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CHLORINE CONTAMINATION IN DIFFERENT POINTS OF POOL – RISK ANALYSIS FOR BATHERS' HEALTH

ZAWARTOŚĆ CHLORU W RÓŻNYCH PUNKTACH NIECKI BASENOWEJ – ANALIZA RYZYKA DLA ZDROWIA KĄPIĄCYCH SIĘ

Abstract: The pool water treatment and disinfection plant fulfills its task only if the hydraulic system cooperates with the appropriate pool basin geometry. Water flow through the pool can cause "dead" zones not involved in circulation. In these zones the degree of mixing the disinfectant with water can be different. In consequence, the effectiveness of microorganisms' deactivation and the health effects on bathers may be different. The physicochemical results of pool water samples taken from the characteristic points of the basin were presented. Attention has been paid to the content of free chlorine and combined chlorine. The study was conducted in two indoor pools, differing in water flow system. Based on the analysis results, chlorine maps for swimming pools were prepared. It has been shown that in order to assess the health risk to bathers samples of water should be collected from representative points of the pool.

Keywords: map of chlorine, pool hydraulic system, risk to bathers' health

Introduction

In public swimming pools, according to hygienic guidelines, the disinfection with chlorine compounds is required [1–3]. The disinfection properties of chlorine are related to its ability to oxidize organic and inorganic compounds. The negative result of chlorination is the formation of disinfection byproducts (DBP). They are formed in swimming pool water in much higher concentration levels than in drinking water, due to higher chlorination levels and higher content of organic matter [3, 4]. More than 600 types of these compounds have been identified and new ones are still being discovered. Among water disinfection products the most important ones are trihalomethane (THM),

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haloacetic acids (HAA) and chloramines (CAM) [5–10] Chloramines are the most troublesome for bathers. They are responsible for the so-called “irritation syndrome” in swimmers, dry skin, irritations of mucous membranes. They also cause unpleasant odor of swimming pool water and have mutagenic properties [11–19]. Due to the high volatility of DBPs, they are harmful not only for people using baths, but also for swimming pool staff, especially for those who spend several hours a day in the swimming pool hall [15, 20–24].

There are many factors affecting the amount and type of DBPs formed in pool water. The most important are the chlorination level (disinfection type and water treatment method), the number of swimmers and their intensity of swimming (pool load) and the pool’s hydraulic system [6–9, 17, 21, 25, 26].

Even the best designed pool water treatment system, with multi-stage and modern disinfection, will not guarantee the health of bathers if the flow of water through the basin will cause „dead” zones not involved in circulation and facilitating both the accumulation of pollutants and the growth of microorganisms (including pathogens).

The process of establishing the location of the representative points for the analysis of the potential health risks for bathers in swimming pool basins should consists of identifying the sections with the worst water quality.

Based on the results of model studies on the hydraulic systems in swimming pools, the points located near the basin walls, in its corners on the shallow and deep sides and the center of the basin are identified as characteristic [27, 28]. It would be best to prepare a “chlorine map” showing the chlorine distribution in pool basin after a night break before opening the pool for swimmers and during the maximum load of the pool. The analysis of obtained data will allow for a reliable identification of the representative points for assessing the quality of water in the pool basin, and the results of the water samples taken from these points will assess the possible risk to the health of the bathers.

The aim of this work was to compare the content of free and combined chlorine at the characteristic points of swimming pools with different hydraulic systems and to select representative water sampling points for evaluation of its quality.

Characteristics of research objects

Because the kind of compounds that are formed in the water subjected to chemical disinfection is influenced by the type of disinfectant used, two swimming pools with similar characteristics (marked as V and H) were chosen for the research. In both pools the same disinfectant is used (14.5% stabilized sodium hypochlorite solution). The attendance is 15–17 persons per hour, so the surface water area of per one person in both swimming pools is 16–19 m^2. In the analyzed swimming pools, the water is treated in closed circuits with overflow channel and compensatory tanks, in the system: prefiltration (fibers and hair trap) + surface coagulation (multilayer pressure filters with sand-gravel bed, coagulant: 5% aluminum hydroxychloride solution) + UV irradiation (low pressure lamp, radiation dose 600 J/m^2) + correction of water pH (30% sulfuric acid solution) + chlorination (14.5% NaOCl solution). For the measurement and regulation of the basic parameters of circulating water quality, microprocessor measuring and control sets with electrodes are used, enabling the measurement of temperature, pH, free and combine chlorine concentration, and redox potential.

The main difference between the tested objects is due to the hydraulic system of the water flow through the basin. V pool uses vertical flow while the water in H pool flows horizontally.

In V pool, the water is drained from the basin through the overflow channels located along the basin walls. It is supplied to a 14 m^3 compensatory tank through six outlet pipes (DN140 and DN225). Fresh water (tap water) is supplied to the compensatory tank through an electrically operated valve. Water from the tank is sucked in by circulating pumps and supplied to the treatment system. Treated water flows into the basin by DN225 pipeline system and two DN160 channels located at the bottom of the pool. The water circulation (V) system ensures that the entire volume of water in the pool basin is exchanged in 2 hours 30 minutes.

In H pool, water flows in a horizontal, press system. Clean water flows into the basin through inlet nozzles placed horizontally in the shorter front wall. On the opposite side of the basin the water from the bottom of the basin is drained with the help of the forced circulation pumps. The installation of water circulation (H) ensures the exchange of the entire water volume in the basin in about 4 hours 45 minutes. Due to the lack of a compensatory tank in this pool installation, the water loss is replenished directly to the basin of pool, when the level of the water table drops by 15 cm.

Materials and research methodology

The main aim of the research was to determine the concentration of the free and combined chlorine in various points of swimming pool basins. In each of the basins, 7 characteristic points were selected: points 1 and 4 in the basin corners on the shallow side, points 3 and 6 in the corners of the basin on the deep side, points 2 and 5 at the walls in the central part of the basin and point 7 in the middle of the basin (Fig. 1). Water samples for physicochemical and bacteriological analyzes were collected in the

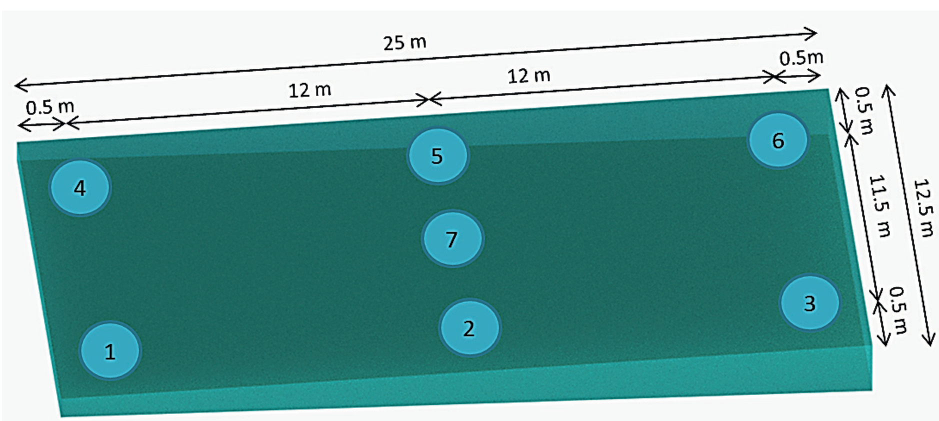

Fig. 1. Location of water sampling points in pools V and H

morning before the opening. Samples were collected 5 times from V pool and 4 times from H pool. The concentration of free chlorine and combined chlorine was determined in situ for each water sample collected from the selected characteristic points. Complementarily, for the mixed samples, the pH of the water, the ultraviolet absorbance at 254 nm, the conductivity, the redox potential and total organic carbon (TOC) were determined on each day of research. The measurement of chlorine concentration using the colorimetric method was carried out with Hach® portable Pocket ColorimeterTM II device. The measurement of conductivity and pH of water samples was carried out with a multi-parameter gauge inoLab® 740 (WTW, Measuring and Analytical Technical Equipment). Absorbance was measured using UV VIS Cecil 1000 from Analytik Jena AG, with the optical path length of the cuvette d = 1 cm. The absorbance value at wavelength of 254 nm was determined on the basis of UV_{254} ultraviolet absorbance measurement method, in accordance with the standards adopted by the US EPA [29]. The final result of the analysis was summarized as UV_{254} in m^{-1}. The measurement of TOC was performed by non-dispersive infrared spectroscopy (NDIR) using TOC-L analyzer (SHIMADZU). On 3th day of research in basin V and the 2nd day of study in basin H bacteriological analysis was performed for the mixed sample. The CFU (colony forming units) of *Escherichia coli, Pseudomonas aeruginosa* and the total number of microorganisms (at 36 ± 2°C after 48 hours) were determined.

The results of the research were compared with the recommendations of the regulation on the requirements for water in swimming pools [1–3].

Results and discussion

Figures 2–5 present the distribution of free and combined chlorine at the characteristic points of swimming pools. In Figure 6, the results of analysis of complementary parameters are presented in the form of comparative bar charts.

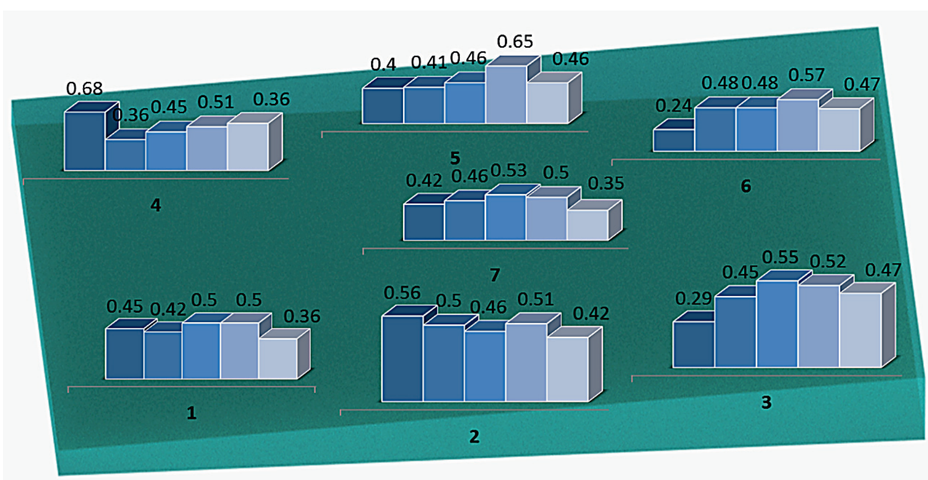

Fig. 2. Distribution of free chlorine concentrations in pool V

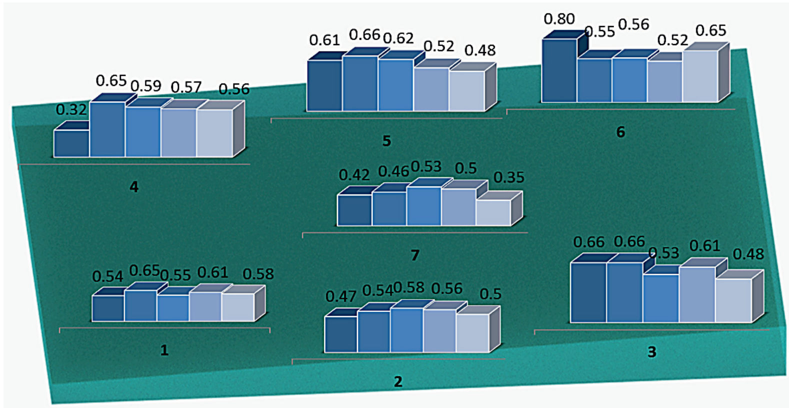

Fig. 3. Distribution of combined chlorine concentrations in pool V

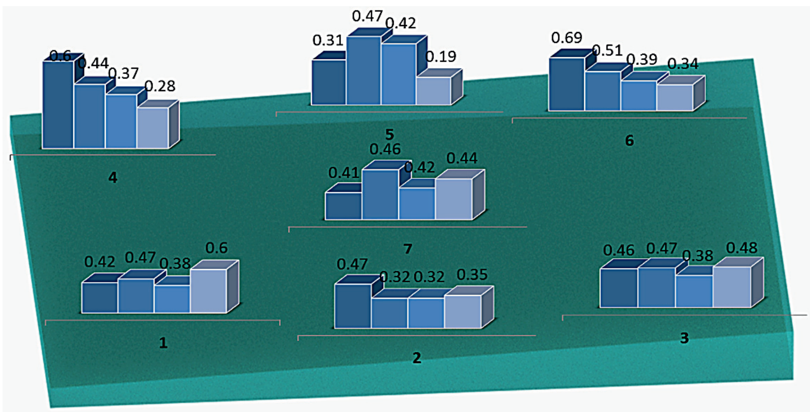

Fig. 4. Distribution of free chlorine concentrations in pool H

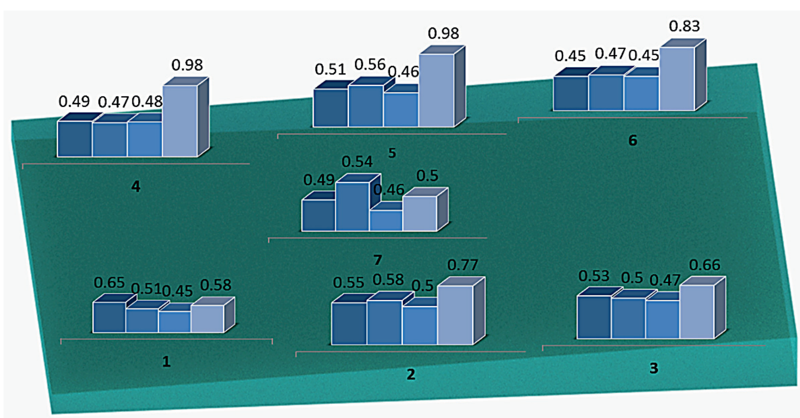

Fig. 5. Distribution of combined chlorine concentrations in pool H

The most uniform distribution of the concentrations of free and combined chlorine was found in the middle of the pools (point 7) and the least uniform one in the corners of the basins on both the shallow and the deep side of the basin (points 4 and 6).

In both analyzed pools, the content of combined chlorine in all water samples significantly exceeded the permissible value, i.e. 0.3 mgCl_2/dm^3. In V pool, depending on the sampling point, the overruns ranged from 177% to 207%, while in H pool it varied from 167% to 210%.

The free chlorine concentrations in most of water samples were in the recommended range, i.e. 0.3–0.6 mg Cl_2/dm^3. The exceptions were water samples from points 4 and 6 (the pool corners) where concentrations were smaller or larger than required. The mean concentration of free chlorine in V pool, depending on the sampling point, was 0.45–0.51 mgCl_2/dm^3, while in H pool it was 0.35–0.48 mgCl_2/dm^3.

The analysis of the complementary parameters (Fig. 6 and Fig. 7) indicates a better quality of water in V pool, where a vertical hydraulic system, recommended for regular shaped pools [27, 28], was used. The pH values of water in pool V corresponded to the requirements (pH = 7.2–7.6) and were on average 7.33. In pool H the average pH of the water was 7.09. Absorbance values in pool V were about 13% lower than those measured in pool H water samples. Conductivity values were about 21% lower when compared to pool H. Redox potential values should be in the range of 750–770 mV. The most similar values to those required were measured in pool V water (average 714 mV). As disinfection by-products (DBP) are formed when the disinfectants react with the

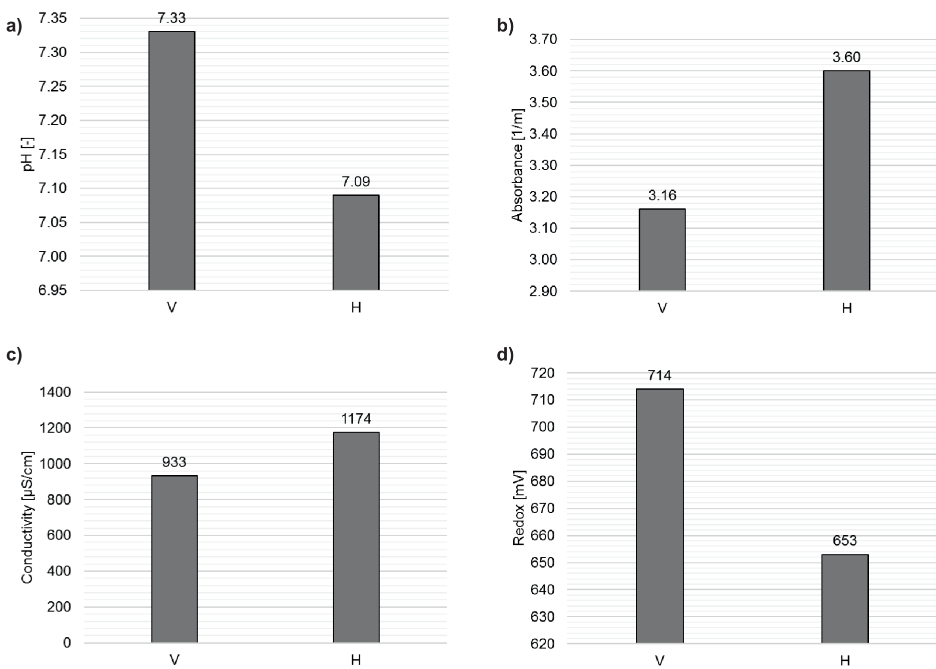

Fig. 6. Comparison of the complementary parameters: a) pH, b) absorbance, c) conductivity d) redox

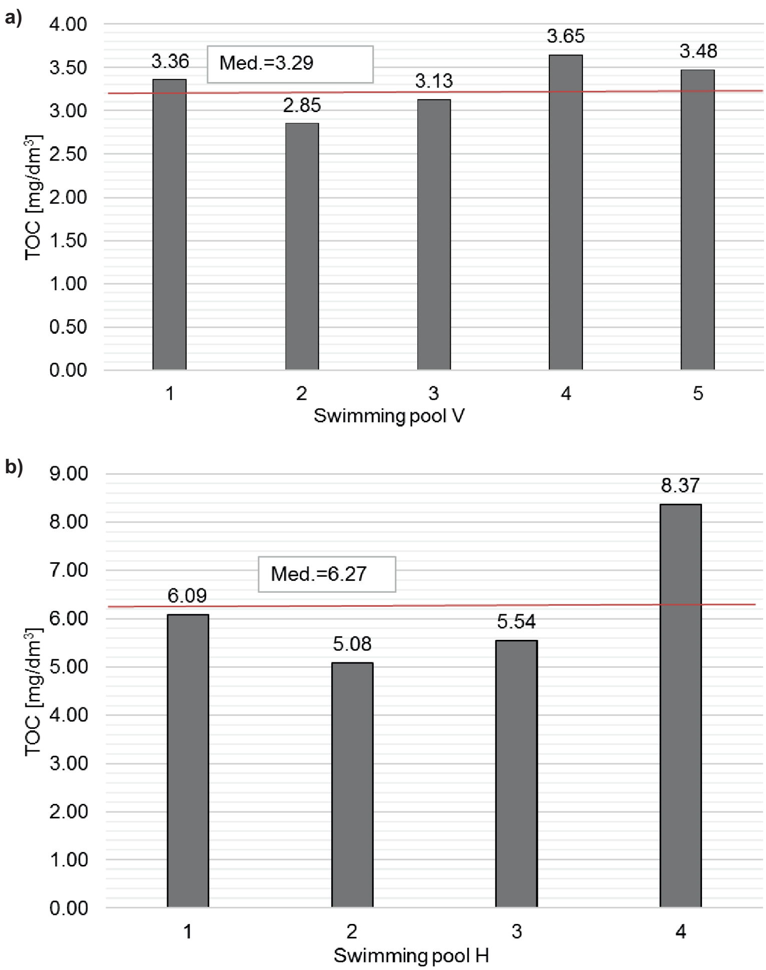

Fig. 7. Comparison of TOC concentrations in water on subsequent days of measurement: a) swimming pool V, b) swimming pool H

organic substance, special attention has also been paid to the content of TOC in the pool water samples. As with the other parameters, better quality of water has also been demonstrated in pool with vertical hydraulic system. The average content of TOC in pool V water was 3.29 mg/dm^3. In water from pool H this value was almost twice as high (6.27 mg/dm^3).

The water circulation system used in H pool is not recommended for public swimming pools. The inflow in the short wall of the basin, the number of inlet nozzles and the outflow of water from the bottom, do not comply with the requirements of a modern swimming pool. The high variability of the concentration of the tested parameters at various sampling points of H pool indicates insufficient mixing of water. This conclusion is confirmed not only by the greater spread of free and combined chlorine concentrations compared to those determined in pool V, but also by worse overall sanitary condition of the water.

The results of the microbiological analysis of the pool water sampled from V pool did not raise any objections. No CFU of the total number of microorganisms (at 36 ± 2°C after 48 h), *Escherichia coli and Pseudomonas aeruginosa* was found in V pool while, in the water samples from H pool, 2 CFU/100cm^3 of *Escherichia coli* were present.

Summary and conclusions

Particular attention was paid to the distribution of free and combined chlorine in water from basins with different water flow systems in the pool basin. The selected parameters which are the most important and, at the same time, easy to determine, are chemical parameters in the field of analysis of health risk to people using swimming pools. The amount of free chlorine in pool water defines its antiseptic effect. The concentration of combined chlorine determines the comfort and safety of bathing as it causes allergy, irritation of mucous membranes and digestive system.

The most uniform distribution of the concentrations of both free and combined chlorine was observed at the middle point of swimming pools, while the deviations from the required values were found in the corners of the basins and near their walls.

According to the WHO, DIN and Polish regulations [1–3], the concentration of combined chlorine in water sampled from the pool basin should not exceed 0.3 $mgCl_2/dm^3$. Both in V pool and H pool in all points, the concentrations were almost twice as high. Considering the high content of combined chlorine, there is a need to modernize the water treatment system in both V and H pools, and especially the circulating system in H pool.

Hygiene of water is undoubtedly influenced by the type of hydraulic system, which should be related to the number of bathers (load factor), the area of the water surface, the depth of the pool and the intensity of its use. The hydraulic system should be adapted to the geometry and structure of the swimming pool. The flow of water through the basin should not cause „dead" zones that do not take part in the circulation. To avoid them, the flow of water through the basin should be as short as possible. The flow time (2 hours 30 min in V pool, 4 hours 45 min in H pool) and the localization and distance between the inflow and outflow nozzle clearly demonstrate the superiority of water in V pool with a vertical hydraulic system. The results of analysis of free and combined chlorine content and complementary parameters (pH, absorbance, conductivity, redox potential, TOC), confirm the better efficiency of the vertical hydraulic system.

It should be highlighted that the way of swimming pool exploitation and cooperation of the hydraulic system with the treatment and disinfection system guarantee that the quality of the pool water is safe for its users.

The authors have started further research, the expanded analysis of the distribution of concentrations of chlorine in pools of different designs and functions. Such tests will allow to determine representative points of pool water sampling to assess its quality and health risk for bathers.

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References

[1] Aufbereitung von Schwimm und Badebeckenwasser (Water treatment for swimming and bathing pools). DIN 19643 1-4:2012-11, Beuth-Verlag, Berlin, 2012. https://www.beuth.de/de/publikation/aufbereitung-von-schwimm-und-badebeckenwasser-kommentar-zu-din-19643/186065025.
[2] Rozporządzenie Ministra Zdrowia z dn. 9 listopada 2015 r. w sprawie wymagań jakim powinna odpowiadać woda na pływalniach, Dz.U. 2015, poz. 2016. (Polish Ordinance of the Minister of Health of 9 November 2015: On the requirements that should be met by swimming pool water) http://isap.sejm.gov.pl/DetailsServlet?id=WDU20150002016.
[3] Guidelines for Safe Recreational Water Environments. Volume 2: Swimming Pools and Similar. WHO, Geneva, 2006. http://www.who.int/water_sanitation_health/bathing/srwe2full.pdf.
[4] Teo TLL, Coleman HM, Khan SJ. Chemical contaminants in swimming pools: Occurrence, implications and control. Environ Int. 2015;76:16-31. DOI: 10.1016/j.envint.2014.11.012.
[5] Chowdhury S, Al-hooshani K, Karanfil T. Disinfection byproducts in swimming pool: Occurrences, implications and future needs. Water Res. 2014;53:68-109. DOI: 10.1016/j.watres.2014.01.017.
[6] Kanan A, Karanfil T. Formation of disinfection by-products in indoor swimming pool water: The contribution from filling water natural organic matter and swimmer body fluids. Water Res. 2011;45:926-932. DOI: 10.1016/j.watres.2010.09.031.
[7] Lee J, Jun MJ, Lee MH, Lee MH, Eom SW, Zoh KD. Production of various disinfection byproducts in indoor swimming pool waters treated with different disinfection methods. Int J Hyg Environ Health. 2010;213:465-474. DOI: 10.1016/j.ijheh.2010.09.005.
[8] Simard S, Tardif R, Rodriguez MJ. Variability of chlorination by-product occurrence in water of indoor and outdoor swimming pools. Water Res. 2013;47:1763-1772. DOI: 10.1016/j.watres.2012.12.024.
[9] Wyczarska-Kokot J. Wpływ metody dezynfekcji na zawartość chloramin w wodzie basenowej (Impact of disinfection method on chloramine content in swimming pool water). Ochr Środ. 2014;36:37-42. http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-2999fa34-e67e-401c-9262-a43a4bda 9528
[10] Carter RAA, Joll CA. Occurrence and formation of disinfection by-products in the swimming pool environment: A critical review. J Environ Sci. 2017;58:19-50. DOI: 10.1016/j.jes.2017.06.013.
[11] Florentin A, Hautemaničre A, Hartemann P. Health effects of disinfection by-products in chlorinated swimming pools. Int J Hyg Environ Health. 2011;214:461-469. DOI: 10.1016/j.ijheh.2011.07.012.
[12] Kaydos-Daniels SC, Beach MJ, Shwe T, Magri J, Bixler D. Health effects associated with indoor swimming pools: A suspected toxic chloramine exposure. Public Health. 2008;122:195-200. DOI: 10.1016/j.puhe.2007.06.011.
[13] Kogevinas M, Villanueva CM, Font-Ribera L, Liviac D, Bustamante M, Espinoza F, et al. Genotoxic Effects in Swimmers Exposed to Disinfection By-products in Indoor Swimming Pools. Environ Health Perspect. 2010;118:1531-1537. DOI: 10.1289/ehp.1001959.
[14] Villanueva CM, Font-Ribera L. Health impact of disinfection by-products in swimming pools. Ann Ist Super Sanita. 2012;48:387-396. DOI: DOI: 10.4415/ANN_12_04_06.
[15] Voisin C, Sardella A, Marcucci F, Bernard A. Infant swimming in chlorinated pools and the risks of bronchiolitis, asthma and allergy. Eur Respir J. 2010;36:41-47. DOI: 10.1183/09031936.00118009.
[16] Zwiener C, Richardson SD, De Marini DM, Grummt T, Glauner T, Frimmel FH. Drowning in disinfection byproducts? Assessing swimming pool water. Environ Sci Technol. 2007;41:363-372. DOI: 10.1021/es062367v.
[17] Gomà A, de Lluis R, Roca-Ferrer J, Lafuente J, Picado C. Respiratory, ocular and skin health in recreational and competitive swimmers: Beneficial effect of a new method to reduce chlorine oxidant derivatives. Environ Res. 2017;152:315-321. DOI: 10.1016/j.envres.2016.10.030.
[18] Li JH, Wang ZH, Zhu XJ, Deng ZH, Cai CX, Qiu LQ, et al. Health effects from swimming training in chlorinated pools and the corresponding metabolic stress pathways. PLoS One. 2015;10:1-14. DOI: 10.1371/journal.pone.0119241.

[19] Llana-Belloch S, Priego Quesada JI, Pérez-Soriano P, Lucas-Cuevas ÁG, Salvador-Pascual A, Olaso-González G, et al. Disinfection by-products effect on swimmers oxidative stress and respiratory damage. Eur J Sport Sci. 2016;16:609-617. DOI: 10.1080/17461391.2015.1080306.
[20] Catto C, Sabrina S, Ginette C-T, Manuel R, Robert T. Occurrence and spatial and temporal variations of disinfection by-products in the water and air of two indoor swimming pools. Int J Environ Res Public Health. 2012;9:2562-2586. DOI: 10.3390/ijerph9082562.
[21] Freuze I, Brosillon S, Laplanche A, Tozza D, Cavard J. Effect of chlorination on the formation of odorous disinfection by-products. Water Res. 2005;39:2636-2642. DOI: 10.1016/j.watres.2005.04.026.
[22] Jacobs JH, Spaan S, van Rooy GBGJ, Meliefste C, Zaat VAC, Rooyackers JM, et al. Exposure to trichloramine and respiratory symptoms in indoor swimming pool workers. Eur Respir J. 2007;29:690-698. DOI: 10.1183/09031936.00024706.
[23] Thickett KM, McCoach JS, Gerber JM, Sadhra S, Burge PS. Occupational asthma caused by chloramines in indoor swimming-pool air. Eur Respir J. 2002;19:827-832. DOI: 10.1183/09031936.02.00232802.
[24] Gallè F, Dallolio L, Marotta M, Raggi A, Di Onofrio V, Liguori G, et al. Health-Related Behaviors in Swimming Pool Users: Influence of Knowledge of Regulations and Awareness of Health Risks. Int J Environ Res Public Health. 2016;13:513. DOI: 10.3390/ijerph13050513.
[25] Wyczarska-Kokot J. Comparision of chloramine concentration in swimming pool water depending on swimming pool intendend use. Ecol Chem Eng A. 2015;22:27-37. DOI: 10.2428/ecea.2015.22(1)03.
[26] Tardif R, Rodriguez M, Catto C, Charest-Tardif G, Simard S. Concentrations of disinfection by-products in swimming pool following modifications of the water treatment process: An exploratory study. J Environ Sci. 2017;58:163-172. DOI: 10.1016/j.jes.2017.05.021.
[27] Saunus C. Planug von Schwimmbadern (Planning of swimming pools). Dusseldorf: Krammer Verlag Dusseldorf AG, 1998. ISBN 3883820709 / 3-88382-070-9.
[28] Piechurski F. Instalacje basenowe. Badania modelowe warunków przepływu wody w niecce basenu pływackiego (Model studies of water flow conditions in a swimming pool). Gliwice: Politechnika Śląska, 2005. ISBN 83-913276-7-1.
[29] Potter B, Wimsatt J. Determination of total organic carbon and specific UV absorbance at 254 nm in source water and drinking water. EPA Document, Method 415. https://cfpub.epa.gov/si/si_public_record_report.cfm?direntryid=103917.

ZAWARTOŚĆ CHLORU W RÓŻNYCH PUNKTACH NIECKI BASENOWEJ – ANALIZA RYZYKA DLA ZDROWIA KĄPIĄCYCH SIĘ

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Abstrakt: Stacja oczyszczania i dezynfekcji wody basenowej spełnia swoje zadanie pod warunkiem współpracy systemu hydraulicznego z odpowiednią geometrią niecki basenowej. Przepływ wody przez nieckę basenu może powodować powstawanie „martwych” stref niebiorących udziału w cyrkulacji. W strefach tych różny może być stopień wymieszania dezynfektanta z wodą. Tym samym różna może być skuteczność dezaktywacji mikroorganizmów i wpływ na zdrowie osób kąpiących się. Przedstawiono wyniki fizyczno-chemicznych badań próbek wody basenowej pobranych z charakterystycznych punktów niecki. Szczególną uwagę zwrócono na zawartość chloru wolnego i chloru związanego. Badania przeprowadzono w dwóch krytych basenach różniących się systemem przepływu wody. Na podstawie wyników analiz sporządzono mapy chloru dla niecek basenowych. Wykazano, że do oceny ryzyka zagrożenia zdrowia osób kąpiących się próbki wody powinny być pobierane z punktów niecki basenowej uznanych za reprezentatywne.

Słowa kluczowe: mapa chloru, system hydrauliczny basenu, zagrożenie zdrowia kąpiących się