EFFECT OF DISINFECTION METHODS ON MICROBIOLOGICAL WATER QUALITY IN INDOOR SWIMMING POOLS

Joanna WYCZARSKA-KOKOT *

* Dr.; Faculty of Energy and Environmental Engineering, The Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland
E-mail address: *joanna.wyczarska-kokot@polsl.pl*

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Abstract

The work presents results of analysis of indoor swimming pool water quality of in based on microbiology parameters and extended by physical and chemical parameters (taken as a standard sample). Tests were performed in seven sports pools in which different methods of disinfection were applied. The analysis of results collected between June 2006 and June 2008 was carried out. Total of 228 water samples were analyzed. The suitability of water for bathing was determined by comparing research result with accepted values of contamination indicators. Generally good quality of water was found in respect of microbiological tests. The analysis of bacteriology, physical and chemical results showed the effect of disinfection methods on water quality in swimming pools. Additionally, it was shown that physical and chemical indicators should not be treated as additional parameters but they should be taken into consideration equally with bacteriological indicators in determining swimming pool water quality.

Streszczenie

Referat prezentuje wyniki analiz jakości wody w krytych pływalniach głównie na podstawie wielkości parametrów mikrobiologicznych, uzupełnionych o parametry fizyczno-chemiczne, przyjętych jako wskaźnikowe. Przedmiotem badań było siedem basenów sportowo-rekreacyjnych, w których zastosowano różne metody dezynfekcji wody. Analizie poddano wyniki badań wykonanych w okresie od czerwca 2006 roku do czerwca 2008 roku. Łącznie przeanalizowano 228 próbek wody z niecek basenowych. Przydatność wody basenowej do kąpieli oceniono na podstawie porównania wyników badań z dopuszczalnymi wartościami wskaźników zanieczyszczeń. Ogólnie stwierdzono dobrą jakość wody basenowej pod względem mikrobiologicznym. Analiza wyników badań bakteriologicznych prowadzonych równolegle z badaniami fizyczno-chemicznymi wykazała wpływ metody dezynfekcji wody basenowej na jej jakość. Dodatkowo wykazano, iż wskaźniki fizyczno-chemiczne należałoby traktować nie jako pomocnicze w stosunku do wskaźników bakteriologicznych, ale jako współdecydujące o dopuszczeniu pływalni do użytku.

Keywords: **Microbiology; Indoor swimming pool; Water disinfection.**

1. INTRODUCTION

The sanitary evaluation of swimming pools, according to both national and EU regulations depends first of all on laboratory research, which allows to establish suitability of water for bathing and on a visual inspection of equipment and tidiness in the inspected area.

Bacteriological, physical and chemical research play a predominant part in the inspection process. The main goal of the former is research into the risks from microorganisms, and the latter - to determine chemical composition of water, with special consideration of substances hazardous to health. Comparison of obtained results with admissible levels of pollutants is the basis for qualification of water suitability to bathe [4].

Pollution of water in swimming pools in respect to sanitary pollution could be a cause of infections. Water in swimming pools can be the source of pathogenic micro-organisms creating an epidemiological risk. Additionally, the fact that the skin of a single human being can transmit from 10^3 to $3x10^9$ bacteria into the water confirms necessity of using higher concentration of disinfection agents [5].

Qualitative parameters of swimming pool water and additional project and exploitation requirements are described in the German standard DIN 19643. On the basis of this standard the hygienic-sanitary requirements for indoor swimming pools were determined in 1998 by *Polish Sanitary Engineers and Technicians Association* [2, 10].

According to the sanitary and epidemiological regulations issued in 1986 by *the Department of Sanitary Inspection*, chemical coefficients of water quality are treated as auxiliary indicators, and the results of bacteriological investigation as well as the opinion about the swimming pool facilities and equipment based on the findings of the sanitary inspection are found to be decisive indicators in determining a swimming pool suitability for use [6].

For qualification and opinion of sanitary state of water in indoor swimming pools factors likely to cause bacteriological, physical and chemical danger (irritation of skin and mucous membranes) are used.

In case of exceeding of admissible values of physical and chemical parameters – the management of the swimming pool facility is informed about this fact with recommendation to normalize them. In case of excess of the admissible values of bacteriological parameters – immediate corrective action is required. Decisions are made based on the law regarding *the State Sanitary Inspection* (Act. Journal of Laws of 2006, No. 122, item 851) and the law about infectious diseases and contagion (Act. Journal of Laws of 2001, No. 126, item 1384).

2. METHODS OF WATER DISINFECTION IN TESTED INDOOR SWIMMING POOLS

As the research subject seven indoor swimming pools with different methods of water disinfection were chosen. In this paper they are marked as B1, B2, B3, B4, B5, B6 and B7.

The following methods of disinfection are applied in tested swimming pools:

- for swimming pools B1 and B2 – irradiation by UV rays by the use of low-pressure lamps and final chlorinating with hypochlorite sodium,
- for swimming pools B3 and B4 – ozonation of part of the stream of circulating water and final chlorinating by the hypochlorite sodium which is produced in the process of tympanic electrolysis,
- for swimming pools B5, B6 and B7 – chlorinating with the hypochlorite sodium.

2.1. Chlorinating by means of hypochlorite sodium

Addition of chlorine as hypochlorite sodium is widely applied method of water disinfection in swimming pools in Poland. Chlorine should be added to disinfected water in quantity sufficient to cover demand for the oxidation of organic and inorganic substances and leave the excess of so-called free chlorine, assuring bacteriostatic proprieties of water.

The NaOCl solution forms by addition of gas chlorine to dilute soda lye. Chlorine occurs here in the form of salts of hypochlorous acid and this is the solution with strong alkaline proprieties. Typically, hypochlorite sodium is used in small school pools and pools used for swimming classes.

Advantages of disinfection by means of hypochlorite sodium are: easy assembly of installation, low costs of investment, easy impactive dosage and elongated working time of chlorine. Disadvantages of this method include: limited durability of storing hypochlorite, creating chloramines and the growth of pH value which can be regulated only by addition of larger quantities of acid.

2.2. Disinfection by means of hypochlorite sodium formed in the process of tympanic electrolysis

Production of chlorine by means of the tympanic electrolysis method involves the two cheapest and widely available products – water and kitchen salt.

The “packet of electrolysis”, also called packet of the tympanic cell, is the basis of plant to produce NaOCl in the process of tympanic electrolysis.

Basic advantages of the tympanic electrolysis installation are as follows: larger concentration of chlorine (35 g of active chlorine per 1 litre of water) in comparison with different methods of its production ($15 \div 18$ g of active chlorine per 1 litre), the solution is devoid of additional dirt thanks to additional water softening and salinity of swimming pool water is enlarged to smaller degree than usual hypochlorite sodium, full utilization of applied salts thanks to closing of the set (total rejection of by-products), small spare container, small dosing pumps, negligible influence on pH value of the swimming pool water, the ease of adjustment of the size to utilization requirements, easy installation and start up, automated operation, ability to start process at a moment's notice, high safety, efficiency and economics of the process [11].

2.3. Ozonation of the part of stream circulating water

The advantages of the ozonation process: almost total disposition of organic pollutions, on the result of the large ability of the oxygenation – favour the removing of human contaminants, large efficiency of removing colour, turbidity and odour, considerable decrease of chloramine formations and THM as well as decrease of the chlorine dose applied to disinfection.

Proper dosing of ozone before filtering aids microfloculation process, efficiency of the anti-algae activity and maintenance of purity of filter beds as well as the machinery providing water to the pool.

The process of ozonation also has disadvantages. First of all very high investment and exploitation costs and necessity of specialized maintenance. High costs forced designers and investors to search for new solutions; allowing preservation of majority of the advantages of the ozonation method with the simultaneous lowering of its installation and exploitation costs. The system of ozonation of part of the stream circulating water in swimming pools installations is one of such solutions.

The following advantages of part of the stream water ozonation possesses: much smaller investment costs than by applying full ozonation (we ozonise only 10 ÷ 20% capacity of the main stream of circulating water), lower exploration costs, smaller surfaces needed for plant, no necessity of using active carbon (there is no overproduction of ozone) and reduction of chlorine to final chlorination approx. by 30% in the comparison with the method with ozone and active carbon [12, 13].

2.4. Irradiation of water by means of UV rays

The ultra-violet light is the invisible electromagnetic radiation of the wave length 100÷ 400 nm. The range UV-C from 200 to 280 nm realizes the germicidal influence of light UV on microorganisms. The wave about 265 nm long has got maximum disinfecting effectiveness. The germicidal work consists in absorbing UV-C light by microorganisms DNA structure. Applying suitably well-chosen time of radiation and intensity of UV light, it is possible to destroy bacteria and varied micro-organisms entirely [1, 15].

Special lamps emitting ultraviolet rays are the source of germicidal UV light. Depending on the pressure of gases steam inside the lamp and concentration of power, three kinds of lamps are distinguished: low-pressure, medium-pressure and multiwaves.

UV disinfection consists of the irradiation of the water flowing through the cylinders in which lamps emitting the ultra-violet radiation with the suitable power rating are placed.

The method of irradiation of water by means of UV rays does not protect water from secondary contamination and similarly to the ozonation method has to be combined with final disinfection by means of chlorine to assure concentration of active chlorine on the level of 0.3 $mgCl_2/dm^3$ in the basin.

Principal advantages of this method are: effective destruction of the pathogenic bacteria, viruses, algae, fungus and mould and smaller quantity of chlorine added to the final disinfection allowing reduced formation of chloramines [13].

3. MICROBIOLOGY INDICATORS OF SWIMMING POOL WATER QUALITY

It is impossible to test all pathogenic organisms during microbiological analysis. It is easier to test only indicator-microorganisms which warn against infection.

Indicator microorganisms used to appraise bacteriological contamination of swimming pool water are [2, 6, 7, 9, 10]:

- *Pseudomonas aeruginosa*,
- *Legionella pneumophila*,
- *Escherichia coli* or bacteria groups *coli* thermo-tolerant faeces types,
- Staphylococcus coagulation-positive,
- Total microorganisms number determined in 48 hours test of water specimen incubation in temperature 37°C.

4. THE OBJECTIVE AND SCOPE OF INVESTIGATION

The main goal of undertaken investigation is estimation of influence of swimming pool water disinfection on water quality and suitability for bathing using mainly microbiological indexes and supplemented by physical and chemical indexes used as indicators.

The results of investigation performed in period of last three years, since June 2006 till June 2008, were subject to analysis [14].

Total of 228 water samples from swimming pools

Table 1.
Bacteriological parameters of water quality in tested swimming pools

Bacteriological parameters	According to *The Department of Sanitary Inspection* EN-4435-26/86	According to DIN 19643	According to Decree of *Health Minister* (Act Journal of Laws of 2007, No 61, item 417)	B1	B2	B3	B4	B5	B6	B7
				the number of water specimens						
				21	21	32	34	36	43	41
				the number of CFU in water specimens						
Bacteria from *coli* groups in 100 cm^3	0	-	-	**0** (in all samples)	**0** (in all samples)	**0** (in all samples)	**0** (in all samples)	**52** (in sample No 3), **0** (in the rest of samples)	**0** (in all samples)	**0** (in all samples)
Escherichia coli or bacteria from faeces types *coli* thermo-tolerant groups (in 100 cm3),	0	0	0	**0** (in all samples)	**0** (in all samples)	**0** (in all samples)	**0** (in all samples)	**0** (in all samples)	**0** (in all samples)	**0** (in all samples)
Coagulation-positive staphylococcus	2	-	-	**0** (in all samples)	**15** (in sample No 16), **0** (in the rest of samples)	**0** (in all samples)	**0** (in all samples)	**18** (in sample No 32), **0** (in the rest of samples)	**50** (in sample No 2), **0** (in the rest of samples)	**28** (in sample No 23), **15** (in sample No 24), **0** (in the rest of samples)

Table 2.
Bacteriological parameters of water quality in tested swimming pools (continuation)

Bacteriological parameters	According to *The Department of Sanitary Inspection* EN-4435-26/86	According to DIN 19643	According to Decree of *Health Minister* (Act Journal of Laws of 2007, No 61, item 417)	The number of CFU	B1	B2	B3	B4	B5	B6	B7
					the number of water specimens						
					21	21	32	34	36	43	41
					the number of CFU in water specimens						
Total number of bacteria (in 1 cm^3) after specimen incubation in 37 degrees Celsius for 48 hours	100	100	50	-	11	5	13	9	7	12	12
				1-10	10	15	19	20	24	24	25
				11-20	-	1	-	4	2	4	2
				21-30	-	-	-	-	1	3	-
				31-40	-	-	-	-	1	-	-
				41-50	-	-	-	-	1	-	-
				51-60	-	-	-	-	-	-	-
				61-70	-	-	-	1	-	-	-
				71-80	-	-	-	-	-	-	1
				81-90	-	-	-	-	-	-	1
				91-100	-	-	-	-	-	-	-

Table 3.
Physical and chemical parameters of water quality in tested swimming pools

Physical and chemical parameters	The unit	According to The Department of Sanitary Inspection EN-4435-26/86	According to DIN 19643	According to the Decree of the Health Minister (Act Journal of Laws of 2007, No 61, item 417)	B1	B2	B3	B4	B5	B6	B7
Turbidity	NTU	1,0	0,5	1,0	0,35	0,27	0,34	0,25	0,30	0,29	0,32
Colour	$mgPt/dm^3$	15	0,5[1)]	15	5	5	5	5	4	5	5
Transparency	-	the bottom well visible		-	the bottom well visible						
pH	-	6,5 - 7,6	6,5 - 7,6	6,5 - 9,5	7,5	7,4	7,4	7,4	7,2	7,5	7,2
Ammonium	$mgNH_4^+/dm^3$	0,3	0,5	0,5	0,10	0,11	0,14	0,14	0,12	0,20	0,10
COD	mgO_2/dm^3	5,0	0,75[2)]	5,0	2,0	2,2	2,7	2,6	2,4	3,2	3,2
Chlorides	$mgCl^-/dm^3$	300	-	250	169	126	189	304	224	243	223
Free chlorine	$mgCl_2/dm^3$	0,3 - 0,6	0,3 - 0,6[3)] i 0,2 - 0,5[4)]	0,3	0,41	0,38	0,44	0,39	0,39	0,40	0,41
Chloramines	$mgCl_2/dm^3$	-	0,2	0,5	0,21	0,23	0,42	0,31	0,22	0,58	0,54
Redox	mV	min.750	min. 750 for pH:6,5-7,3 min.770 for pH:7,3-7,6	-	690	689	722	670	655	662	637
Chloroform	mg/dm^3	0,03	0,02	0,03	0,010	0,013	0,012	0,002	0,001	0,007	0,005
	mg/dm^3	0,15	-	0,15	0,011	0,014	0,014	0,006	0,004	0,010	0,008

[1)] colour by spectral absorption coeficient = 436 mm
[2)] above value in supply water (from water-line)
[3)] apply to method: coagulation-filtration-chlorination
[4)] apply to method: ozonation-coagulation-filtration-chlorination

were collected. Specimens were collected at least 50 cm from swimming pool wall and at the depth of 20-30 cm under the water surface level. The samples were collected once a month. The specimens were subject to bacteriological and physical as well as chemical tests in the range of basic swimming pool water parameters according to the Sanitary-Epidemiological Center standards.

The following microbiological tests were performed: bacteria from *coli* groups (in 100 cm^3), *Escherichia coli* or bacteria from faeces types coli thermo-tolerant groups (in 100 cm^3), total number of bacteria (in 1 cm^3) after specimen incubation in 37 degrees Celsius for 48 hours, and coagulation-positive staphylococcus.

The following physical and chemical tests were carried out: turbidity, colour, transparency, pH, ammonium ion, chemical oxygen demand (COD), chlorides, free chlorine, chloramines, index redox, chloroform and ΣTHM.

Sampling and tests were performed in accordance with valid standards and methods [3]. Every swimming pool water quality indicator was assayed three-times in a sampling day and the mean value was taken as the results to further analysis.

5. THE ANALYSIS OF RESEARCH RESULTS

Suitability of swimming pool water for bathing was appraised on the basis of comparison of bacteriological tests results (table 1 and 2) as well as physical and chemical tests results (table 3) with admissible value specified in:

- Sanitary and anti-septic requirements for swimming pools. *The Department of Sanitary Inspection* by the Ministry of Health and Social Protection, EN-4435-26/86 [6],
- Decree of *Health Minister* regarding the quality of water designed to consumption for people (Act Journal of Laws of 2007, No. 61, item 417) [8],
- Hygienic requirement for indoor swimming pools. *The Ministry of Health and Social Protection, the Department of Public Health, the Polish Society of Technicians and Engineers*, Warsaw 1998, No. arch. 760 [10].

Based on the physical and chemical analyses of water specimens sampled from seven indoor swimming pools within the last three years it can be generally stated that the quality and suitability of water were good (high).

The bacteriology tests showed that:

- In all water samples subjected to microbiological tests (228 samples), regardless of the method of disinfection, presence of *Escherichia coli* or the thermo-tolerant faeces types of bacteria was not affirmed.
- Bacteria of *coli* group were confirmed in one sample of water taken from basin of pool B5 (disinfection NaOCl), in the number of 52 CFU (colony forming units). In additional specimens, sampled after 7 days, *coli* group bacteria were not present.

  In 159 water specimens the bacteria colony presence was determined (colony forming units, after 48 hours of specimen incubation in 36 degrees Celsius). 1 to 10 CFU were determined in 137 water specimens (60.1% of specimens). 11 to 50 CFU were determined in 19 water specimens (8.3% of specimens). 51 to 100 CFU were determined in 3 water specimens (1.3% of specimens). In the rest of specimens the colony forming units were not present. Much more colony forming units with higher value were determined in water, where dosage of sodium hypochlorite is used as the disinfection method (swimming pools B5, B6 and B7).
- In all water samples tested 100 CFU of bacteria total number were not stated.
- Coagulation-positive staphylococcus in 5 water specimens were determined (2.2% of specimens). 15 CFU were determined in one water specimen sampled from swimming pool B2. 18 CFU were determined in one water specimen sampled from swimming pool B5. 50 CFU were determined in one water specimen sampled from swimming pool B6. 28 and 15 CFU (in turn) were determined in two water specimens sampled from swimming pool B7. Preinspection of swimming pool water quality and suitability for bathing was carried out after 7 days. The coagulation-positive staphylococcus were not found in samples from swimming pools B2, B5 and B6, while they were present in sample from swimming pool B7. This swimming pool facilities were closed to the public and cleaning of basin as well as disinfection of water treatment circulation were performed.

  Similarly as in case of the colony forming units, also coagulation-positive staphylococcus were determined first of all in specimens of water sampled from pools, where final disinfection is not aided by ozonation or UV rays exposure (the pools: B5, B6 and B7, except made up the pool B2).

Table 4.
Correlation between indicators of water quality in tested swimming pools

Swimming pool	The bacteriological indicator of water dirt (the number of CFU over limit)	The values of water quality parameters in sample in which the number of CFU (bacteria of the *coli* group or staphylococcus coagulation-positive) were marked as"exceed"				
		Total number of bacteria (in 1 cm^3) after specimen incubation in 37 degrees Celsius for 48 hours	Redox [mV]	Free Chlorine [$mgCl_2/dm^3$]	COD [mgO_2/dm^3]	Turbidity [NTU]
B2	Staphylococcus coagulation-positive - **15 CFU**	4	572 (on average: 689)	0,20 (on average: 0,38)	3,9 (on average: 2,2)	0,49 (on average: 0,27)
B5	The bacteria of the *coli* group - **52 CFU**	31	570 (on average: 689)	0,24 (on average: 0,39)	3,6 (on average: 2,4)	2,60 (on average: 0,30)
B5	Staphylococcus coagulation-positive - **18 CFU**	41	582 (on average: 689)	0,32 (on average: 0,39)	3,7 (on average: 2,4)	0,48 (on average: 0,30)
B6	Staphylococcus coagulation-positive - **50 CFU**	29	577 (on average: 689)	0,22 (on average: 0,40)	5,2 (on average: 3,2)	0,50 (on average: 0,29)
B7	Staphylococcus coagulation-positive - **28 CFU**	79	584 (on average: 689)	0,26 (on average: 0,41)	4,6 (on average: 3,2)	0,24 (on average: 0,32)
B7	Staphylococcus coagulation-positive - **15 CFU**	2	620 (on average: 689)	0,42 (on average: 0,41)	4,3 (on average: 3,2)	0,21 (on average: 0,32)

6. CONCLUSIONS

Water in indoor swimming pools creates a specific environment, where fulfilling of numerous sanitary requirements is crucial to minimize hazards to the personal health of the bathers.

From the user's point of view the quality of water in the swimming pool is of paramount importance. Water quality must be compatible with hygienic and sanitary standards and it must not cause infections or skin and mucous membrane irritation.

Rapidly-undertaken "repairs" (thorough cleaning and disinfection of walls and bottoms of basin, poolsides, overflowing gutters, rooms adjacent to the pool and disinfection of backwashing filters in the swimming pool facilities) are the basis for efficient and safe operation of every swimming pool in case of excessive bacteria number.

On the basis of physical, chemical and bacteriological analysis of water samples taken from seven indoor swimming pools, in the period of recent three years, the good quality of water and its suitability for bathing is generally affirmed.

Majority of analyzed samples of swimming pool water, in which number of colony forming units were marked as "exceeded" were taken from the pools in which only hypochlorite sodium was applied as the method of disinfection.

Additionally, those samples showed raised values of turbidity and chemical oxygen demand and much lower than required values of potential redox and concentrations of free chlorine. These correlations were presented in table 4.

Comparison of modern methods of water disinfection in swimming pools (swimming pools B1, B2, B3 and B4) with traditional one (pools B5, B6 and B7) shows that the use of the hypochlorite sodium produced by the method of tympanic electrolysis, lamps emitting radiation of ultra-violet with suitable power and system of ozonation as part of the stream of circulating water to disinfection, produces swimming pool water with better microbiological, physical and chemical parameters.

The analysis of bacteriology, physical and chemical results showed that physical and chemical indicators should not be treated as additional parameters only, but that they should be taken into consideration equally with bacterial indicators in determining swimming pool water quality.

Lowering of the redox potential, lowering of free chlorine concentration, raised turbidity of water and the level of chemical oxygen demand (COD) are "quick" indicators of poor water quality and of the raised probability of the pathogenic microorganisms growth.

The measurement of turbidity, potential redox and free chlorine can be executed *in situ*, and obtained results can be treated as preliminary indication of water suitability for bathing.

Cultivation of the bacterium colony require at least a 24 hour-long incubation of a sample, and the obtained results will not accurately reflect the water quality in the days prior to and following the collection of samples.

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