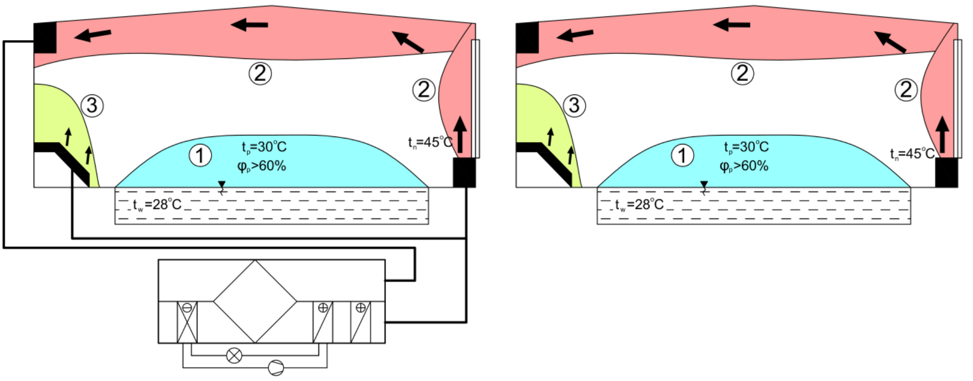

Fig. 4. Traditional air ventilation system of swimming pool with air distribution down-up (explanation as in Figure 3)

Source: [28]

Due to the fact that a pool's basin (where pollution and moisture are emitted) is designed for users, such a division scheme does not seem to be proper. Fresh air is supplied in the vicinity of the windows, not to the zone occupied by people. Only the glazing surfaces are protected in this manner, as the intake air has a high temperature; however, this increases the temperature of the partition's surface and, additionally, the transfer coefficient is higher. Having said that, the external partition can also be protected in a different way. If windows with a low heat transfer coefficient will be applied, the risk of condensation is reduced to a minimum. Analyses of the dependency between the window's heat transfer coefficient and the condensation risk is presented in Figure 5 (in yellow).

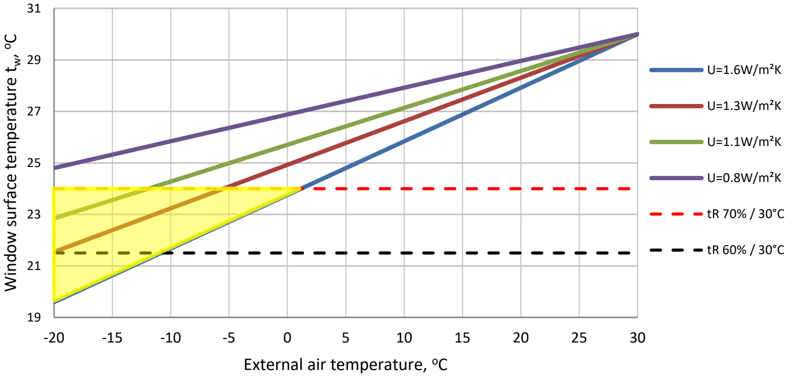

Fig. 5. Risk of condensation of moisture depending on heat transfer coefficient of window and outdoor temperature

Source: [28]

The graph shows that, when using windows with a heat transfer coefficient below 1 W/($m^2 \cdot$ K) (even with an outdoor temperature below –20°C), there is no risk of condensation, as the temperature of window's surface will be higher that the dew point temperature.

Therefore, a decentralized ventilation system can be applied to a swimming pool, particularly if the air flow is directed in such a way as to remove the harmful chemical compounds from the place of their origin; i.e., the vicinity of the pool's basin [31]. It would be reasonable to give up the generally applied down-up-type ventilation system in favor of the up-down system shown in Figure 6.

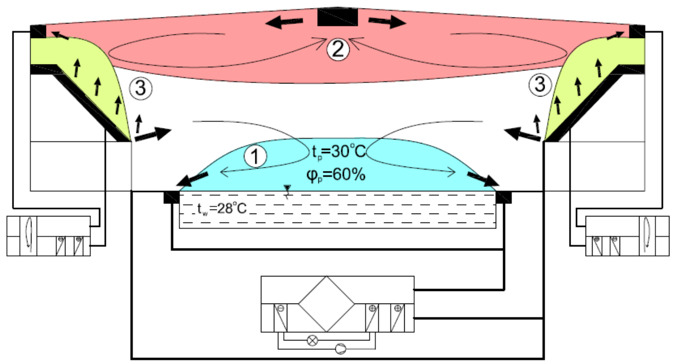

Fig. 6. Decentralized ventilation system for swimming pool with up-down air distribution (explanation as in Figure 3)

Source: [28]

In this type of ventilation system, the air is removed in the lower part of the pool's basin; i.e., from the place where the volatile DBPs are present in the air. This will protect swimmers against inhaling the polluted air. Moreover, such an attitude towards the ventilation system may help to decrease energy consumption for ventilation purposes [32].

The up-down-type of air distribution systems are used in the United States, because special attention is paid in this country to the problem of users' protection against the harmful substances related to water DBPs.

The additional profit of applying a decentralized ventilation system (described very often in the other papers) is the significant saving of the energy necessary for heating the intake air [28].

3.3. Selection of Appropriate Method of Water Disinfection

There is much scientific research regarding the presence of DBPs in swimming pools when applying different methods of water disinfection [24, 33]. Often, this is focused on a comparison of the concentration of these compounds in the water and air when different methods of disinfection are applied. The direct measurement of DBPs or their representatives (e.g., THM) in a pool's water is complicated and costly. Among other methods, the authors of this paper decided to measure the combined chlorine for the purpose of analyzing the influence of the disinfection method on DBP concentration – the parameter included to the obligatory checking in the regulation regarding the requirements for pool water (valid from mid-2016) [1]. Exceeding the maximum level of combined chlorine in a pool's water indicates the insufficient work of the water-treatment system and proves that the chloramines and trihalomethanes are concentrating in the water.

The effects, of exceeding the maximum level of chlorine might be as follows:
- skin lesions and asthma,
- irritation of mucous membrane of eyes and respiratory tracts,
- characteristic "chlorine's smell."

The measurement of free chlorine in a pool's water is also a significant parameter proving the proper selection of the water disinfection method. Free chlorine is a chlorine contained in a solution in the form of solved elementary chlorine (Cl_2), as hypochlorous acid (HClO), and in the form of a hypochlorite ion (OCl^-). Free chlorine contained in a pool's water reduces the bacteria and viruses introduced to the water by users.

Both the potable and pool water must be disinfected. It is necessary to prevent epidemics by means of disintegrating any microbes that might be present in the water. There are a few generally applied methods of water disinfection (potable as well as that in the pool) where the main sanitizer is chlorine. The following should be listed among them:
- filtration via multi-layer bed + chlorination,
- ozonation + filtration via the multi-layer bed + chlorination,
- filtration via multi-layer bed + UV lamp + chlorination,
- filtration via diatomite bed + chlorination.

Each of above methods has some pros and cons in terms of their effectiveness of disinfection, exploitation, and investment. The most popular water-treatment systems designed in Polish swimming pools is based on the modules presented in Figure 7.

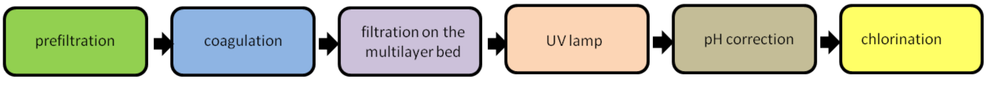

Fig. 7. Scheme of standard water-treatment system used in public swimming pools

Pre-filtration

The first stage of pool water filtration is pre-filtration, which separates the water that is directed towards the treatment system from bigger mechanical pollution (hair, fibers, etc.) in order to protect the pumps and filters against contamination or damage. The filtration is carried out by means of a hair catcher. In older systems, it is separately mounted on the pipework. Presently, it is standard to use catchers integrated with a filtration pump. This solution reduces the flow resistance in the system and is more convenient for the user, as it provides the possibility of quick cleaning.

Coagulation

The coagulation process supports the removal of suspensions (mainly colloidal ones) and partial removal of the dissolved organic carbon. In the water, a coagulant undergoes hydrolysis, and the formed flocks intensify the process if dissolved organic carbon is removed. These coagulations allow us to increase filtration efficiency by means of decreasing the water hardness.

Filtration via Multilayer Bed

A filter with a multilayer bed is commonly used in pool water-treatment systems, as it has a simple structure and easy exploitation. Additionally, the investment and exploitation costs are not too high. The filter’s task is to remove the smaller mechanical dirt from the water not removed by the pre-filtration (e.g., epidermis), the suspensions (e.g., suntan oil), and colloidal particles (fats, creams, etc.). The filter is usually filled with a four-layer bed with different heights and granulations and placed in a strictly determinate order, increasing the bed work efficiency.

UV Lamp

Disinfection by means of a UV lamp is a disinfection process and is applied to improve the effectiveness of the filtration via the multilayer bed and to limit the quantity of the free chlorine in the water introduced to the basin. Water flows through the device where the lamps are placed, emitting ultraviolet radiation at a certain level. The use of UV lamps significantly raises the efficiency of the bacteria- and virus-destroying process and influences the chemical reactions, helping to reduce the chloramines in the water.

Moreover, disinfection by means of UV lamp allows for the reduction of chorine doses. The UV device is located between the filter and the spot of the pH corrector and chlorine dosing. The key element of effective UV lamp disinfection is the proper selection of a lamp. It should be chosen based on the maximum instantaneous flow rate, the quality of the water, and the required portion of UV radiation.

pH Correction

The optimal value of pH for pool water is between 7.0 and 7.4; these results from the effectiveness of the chlorination and the neutral impact on the mucosa. In the modern water-treatment systems, the pH value of water is measured constantly permanently and is corrected automatically if necessary. If the pH is too low, sodium hypochlorite is added to the treated water. Sustaining a pH level below 7.0 can cause a lachrymation (the corrosion of metal parts submerged in the water) and the appearance of chlorides. In the case of a too-high pH level, sulfuric acid is added to the water. Water with a pH level above 7.8 might cause skin itching and the precipitation of scales in the water.

Chlorination

Chlorine dosing should be the last stage of a pool's water-treatment process; it is executed automatically based on the measurement of the water poured to the basin. The water is treated with chlorine in the gaseous form or with a sodium hypochlorite dilution. Gaseous chlorine is supplied by means of a gas bottle or electrolysis device. Using gas bottles is no longer recommended due to safety reasons, but electrolysis device usage is very expensive; thus, it is not very popular. Sodium hypochlorite dilution is commonly used in water-treatment systems in the swimming pools of Poland. For hygiene purposes as well as the comfort of users, the content of free and combined chlorines is controlled and limited by the regulations regarding the quality of pool water [1].

4. Evaluation of Proposed Improvements in Water-Treatment Systems

4.1. Improvements in Water-Treatment Systems in Three Pools

In the Type I swimming pool, the water-treatment system for the recreation basin's circulation is supplemented with the segment using the adsorption process. The localization of the column with a granulated activated carbon bed is presented in Figure 8.

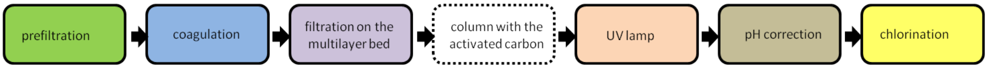

Fig. 8. Scheme of water-treatment system used in Pool I

The adsorption process with the use of activated carbon is intended to remove dirt and collect it at the surface of the adsorbent. At the same time, physical adsorptions (the particles of the adsorbent are arrested on the bed's surface) and chemical adsortions (the particles of dirt are chemically connected to the surface of the activated carbon) take place. The main problem with a bed of such a type is the necessity of its periodical replacement, as chemisorption is a permanent process and the bed cannot be regenerated. Also, the quality of the introduced water has an impact on the efficiency and performance time of the activated carbon bed, so the column was inserted after pre-filtration, coagulation, and the multilayer bed. The proper location of the column provides the removal of the suspension, emulsion, and substances that can be settled on the adsorption bed. The adsorption process is used in the water-treatment technology to remove the natural or anthropogenic organic compounds in particular, as they are the precursors of DBPs.

The activated carbon bed is characterized by a very well-developed specific surface area; as a result, it can adsorb numerous quantities of dirt, even hazardous (e.g., heavy metals such as chrome or arsenic) and burdensome materials or these worsening the taste and smell of the water.

In the Type II pool, a column with an ion exchanger selected especially for water treatment was applied as an additional segment of the water-treatment system. The resin used during the ion exchange process was an Amberlite IRA-958 nonionic macroporous resin. The efficiency of the organic compound removal was approximately 70%. The ion exchange deposit (located as shown in Figure 9) absorbs the negatively charged anions of the dissolved organic carbon contained in the water and it exchanges them into the chloride ions located in the active places. As a result of this process, the DBPs' precursors are reduced. When the deposit's capability for ion exchanging is exhausted, it must be regenerated by means of a NaCl solution.

Fig. 9. Scheme of the water-treatment system used in Pool II

In the Type III pool (Fig. 10), the method of chlorine dosage was changed at the last stage of the water-treatment process. The carried-out tests indicated that changing the sodium hypochlorite into chlorine dioxide causes a significant reduction in the number of DBP precursors; these results from the changed character of the chemical reactions. This disinfectant shows a worse reactivity in connection to the organic compounds present in water and ammonia, which causes a smaller quantity of halogen derivatives (trihalomethanes included).

Chlorine dioxide shows better oxidizing properties than chlorine, and it also destroys the organic substances, viruses, and bacterial spores that chlorine is not able to destroy.

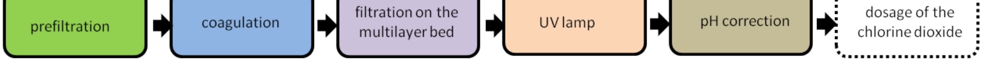

Fig. 10. Scheme of water-treatment system used in Pool III

4.2. Results of Measurements

Table 2 presents the collective results of the measurements on the technology systems described above.

Table 2. Summary of results obtained for three pools (average monthly values)

	Pool I			Pool II			Pool III		
	pH	T [°C]	combined chlorine [mg/dm³]	pH	T [°C]	combined chlorine [mg/dm³]	pH	T [°C]	combined chlorine [mg/dm³]
Date	before								
04.2016	7.0	32	**0.52**	6.7	35	**0.44**	7.1	33	**0.49**
05.2016	7.2	32	**0.53**	6.8	35	**0.39**	7.2	33	**0.48**
06.2016*	7.0	32	**0.34**	6.8	35	**0.32**	7.2	33	**0.35**
Date	after modification								
	adsorption process (column with activated carbon)			ion exchange process (column with ion exchange deposit)			dosage of chlorine dioxide in final stage		
09.2016	7.0	32	0.01	6.7	35	0.07	7.5	33	0.11
10.2016	6.9	32	0.05	6.6	35	0.07	7.5	33	0.13
11.2016	7.0	32	0.15	6.7	35	0.08	7.5	33	0.12
Permitted value according to recommendations of regulation [1]	6.5–7.6	–	0.3	6.5–7.6	–	0.3	6.5–7.6	–	0.3

* This month, a two-week technological break was conducted during which the system was reviewed and cleaned and the pool water completely replaced.

A comparison of the results for all three swimming pools with the maximum permitted value according to the recommendations of the regulation [1] is presented in Figures 11–14.

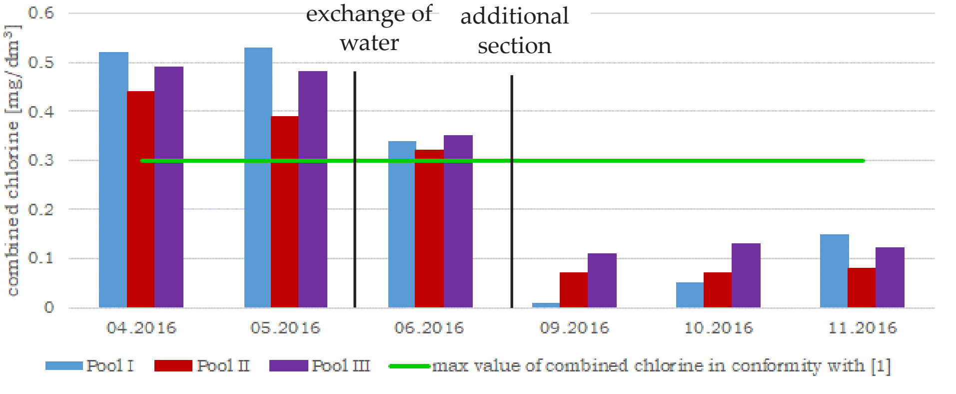

Fig. 11. Comparison of results of combined chlorine concentration obtained for all three swimming pools with maximum permitted value according to the recommendations of regulation

A summary of the results of the free and combined chlorine for Pool I as compared to the maximum permitted values according to the recommendations from the regulation [1] is presented in Figure 12.

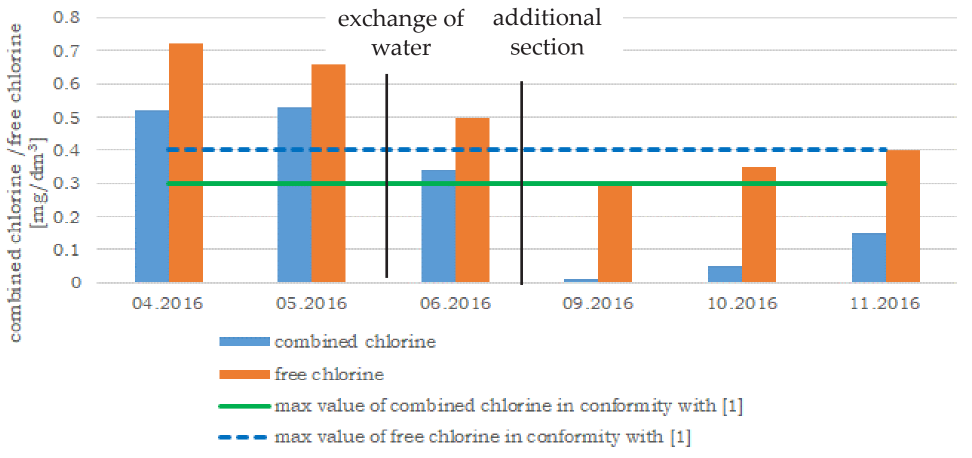

Fig. 12. Summary of results of free and combined chlorine concentration obtained for Pool I as compared to maximum permitted values according to recommendations of regulation

A summary of the results of the measurement of the combined chlorine for Pool II as compared to the maximum permitted value according to the recommendations from the regulation [1] is presented in Figure 13.

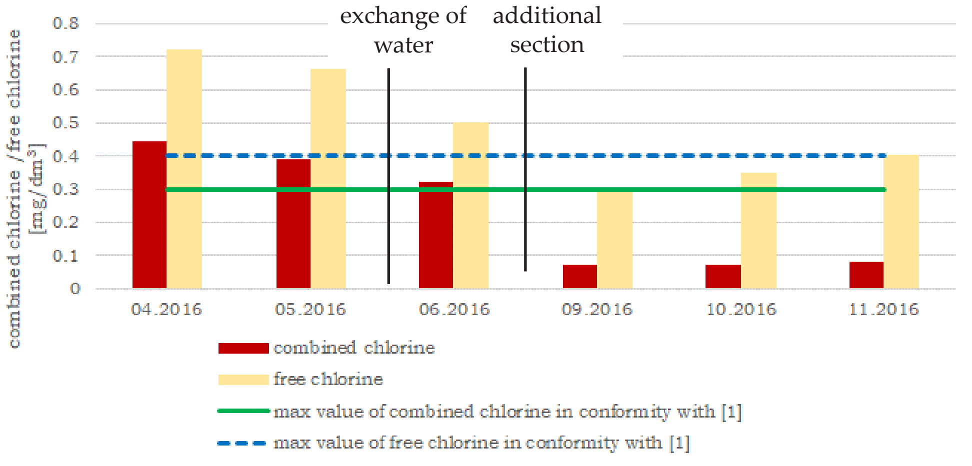

Fig. 13. Summary of results of free and combined chlorine concentration obtained for Pool II as compared to maximum permitted values according to recommendations of regulation

A summary of the results of the combined chlorine measurements for Pool III as compared to the maximum permitted value according to the recommendations from the regulation [1] is presented in Figure 14.

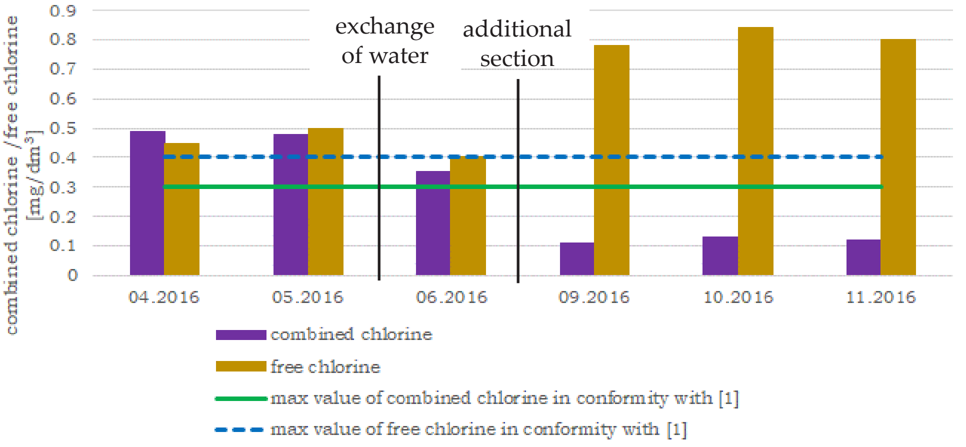

Fig. 14. Summary of results of free and combined chlorine concentration obtained for Pool III as compared to the maximum permitted values according to recommendations of regulation

4.3. Discussion

In each of the tested pools, the level of the combined chlorine was exceeded when the water was cleaned by means of the standard water-treatment system. It is worth mentioning and drawing one's attention to the fact that, during the month when the water in the basins were entirely exchanged (June 2016), the level of the combined chlorine decreased to the maximum permitted value; hence, it can be assumed that the exchange of water once per month could be a solution for adapting the swimming pool installation to the new regulation (which has also been indicated by other authors) [5]. However, the constantly rising costs of water and sewage disposal exclude this solution.

The measured average concentration of combined chlorine in each of the three pools with the standard water-treatment system was 0.46, 0.38, and 0.44 mg/dm^3, respectively. After introducing additional elements into the pool water-treatment system, a lower mean concentration of combined chlorine was obtained: 0.07 mg/dm^3 (the column with the activated carbon), 0.073 mg/dm^3 (the column with the ion exchange deposit), and 0.12 mg/dm^3 (the dosage of chlorine dioxide). After using these additional segments, the concentration of combined chlorine was lowered by 3.7 to 6.6 times. The best effect of reducing the concentration of combined chlorine was obtained by using the column with activated carbon (reduced by 6.6 times) and the column with ion exchange deposit (by 5.7 times) with respect to the concentration measured when a standard swimming pool water-treatment system was used.

The results of the measurements taken on the systems complemented with the additional technological processes indicated the possibilities of their practical application. The level of the combined chlorine in these cases was below the maximum permitted value.

5. Conclusions

Based on the scientific literature (discussed in Point 3), it can be stated that limiting the impact of pool water disinfection by-products on the health of swimmers can be achieved by the following:

– an education process regarding the necessity of carrying out hygienic operations before entering a pool, such as a taking a shower, cleaning the body with soap, and using of swimming caps; these actions would limit the presence of the precursors of DBPs;
– the proper ventilation of a pool's venue with a properly directed air flow can significantly improve the quality of the air; this is important due to the fact that human respiratory tracts are most vulnerable to the harmful impact of DBPs.

The conducted measurements assessing the use of additional elements in a water-treatment system showed the following:

– a properly carried out water-treatment process in which additional filtration elements will be applied might contribute to the fulfillment of the requirements resulting from the regulation [1];
– this is confirmed by the results of the carried-out measurements shown in Figures 12–15. In each of the tested systems, the results are promising; however, before deciding on an application of a certain technology, a yearly exploitation would be recommended.

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Produkty uboczne dezynfekcji wody basenowej i możliwości ograniczania ich wpływu na zdrowie użytkowników

Streszczenie: Obecność produktów ubocznych dezynfekcji wody (DBPs) w środowisku basenowym jest zagrożeniem dla zdrowia użytkowników pływalni. Z uwagi na mechanizm formowania DBPs nie jesteśmy w stanie zapobiec ich powstawaniu. Istnieje jednak kilka możliwości zapobiegania szkodliwemu wpływowi DBPs na zdrowie użytkowników basenów, wśród których należy wymienić różne rodzaje metod redukcji prekursorów chloru związanego i DBPs oraz nowe podejście do projektowania rozdziału powietrza wentylacyjnego.

Słowa kluczowe: uzdatnianie wody basenowej, THM, produkty uboczne dezynfekcji wody, wentylacja