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EFFECTS OF MODERNIZATION OF THE WATER TREATMENT SYSTEM IN A SELECTED SWIMMING POOL

Based on the analysis of the modernization activities of the pool water treatment technology in a selected indoor swimming pool, the results of water quality improvement have been presented. The analysis of water quality parameters, operating parameters and in-house research that has been carried out in this pool for many years allowed us to evaluate the effects of modernization on water quality improvement, with special consideration of chloramine content in pool water (as a disinfection by product). The results of the research have been analyzed in terms of the current sanitary and hygienic guidelines for swimming pools.

1. INTRODUCTION

Microbiological and physicochemical contaminants present in swimming pool water and exceeding the normative values may be harmful to health [1–3]. The effects of swimming pool water treatment depend on many factors, from the design process and selection of technology to a proper administration of the facility. In 2002, in Poland, the ordinance regarding the requirements for swimming pools water and the rules for the control of the water quality by the Sanitary Inspection authorities [4] was repealed and the public swimming pools were supervised by the District Sanitary and Epidemiological Stations under the State Sanitary Inspection Act and the Act regarding the prevention and elimination of infections and contagious diseases affecting people [5, 6]. The requirements for swimming pool water were established as late as in 2015, by the ordinance of the Polish Minister of Health [7].

Monitoring microbiological indicators of swimming pool water quality comprises: total plate count at 36±2 °C) after 48 h in 1 cm^3 of water, *Escherichia coli*, *Pseudomonas*

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aeruginosa, coagulase positive staphylococcus (in pools for swimming lessons for infants and small children up to 3 years), *Legionella* sp. (in swimming pools with water temperature higher than 30°C and equipped with devices generating water-air aerosol) in 100 cm^3 of water. Monitoring of physicochemical indicators of swimming pool water quality covers basic parameters (redox potential, pH, free chlorine – indicator of disinfection effectiveness) and additional parameters (turbidity, combined chlorine, chloroform, total trihalomethanes (THM), aluminum, ozone, nitrates, oxidisability, isocyanuric acid). Additional monitoring of the volume of water replenishing the water treatment system and the number of bathers (swimming pool load) allows us to evaluate the effectiveness of the entire swimming pool facility and make decisions regarding its modernization.

Swimming pool water treatment systems are based on processes performed in a closed circuit with an active overflow system that guarantee correct circulation of water in a swimming pool basin and sustainable water use. The majority of pools constructed in Poland between 1990 and 2005 use the standard water treatment method, that is directing water to swimming pool through a system of adjustable flow jets located at the pool bottom, draining water through an overflow trough and bottom outlets, intake of water to a retention tank, sucking water with circulation pumps integrated with fiber and hair traps and pumping it to filters. In the filtration bed, all contaminants present in water are stopped. This process is enhanced by the use of coagulant that is dosed before the filters section. The filtered water is heated in heat exchangers, then its pH is regulated and the water goes through the disinfection process [8, 9].

Complying with the strict requirements regarding swimming pool water quality, makes it necessary to modernize older treatment systems by replacing the currently used devices or introducing additional modern devices to the treatment circuit [10–12]. In the contemplated swimming pool facility, all analyzed stages of its modernization were aimed to meet the changing requirements of water quality, protect the bathers from microbiological contamination and the adverse effects of disinfection products [13–15] as well as allow more sustainable use of water and sewage with lower the operation costs. Replacement of the filtration system, installation of control and measurement devices, modernization of the water heating system, optimization of hydraulic conditions, the use of integrated system to support the classic water treatment system and modern chemical reagents in subsequent stages guaranteed the appropriate quality of water and safety for the bathers.

The main aim of this study was to analyze how particular stages of modernization influenced the quality of swimming pool water with emphasis on chloramines content. This paper presents the characteristics of the technological system of the swimming pool in successive stages, the method of undertaken research, results of microbiological and physicochemical analyses of the water and evaluation of its quality in relation to the undertaken modernization measures and the quality standards in force at that time.

2. CHARACTERISTICS OF THE FACILITY AND STAGES OF ITS MODERNIZATION

The analyzed facility is a swimming pool with the dimensions of 12.5×25.0 m and volume of 531 m^3, for people who can swim and for swimming lessons in the shallow part of the pool (depth of 1.2–2.2 m). The swimming pool basin is equipped with a vertical water flow system with an active overflow and a retention tank. The facility draws water from the municipal water supply system. Between 1989 and 2002 (stage 0), a technology was used that did not allow one to obtain water compliant with the requirements that were in force at that time [4, 8, 9, 16] and the process of dosing the reagents was conducted manually, straight to the swimming pool basin and the retention tank.

In 2002 (stage 1), the technological system was thoroughly modernized. The filters were replaced, an automatic system for dosing the reagents and controlling the water quality was installed. The type of reagents and the place of their dosage also underwent a change. To 2016, the principal technological system which consisted of: preliminary filtration, surface coagulation, pH correction, disinfection with sodium hypochlorite did not change. Because the swimming pool operating conditions depend on the numbers of bathers, they were recorded throughout the entire testing period. Every hour the swimming pool was used by, on average, 18–20 persons. Every person's actual usable water surface area was 15.6–17.4 m^2. During subsequent years, numerous renovation and modernization works were performed. Their aim was to improve the operation of the water circulation system and, in turn, enhance the water quality and the bathers comfort. Table 1 presents the two, significantly different, water systems used in the tested swimming pool during the stages 0 and 1.

In 2005 (stage 2), the changing room and the showers were renovated. The fittings of washbasins and showers were replaced with touchless faucets with a limited water use and mixers that adjusted water temperature to 41 °C. Two boilers (3000 dm^3 each), for heating water for hygienic use, and heat exchangers for swimming pool water were installed. This allowed one to raise the comfort of using warm water and for a smooth adjustment of the swimming pool water temperature what is especially important while organizing various activities and changing the required water temperature (27–32 °C). The more easily accessible showers (especially for children) before the entrance to the swimming pool were built to facilitate the observance of hygiene and to lower the amount of contaminants introduced to the swimming pool by the bathers.

In 2008 (stage 3), the swimming pool and the pool surroundings were renovated (changed ceramic tiles, new outflow points in overflow troughs). In the swimming pool hall, a jacuzzi has been installed. Water flowing to the jacuzzi tub is treated in the swimming pool water treatment system and then heated to 34 °C and disinfected with doses of NaOCl that are higher than those for the swimming pool water. It needs to be mentioned that the requirements stipulate that jacuzzi tubs should have a separate technological circuit [8, 9, 17–19].

In 2012 (stage 4), steel collectors providing water to the swimming pool basin and the pipes of the retention tank were replaced with PVC pipes. The retention tank was also renovated – the concrete lining was replaced with ceramic tiles. The leakage in the swimming pool installation was eliminated, hydraulic pressure and heat losses were reduced and the possibility for the installation to be covered with sediments allowing for the growth of microorganisms and the creation of biofilm was diminished. This allowed one to reduce the possibility of spreading pathogens to the flowing water, infecting it with bacteria living in the biofilm and to limit the use of disinfectant.

Table 1

Basic parameters of the technological system at the stages from 0 to 5

Parameter	Stage			
	0	1 and 2	3 and 4	5
Water circuit efficiency, m^3/h	154.8	152.4	137.2	137.2
Number of filters	4 (2 off and 2 on)	2	2	2
Filter diameter, mm	2400	1800	1800	1800
Filtration bed height, mm	1400	1500	1500	1500
Type of filtration bed	sand and gravel	sand and anthracite		sand and granulated activated carbon (PolaCarb)
Filtration area of the 1st filter, m^2	4.5	2.54	2.54	2.54
Filtration speed, m/h	17.2	30	27	27
Coagulant	10% $Al_2(SO_4)_3$ with soda (2:1)	5% Super Flock		solution of silicic acid and sodium tetrahydroxyaluminate (PolaClear) and 5% Super Flock
pH correction agent	solution of HCl	50% H_2SO_4		
Water disinfection	1% NaOCl dosed manually	14% stabilized NaOCl, automatic dosage		stabilized chlorine dioxide (PolaActive), 14% stabilized NaOCl, automatic dosage
Demand for supplementary water, m^3/d	8.2–9.0	4.5–5.4	6.0–7.8	4.8–6.6

In 2016 (stage 5), as a result of tightening the requirements for swimming pool water quality and the ensuing need for the adjustment of swimming pool facilities, a decision was made to modernize the swimming pool water filtration installation. It was of vital importance to lower the amount of combined chlorine in the swimming pool water. As a part of the modernization, POLA® process was introduced – an advanced water treatment process being a combination of flocculation, filtration and chlorination. The current water treatment system was supplied with: a solution of silicic acid and sodium tetrahydroxyaluminate (PolaClear), granulated activated carbon (PolaCarb) and a stabilized solution of chlorine dioxide (PolaActive) [20] (Fig. 1).

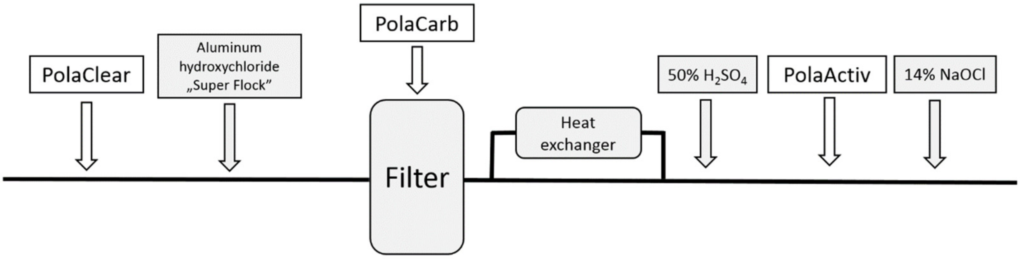

Fig. 1. Scheme of reagent dosage after the stage 5 of modernization

3. METHODS

The quality of bathing water is evaluated on the basis of bacteriological and physicochemical tests. The former is used to determine the risk posed by microorganisms, and the latter to establish the water chemical state with a special emphasis on the substances that are harmful to health. Comparing the obtained results with limit values specified in the ordinance on the requirements of swimming pool water [7] forms the basis for the decision if the water is safe for bathing.

To compare the effects of the modernization of the swimming pool water installation and the treatment system after each stage of the modernization (stages 0–5) water from the swimming pool was sampled and subjected to periodic bacteriological and physicochemical tests. Each period consisted of approximately two months. From 6 to 16 analyses were conducted for the indicators describing the water quality and its safety for bathers. Since 2012, the readings of the control and measurement devices (temperature, pH, free chlorine, redox potential and, since 2016, combined chlorine) have been recorded in the Swimming Pool Log. These logs were also taken into consideration during the evaluation of the swimming pool water quality.

The bacteriological tests were carried out in an accredited laboratory. The samples for physicochemical tests were taken during the morning hours, when the swimming pool was in operation, from 3 places (ca. 40 cm from the edge and ca. 30 cm under the water surface) which provided a mean mixed sample. The analyses of physicochemical properties were carried out in accordance with applicable standards and methods [21, 22]. The parameters that best described the changing water quality in the swimming pool circuit were: pH (colorimetric method, photometer DSC 400, Dinotec and potentiometric method, HQ11D digital pH meter kit, Hach), redox potential (potentiometric method, ORP electrode Ag/AgCl, 3.5 M KCl, HQ11D digital, Hach), free, combined and total chlorine (DPD colorimetric method, photometer DSC 400, Dinotec and POCKET colorimeter II, Hach), turbidity (nephelometric method, CyberScan TN 100 turbidimeter), oxidisability (titration method).

In order to control the effects of coagulation, the concentration of aluminium in swimming pool water was controlled (photometer DSC 400, Dinotec and DR 5000 UV--Vis laboratory spectrophotometer, Hach). In connection with the use of a stabilised NaOCl solution for water disinfection, the concentration of cyanuric acid was also monitored (photometer DSC 400, Dinotec).

4. RESULTS AND DISCUSSION

On any stage of the bacteriological analysis, in the analyzed samples, the total number of microorganisms in 1 cm^3 did not exceed the level of 100 CFU (colony forming units). The presence of bacteria *Escherichia coli* was detected in 2 samples during the stage 0 and in 1 sample during the stage 1 (maximum acceptable number of *E. coli*: 0 CFU/1 cm^3). Coagulase positive staphylococci were detected in 6 out of 8 samples during the stage 0, in 3 out of 6 samples during the stage 1, and in 1 out 6 samples during the stage 2 (maximum acceptable number of Coagulase positive staphylococci: 0 CFU/100cm^3). *Pseudomonas aeruginosa*, whose control is required by the ordinance [7], was not detected at the stage 5 (maximum acceptable number of *P. aeruginosa*: 0 CFU/100 cm^3).

Installation of new heat exchangers, ensuring constant temperature of shower water and in the pool water circuit (stage 2), improvement of hydraulic conditions and elimination of "dead" zones within the pool and equalisation tank at the stages 3 and 4 significantly improved the bacteriological quality of the pool water and ensured its stability (Table 2). From the stage 3, there were no indications of CFU *E. coli* and coagulase positive *staphylococci* in water samples.

Table 2

The results of bacteriological analyses for the stages 0–5 of the research

Parameter	Stage 0								Stage 1						Stage 2						Stage 3						Stage 4						Stage 5					
A	1	0	0	0	0	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B	3	2	17	2	6	6	1	2	1	1	2	3	5	1	1	1	2	3	2	0	2	2	2	0	12	1	0	0	1	0	0	50	1	0	0	0	1	0
C	0	0	20	8	7	35	1	2	0	0	4	0	9	2	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0	0	0	0	0

A – *Escherichia coli*, CFU/100 cm^3, B – total number of microorganisms (36±2 °C, 48h), CFU/1 cm^3, 3 – coagulase positive *staphylococci*, CFU/100 cm^3, 4 – *Pseudomonas aeruginosa*, CFU/100 cm^3.

The results of physicochemical analyses of the water quality are presented in Tables 3, 4 and in Fig. 2. pH in the stage 0 did not meet the required values of 6.5–7.6 and amounted to 9.22–9.66. Such a result was due to the manual dosing of HCl straight to the swimming pool basin and the lack of pH control.

Table 3

The results of physicochemical analyses from the stages 0–2 of research

Parameter	Stage 0				Stage 1				Stage 2			
	Min	Max	Med	Std. dev.	Min	Max	Med	Std. dev.	Min	Max	Med	Std. dev.
pH	9.22	9.66	9.41	0.15	7.09	7.15	7.13	0.02	5.84	7.42	7.00	0.46
Redox potential, mV	–	–	–	–	752	782	769	9	741	794	782	18
Free chlorine, mg Cl_2/dm^3	0.18	0.40	0.30	0.07	0.27	0.57	0.46	0.09	0.20	1.03	0.73	0.26
Combined chlorine, mg Cl_2/dm^3	0.50	0.69	0.59	0.05	0.14	0.68	0.49	0.16	0.42	0.49	0.45	0.03
Turbidity, NTU	1.00	7.50	5.44	2.04	0.70	2.45	1.31	0.55	0.25	0.40	0.29	0.05
Oxidisability, mg O_2/dm^3	3.70	4.93	4.05	0.42	3.00	3.20	3.08	0.07	0.92	3.34	2.05	0.86
Aluminium, mg Al/dm^3	2.18	3.32	2.86	0.47	0.00	0.20	0.03	0.06	0.00	0.02	0.01	0.01

Table 4

The results of physicochemical analyses from the stages 3–5 of research

Parameter	Stage 3				Stage 4				Stage 5			
	Min	Max	Med	Std. dev.	Min	Max	Med	Std. dev.	Min	Max	Med	Std. dev.
pH	6.00	7.90	7.16	0.33	6.68	7.33	7.19	0.04	6.71	7.86	7.00	0.14
Redox potential, mV	455	778	667	94	630	878	827	19	652	863	722	44
Free chlorine, mg Cl_2/dm^3	0.40	0.64	0.48	0.09	0.48	1.25	0.60	0.11	0.17	0.97	0.58	0.18
Combined chlorine, mg Cl_2/dm^3	0.03	0.62	0.31	0.17	0.21	0.80	0.43	0.12	0.02	0.65	0.21	0.15
Turbidity, NTU	0.04	0.53	0.24	0.15	0.04	0.56	0.34	0.13	0.14	0.27	0.20	0.04
Oxidisability, mg O_2/dm^3	0.86	3.00	2.16	0.63	1.33	2.42	1.76	0.34	0.50	1.00	0.71	0.24
Aluminium, mg Al/dm^3	0.00	0.05	0.02	0.02	0.00	0.30	0.10	0.12	0.00	0.02	0.01	0.01

The redox potential was measured since the stage 1. The majority of the results obtained at the stages 1, 2, 4 and 5 met the required values of 750–770 mV. At the stage 3, the redox potentials were the most unstable ones (455–778 mV). The concentration of free chlorine should fall within the range of 0.3–0.6 mg Cl_2/dm^3. At the stages 1–5, its minimal concentration was ensured by the automatic dosing and control system

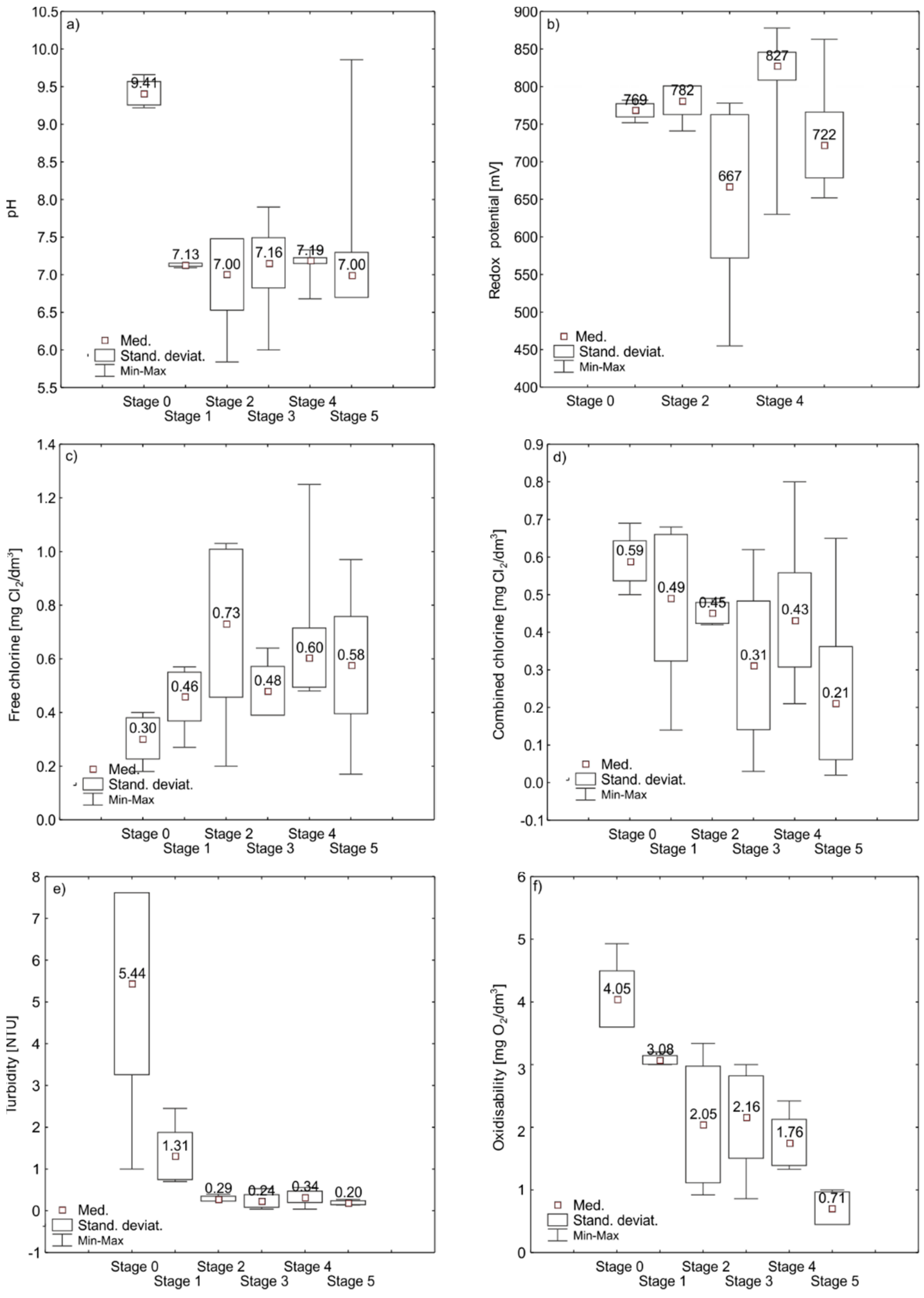

Fig. 2. Results of physicochemical analysis of water after subsequent stages of modernization: a) pH of water, b) redox potential, c) free chlorine, d) combined chlorine, e) turbidity, f) oxidisability

and the use of a stabilized solution of sodium hypochlorite. Maintaining the minimal concentration of free chlorine was difficult only at the stage 0, when technical sodium hypochlorite was poured directly to the swimming pool basin and the retention tank.

The mandatory control of the concentration of combined chlorine as a by-product of the disinfection process in swimming pool water came into force in June 2016. Its maximum permissible level is 0.3 mg Cl_2/dm^3. According to previous recommendations [8, 9, 19], it should not exceed the value of 0.2 mg Cl_2/dm^3. The largest amounts of combined chlorine were detected at the stage 0. This amount was significantly reduced after the modernization of the water heating installation and the replacement of shower faucets at the stage 2, after the renovation of the swimming pool and the pool surroundings at the stage 3 and after the introduction of additional reagents to the treatment circuit at the stage 5. In the majority of water samples taken at the stages 0–2 and 4 the concentrations of combined chlorine differed considerably from the recommended standards (0.14–0.80 mg Cl_2/dm^3, 0.43–0.49 mg Cl_2/dm^3 in average).

Very high water turbidity at the stage 0, exceeding considerably the recommended value (0.5 NTU), resulted from high pH, no possibility of clumping the coagulant and capturing the contaminants by the filter bed. Suspended solids could be observed on the swimming pool bottom. The subsequent modernization stages improved the water turbidity values. During the stage 1, the turbidity fell within the ranges specified for drinking water (1.0 NTU), and in the later stages it met the requirements for swimming pool water (average values: from 0.20 NTU at the stage 5 to 0.34 NTU at the stage 4).

The oxidisability of the water from the swimming pool basin did not exceed the permissible value of 4.0 mg O_2/dm^3, with the exception of two water samples taken at the stage 0, in which 4.55 mg O_2/dm^3 and 4.93 mg O_2/dm^3 were detected. If aluminum salts are used in the coagulation process, the concentration of aluminum in swimming pool water should also be controlled. In the tested water, the concentration of aluminum above the permissible limit (0.2 mg Al^{+3}/dm^3) was detected only at the stage 0 (2.18–3.32 mg Al^{+3}/dm^3), due to the already mentioned problems with maintaining the correct pH value.

Since 2002, the concentration of cyanuric acid has been monitored once a quarter as part of an internal control carried out by the staff of the swimming pool. In order not to interfere with the release of free chlorine from NaOCl solution, its concentration should not exceed 100 mg/dm^3 [7, 8, 17, 18]. In the tested samples of swimming pool water the concentration of cyanuric acid did not exceed 20 mg/dm^3.

Each of the stages of modernization affected the water quality. The most important stage conducted with the aim to improve the water quality was stage 1 (replacement of filters and installation of automatic chemical reagent dosing devices), at which the physical and chemical stability of water was improved. First of all, pH values of water were significantly lowered (from, on average, 9.41 to, on average, 7.13), as a result of which it was possible to have an effective coagulant which, in turn, led to a significant reduction of the turbidity (by ca. 76%) and oxidability (by ca. 26%). In addition, a constant level of free chlorine content (0.46±0.09 mg Cl_2/dm^3) has been guaranteed.

Stage 2, replacing the water heating system and ensuring the comfort of using warm shower water and thus hygiene among users, led to the further reduction of the turbidity values (by ca. 78%) and oxidation (by ca. 34%) with respect to stage 1. A stable chloramine content, i.e., 0.45 ± 0.03 mg Cl_2/dm^3 has also been obtained.

After the renovation of the basin area and the installation of the jacuzzi at the stage 3 in a technological circuit, the quality of swimming pool water has not changed much. A more frequent problem, however, was ensuring high redox values (recommended 750 mV) and stable chloramine concentration. A common filtration system for the pool and jacuzzi requires daily emptying and cleaning of the jacuzzi and filling it with fresh tap water. Therefore, the demand for complementary water increased by approximately 30–40%.

After the next stage of the modernization (stage 4) that is lowering the chance of the creation of "dead" zones within reservoirs and pipelines, and removing bacterial biofilms along with the old installation, the bacteriological quality of circulating water was not questionable. In addition, quite high concentrations of free chlorine in this stage (0.6±0.11 mg Cl_2/dm^3) and high redox potential values (827±19 mV) protected the pool water against secondary contamination. Despite the actions taken to reduce chloramine concentrations, it was not possible to reduce them to 0.3 mg Cl_2/dm^3. Only the use of additional reagents and granular active carbon at the stage 5 brought the required results. With a free chlorine content of 0.58±0.18 mg Cl_2/dm^3 and a redox potential value of 722±44 mV, the chloramines concentration was 0.21±0.15 mg Cl_2/dm^3.

The modernization activities undertaken significantly improved water and wastewater management. The demand for water supplementing the losses in the pool circuit (Table 1), and thus the volume of washings discharged to the sanitary sewage system, was the highest at the stage 0 (8.2–9.0 m^3/d) when filters of a very large bed surface area were exploited, requiring the use of a large volume of water for efficient cleaning. The lowest demand (4.5–5.4 m^3/d) for water was recorded at the stages 1 and 2, after a thorough modernization of the filtration system. In subsequent stages 3 and 4, after the whirlpool bathtub was added to the circuit and the daily emptying of the bathtub, the demand increased to 6.0–7.8 m^3/d. At the stage 5, the filtration cycle was extended by 1 day after using the integrated system. As a result, the demand for supplementary water decreased by approximately 20%. It should also be pointed that the swimming pool is supplied with water from an urban water supply system, the quality of which, over the analysed period of time, met the requirements of the regulations on water quality for consumption, did not change significantly and did not affect the quality of swimming pool water.

5. SUMMARY AND CONCLUSIONS

A swimming pool facility is an interrelated system of water treatment, distribution and heating combined with taking care of the bathers, their habits and the observance of health and hygiene rules. Many swimming pool facilities built in Poland in the 80s and 90s do not comply with the current regulations. It concerns not only the water technology (water treatment devices, swimming pool chemicals), but also the operation of the swimming pool facility (modern changing rooms and showers) and the availability of water attractions (massage jets, water slides). In the older swimming pool facilities, it is often the case that the pool surroundings, basin linings, retention tanks and the inflow and outflow installations are in need of major renovations due to, for instance, the lack of water tightness, accumulation of deposits and corrosion.

The swimming pool facilities which do not comply with the current regulations are renovated and modernized. Basic renovations concentrate primarily on the swimming pool basins (replacement of lining and circulation system, rebuilding of overflow troughs) and retention tanks (replacement of lining, introduction of automatic water refilling system). Modernization or a complete replacement focuses on the water treatment system–filtration system, automatization, control over the added reagents and the use of highly effective coagulants and disinfectants.

Rigorous regulations and strict requirements regarding the swimming pool water that aim at providing the bathers with the highest standards and ensuring safety and comfort require the use of modern and highly effective water treatment technologies. After longstanding tests of the water quality in the analyzed swimming pool, observations and logs in the Swimming Pool Log, the following conclusions were made:

- The introduction of a standard water system with an effective filtration at the stage 1 was the most important modernization among those described. The replacement of the water filtration system, installation of devices for control and measurement and the automatic dosing of coagulant and disinfectant considerably improved the bacteriological and physicochemical state of the swimming pool water.
- The renovation of showers and the modernization of the water heating system at the stage 2, as well as the optimization of hydraulic conditions in the swimming pool basin and the retention tank at the stage 3 and 4 reduced the creation of "dead" zones in the swimming pool basin, accumulation of deposits on its bottom and allowed to stabilize the water quality.
- Despite numerous endeavors (from improving the technical conditions of devices and water circulation installation, through placing great emphasis on maintaining order in the swimming pool hall and in the showers to regular controls of the water quality) meeting the requirements specified in the ordinance [7] was not possible.
- The use of integrated system to support the classic water treatment system significantly improved the water quality and allowed the concentration of combined chlorine to fall below the permissible limit (0.3 mg Cl_2/dm^3).

In the tested swimming pool, the use of modern chemical reagents, improvement of water filtration effectiveness and the final disinfection with chlorine compounds guaranteed the appropriate quality of water, as well as comfort and safety for the bathers.

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