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# Comparison of the effectiveness of disinfectants in swimming pool footbaths

Agnieszka Włodyka-Bergier*, Tomasz Bergier, Emilia Stańkowska

*Department of Environmental Management and Protection, Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Kraków, Poland, Tel. +48 12 617 47 57; Fax: +48 12 617 50 76; emails: wlodyka@agh.edu.pl (A. Włodyka-Bergier), tbergier@agh.edu.pl (T. Bergier), stankowska@agh.edu.pl (E. Stańkowska)*

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**ABSTRACT**

Footbaths are a barrier to protect against the excessive inflow of pathogens carried on feet to swimming pool facilities. These objects in most cases do not have a separate water treatment system, and only a few have disinfectant dosing devices. The lack of clearly defined guidelines of their designing, constructing, and maintaining makes it difficult to care for the proper quality of water in footbaths. The aim of the article is to evaluate the disinfecting role of the footbaths located in the swimming pool of AGH in Krakow. Two disinfection variants have been analyzed: (1) with calcium hypochlorite and (2) with chlorine dioxide. The assessment has been based on measurements of selected microbiological and physicochemical parameters of water quality in a footbath basin (including the disinfectant concentration, the total number of microorganisms at 36°C ± 2°C and 22°C ± 2°C, the total number of fungi), as well as the cleanliness of flat surfaces before and after the footbath basin, in terms of the total number of microorganisms, pathogenic staphylococci, and fungi. The obtained results have shown that the type of applied disinfectant has an impact on water quality – in the case of chlorine dioxide, the number of microorganisms was lower (both in the water filling the footbath basin, as well as on flat surfaces). The results suggest the need to deepen the topic, and especially to carefully control the quality of water in footbaths. The experiments presented in this paper confirm that footbaths can play an important role in maintaining the sanitary conditions in the swimming pool.

*Keywords:* Swimming pool water; Disinfection; Microbiological cleanliness

## 1. Introduction

The main disadvantage resulting from the simultaneous use of public pools by many people is the fact that various types of pollutants are continuously supplied and their main source are the users [1–3]. The risk of infection in swimming pools is related to microbial contamination of the water [4–6], however, the direct contact with contaminated surfaces and inhalation of air are also potential routes of exposure to pathogens [7]. Ensuring a safe stay at the swimming pool is strictly connected with maintaining proper sanitary and hygienic conditions, including looking for methods to effectively reduce the harmful impact of pollution. One of the methods to increase the cleanliness in the swimming pool is the use of footbaths for rinsing the feet. They are small basins filled with water, usually located just next to the exit from the changing room [8], which main role is to protect against the excessive inflow of pollutants, carried on the feet, especially microbiological ones. On one hand, several studies indicate the presence of bacteria on flat surfaces of swimming pools, for example, *Pseudomonas* spp., *Stenotrophomonas* spp., and *Sphingomonas* spp., *Moraxella* spp., *Escherichia coli* [9,10], as well as fungi,

* Corresponding author.

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for example, *Cladosporium*, *Aspergillus*, *Fusarium*, and *Trichophyton* [11–14]; on the other hand, this problem is not regulated by law, thus its scale is unknown.

Practice shows that the water in the footbath basin is often muddy, dirty, and containing the remains of socks fabrics, which makes this place badly perceived by the users of the swimming pool. Usually these basins are filled with treated pool water through the pipes, several times a day. Much less often the additional technological devices are applied, which automatically dose the disinfectant directly into the basin or the separate systems treating water to fill exclusively footbath basins. In Poland, according to the Guidelines of the Main Sanitary Inspectorate [15], footbath basin should:

- have dimensions so that it cannot be bypassed or skipped,
- be filled with the treated swimming pool water, and its depth should be 10–15 cm,
- guarantee the full water exchange within 1 h or more often, and there should be no water stagnation areas,
- be completely emptied, cleaned, and disinfected at least once a day,
- enable the release of used water to the sewage system, alternatively it is possible to use a separate water circulation system for a footbath basin, completely independent of the water system in swimming pool and not connected to it,
- additionally, the swimming pool should be equipped with a special footbath, adapted for disabled people, which length should be at least equal to the circumference of a wheelchair's wheels.

In order for footbaths to fulfill their role, the filling water should be subject to constant control, especially the disinfectant concentration. Currently, no institution conducts proper analyses of the quality of water in footbaths, which is caused by the lack of appropriate legal regulations that would clearly impose such a duty. The only normalized parameter determined by the Regulation of Polish Minister of Health is the free chlorine concentration, which should be maintained at the level of 1–2 mg/L [16]. However, this required disinfectant concentration is given as a recommendation, and not as a parameter for mandatory monitoring. Slightly different values of this parameter have been established in the guidelines of the World Health Organization [8], according to which the free chlorine concentration should be in the range of 0.7–1.5 mg/L.

Calcium hypochlorite is one of the most commonly used disinfectants for swimming pool water all over the world [2,3]. This substance is a strong oxidant, having the ability to oxidize the organic and inorganic pollutants of water [2]. Its main advantage is the ability to protect against the secondary multiplication of organisms. Chlorine reacts with other components of water, which causes the formation of disinfection by-products, among which trihalomethanes and inorganic chloramines are the most abundant in the swimming pool water [17,18]. Such formed compounds are often very harmful to health and should be minimized. However, from the point of view of sanitary safety, reactions of chlorine with pollutants of water lead to its consumption, thus it does not act as a disinfectant anymore. While in swimming pools, which are usually equipped with continuous dosing of chlorine compounds (depending on demand), it is not so important, in footbath basins, in which water with disinfectant is periodically replaced, it is a serious problem. The effectiveness of disinfectants is varied, so the choice of the agent should be considered for a given facility on an individual basis. In swimming pool water technology, chlorine dioxide ($ClO_2$), is widely used as a strong oxidant and not as a leading substance used for disinfection purposes [19], even though it is an effective disinfectant. According to the literature, the pathogen neutralizing properties can already be observed with the chlorine dioxide concentration at the level of 0.1 mg/L. $ClO_2$ is characterized by significant biological activity against bacteriophages, viruses (e.g., polio), cysts of protozoa that are resistant to chlorine [20].

The preliminary studies carried out by the authors in 2017 [21] on the impact of footbaths on reducing the number of microbiological contaminants brought to the swimming pool by users have shown that these objects can contribute to increasing the cleanliness of pool surfaces and can be a barrier against pollution brought by people. This paper presents the results of the studies in which the effectiveness of two disinfectants (calcium hypochlorite and chlorine dioxide) has been compared and their effectiveness in maintaining microbiological purity of flat surfaces behind the footbath basin (that is around the swimming pool) has been also assessed. The research was carried out on a real facility in the swimming pool of AGH in Krakow.

## 2. Materials and methods

The research object was the footbath basin with a capacity of approximately 120 L, located in the indoor swimming pool of the AGH University of Science and Technology in Krakow. Two variants of disinfection were analyzed for the purposes of the experiment. Variant 1 is the standard treatment, which the footbath basin is filled with treated pool water, directly from the neighboring swimming pool, disinfected with calcium hypochlorite. In Variant 2, the footbath basin was filled with tap water with the addition of chlorine dioxide at the concentration of 1 mg/L. Four measurement series were realized for each of these variants. In each series, the water samples were taken every 15 min, for 90 min; all measurements were done twice. Chemical analyses included on-site disinfectant concentration tests, that is, the free chlorine concentration (in the case of Variant 1) and chlorine dioxide concentration (in the case of Variant 2) using the VISOCOLOR®ECO tests, with the Macherey–Nagel PF-12 photometer. The detection limit for free chlorine was 0.05 mg/L as $Cl_2$, and for chlorine dioxide was 0.20 mg/L as $ClO_2$. In the water samples taken from the footbath basin, a number of other water quality parameters were also measured, including microbiological and physicochemical ones. The concentrations of total nitrogen (TN), ammonium nitrogen ($N–NH_4$), nitrite–nitrogen ($N–NO_2$), and nitrate–nitrogen ($N–NO_3$) were determined photometrically with Nanocolor tests and nanocolor UV-Vis spectrophotometer by Macherey–Nagel. The detection limits for nitrogen compounds were: TN – 0.1 mg/L; $N–NH_4$ – 0.01 mg/L; $N–NO_2$ – 0.002 mg/L; $N–NO_3$ – 0.02 mg/L. The concentration of organic nitrogen was calculated as the difference between total and inorganic nitrogen. The conductivity and pH were determined with electrometric methods. The oxidizability was analyzed with the titration by the permanganate method (the detection limit – 0.5 mg/L). The determination of the total number of microorganisms was realized with the pour plate method in plates with agar with yeast extract. Mesophilic bacteria were incubated at 36°C ± 2°C for 44 h and psychrophilic bacteria at 22°C ± 2°C for 72 h. The total number of fungi was cultured at 22°C ± 2°C on Sabouraud dextrose agar plate for 7 d. The determination of the total number of mesophilic and psychrophilic bacteria was made with yeast extract agar (Merck KGaA, Germany), while fungi – with Sabouraud agar (Merck Merck KGaA, Germany). During the experiment, the number of people who passed through the footbath basin from the changing room to the swimming pool hall was counted. To determine the impact of the foot baths on the number of microbiological contaminants transported to the swimming pool area, a cleanliness test was carried out on flat surfaces before and after the footbath basin, at a distance <0.5 m. To guarantee the same conditions for all measurements, the surfaces were disinfected prior to testing. Each surface sample was taken by applying to replicate organism detection and counting (RODAC) contact plates by BTL Company (Poland). RODAC contact plates were applied by pressing the plates gently on the tested surface for 10 s. In the surface samples the following microbiological parameters were determined: the total number of microorganisms, the total number of staphylococcus bacteria, and the total number of fungi. The incubation was conducted for 24–48 h in 37°C ± 1°C for the total number of microorganisms and staphylococcus bacteria; and for 5–7 d in 25°C ± 1°C for fungi. The results presented in the article are an average of three RODAC plates taken in parallel (for each of the four series, for each time interval).

In the first stage of the statistical assessment, Pearson's correlation analysis was performed to assess the relationships between the water quality indicators and experiment parameters. In the second stage, the multiple linear regression analysis was conducted for each studied group of microorganisms. The result of this analysis is the model (the linear equation), describing the mathematical relations between the number of microorganisms in water from the footbath basin and all analyzed controlling parameters (the number of people, the time of experiment, and the concentration of disinfectant). All statistical analyses were performed using Statistica (ver.13.0) by StatSoft on the significance level <0.05.

## 3. Results and discussion

### 3.1. Water quality in footbath basin

Table 1 presents the results of the quality of water in the footbath basin for two disinfection variants: with calcium hypochlorite ($Ca(OCl)_2$) and chlorine dioxide ($ClO_2$).

Table 2 shows the correlations between the water quality indicators and the experiment parameters, such as the duration of the experiment or the number of people who went through the footbath basin.

The passage of swimmers through the footbaths has a crucial impact on the amount of pollutants carried on the feet to the swimming pool area. One of the most important indicators of swimming pool water quality, in regards of sanitary safety, is the disinfectant concentration, which protects the water against secondary microbial contamination. Fig. 1 shows how the average concentrations of free chlorine and chlorine dioxide in the water from the footbath basin changed over time. Fig. 1 also shows the number of people who passed through the footbath, from the changing room to the swimming pool area.

Initially, the concentration of free chlorine changed from 0.25 to 1.40 mg/L. We did not control the concentration of free chlorine – the footbath basin was filled with treated pool water, directly from the neighboring swimming pool system, where water was disinfected with calcium hypochlorite. The changes of the concentration of free chlorine in such a wide range resulted from the dynamics of this system. Over time, the amount of free chlorine dropped to a value below the detection limit after 45 min of the experiment in the case of calcium hypochlorite, and after 60 min in the case of chlorine dioxide. There was a strong negative correlation between the concentration of disinfectants and the duration of the experiment – the Pearson correlation coefficient between these parameters was –0.53 and –0.90, respectively for the variant with calcium hypochlorite and chlorine dioxide. Negative correlations were also observed between the concentration of the disinfectant and the number of people who entered the swimming pool from the changing room, passing through the footbath basin. The correlation coefficient $r$ = –0.42 indicates a moderate correlation between these parameters in the case of Variant 1, while $r$ = –0.72 for a strong correlation for Variant 2.

Low concentration or lack of disinfectant may promote the accumulation of microorganisms in water. Fig. 2 shows how the microbiological water quality (mesophilic and psychrophilic bacteria) in the footbath basin was changing over time.

The major exploitation challenge in swimming pools is to control the health risk associated with microbial pollution. According to the literature reports, the complete elimination of pathogens in the swimming pool environment is not possible [22,23]. Even the most comprehensive solutions will not prevent the lack of hygiene of users. Therefore, an additional element supporting the reduction of pathogenic microorganisms can be footbath basins. The footbath water samples were characterized by high variability of the microbial contamination, as evidenced by the large differences between the minimum and maximum values of the examined parameters. The average initial number of psychrophilic and mesophilic microorganisms in Variant 1 (disinfection with $Ca(OCl)_2$) was 375 and 385 CFU/mL, respectively. After 90 min this parameter increased to 64,240 and 63,190 CFU/mL, respectively. In Variant 2 ($ClO_2$) the water samples were less contaminated. The lowest values were observed at the beginning of the experiment, when the average number of microorganisms was 58 CFU/mL in the case of psychrophilic bacteria and 80 CFU/mL of mesophilic bacteria. However, the average number of these microorganisms increased overtime to 17,000 and 19,175 CFU/mL, respectively. Compared to the

Table1
Quality of water in the footbath

| Parameter | Unit | Variant | Time, min | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| Disinfectant concentration | mg/L | $Ca(OCl)_2$ | 0.54 (<0.05–1.40) | 0.19 (<0.05–0.35) | 0.15 (<0.05–0.37) | <0.05 (<0.05–0.25) | <0.05 (<0.05–0.11) | <0.05 (<0.05–0.23) | <0.05 |
| | | $ClO_2$ | 1.00 | 0.56 (0.47–0.64) | 0.42 (0.36–0.54) | 0.22 (<0.20–0.36) | <0.20 | <0.20 | <0.20 |
| Number of people | – | $Ca(OCl)_2$ | 0 | 6 (0–17) | 17 (1–28) | 20 (1–32) | 27 (3–48) | 31 (3–52) | 44 (22–54) |
| | | $ClO_2$ | 0 | 20 (4–33) | 28 (10–44) | 36 (21–56) | 50 (24–80) | 57 (25–87) | 64 (29–97) |
| Mesophilic bacteria | CFU/mL | $Ca(OCl)_2$ | 375 (1–1,870) | 829 (88–2,250) | 4,576 (380–16,450) | 9,788 (1,460–30,650) | 16,760 (4,300–35,300) | 21,340 (6,700–41,000) | 64,240 (2,000–15,900) |
| | | $ClO_2$ | 58 (26–96) | 191 (132–820) | 238 (90–502) | 826 (160–1,200) | 5,612 (220–17,600) | 8,188 (1,600–25,800) | 17,000 (4,300–44,000) |
| Psychrophilic bacteria | CFU/mL | $Ca(OCl)_2$ | 385 (1–1,920) | 1,071 (76–2,650) | 5,096 (620–17,600) | 13,086 (1,580–39,750) | 35,200 (7,100–98,900) | 33,760 (7,800–5,900) | 63,190 (30,350–182,000) |
| | | $ClO_2$ | 80 (11–159) | 236 (131–416) | 289 (111–690) | 870 (270–1,700) | 2,988 (340–7,800) | 4,495 (2,300–9,600) | 19,175 (5,900–42,000) |
| Fungi | CFU/mL | $Ca(OCl)_2$ | 7 (1–30) | 5 (1–15) | 15 (3–33) | 126 (9–330) | 250 (128–400) | 521 (110–910) | 953 (190–1,560) |
| | | $ClO_2$ | 30 (9–49) | 46 (7–70) | 118 (12–260) | 178 (40–420) | 308 (50–600) | 415 (90–810) | 935 (210–2,200) |
| Oxidizability | mg $O_2$/L | $Ca(OCl)_2$ | 1.27 (0.80–1.60) | 2.54 (1.60–3.20) | 2.54 (1.60–3.20) | 4.28 (3.20–6.27) | 5.39 (3.20–7.84) | 6.97 (4.00–9.41) | 8.23 (4.80–11.76) |
| | | $ClO_2$ | 4.86 (3.14–7.06) | 6.27 (4.71–8.63) | 6.27 (4.71–8.63) | 8.63 (5.49–10.98) | 8.78 (5.49–10.98) | 9.73 (6.27–11.76) | 10.35 (6.27–14.12) |
| TN | mg/L | $Ca(OCl)_2$ | 3.42 (2.70–4.10) | 3.48 (2.80–4.20) | 3.90 (3.10–4.80) | 4.34 (3.50–5.20) | 4.56 (3.50–5.60) | 4.64 (3.70–5.60) | 4.70 (3.70–5.60) |
| | | $ClO_2$ | 3.16 (2.70–3.50) | 3.38 (3.20–3.50) | 3.58 (3.40–3.80) | 3.82 (3.60–4.00) | 4.26 (3.60–4.90) | 4.38 (3.90–4.90) | 4.42 (4.00–4.70) |
| N–$NO_3$ | mg/L | $Ca(OCl)_2$ | 2.46 (2.00–2.90) | 2.56 (2.10–3.10) | 2.76 (2.40–3.10) | 2.78 (2.50–3.10) | 2.84 (2.50–3.10) | 2.88 (2.50–3.10) | 3.10 (2.50–3.70) |
| | | $ClO_2$ | 1.96 (1.80–2.20) | 2.20 (2.00–2.70) | 2.24 (2.00–2.80) | 2.24 (2.00–2.80) | 2.32 (2.10–2.80) | 2.32 (2.10–2.80) | 2.32 (2.10–2.80) |
| N–$NO_2$ | mg/L | $Ca(OCl)_2$ | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| | | $ClO_2$ | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 | <0.002 |
| N–$NH_4$ | mg/L | $Ca(OCl)_2$ | 0.05 (0.03–0.11) | 0.08 (0.03–0.15) | 0.09 (0.03–0.19) | 0.13 (0.03–0.25) | 0.14 (0.03–0.27) | 0.17 (0.03–0.35) | 0.20 (0.03–0.37) |
| | | $ClO_2$ | 0.05 (0.03–0.11) | 0.13 (0.10–0.16) | 0.15 (0.10–0.20) | 0.17 (0.14–0.22) | 0.21 (0.14–0.29) | 0.21 (0.14–30) | 0.24 (0.14–0.30) |
| N–org | mg/L | $Ca(OCl)_2$ | 0.89 (0.57–1.15) | 0.82 (0.53–1.15) | 1.03 (0.29–1.55) | 1.42 (0.63–1.95) | 1.56 (0.51–2.32) | 1.57 (0.83–2.30) | 1.38 (0.81–2.15) |
| | | $ClO_2$ | 1.08 (0.35–1.33) | 1.03 (0.52–1.28) | 1.17 (0.82–1.58) | 1.39 (0.92–1.76) | 1.71 (1.03–2.40) | 1.83 (1.19–2.48) | 1.84 (1.15–2.44) |
| Conductivity | mS/cm | $Ca(OCl)_2$ | 1.18 (0.84–2.09) | 0.96 (0.86–1.01) | 0.97 (0.85–1.04) | 0.95 (0.81–1.03) | 0.97 (0.84–1.04) | 1.20 (0.86–2.14) | 0.98 (0.86–1.07) |
| | | $ClO_2$ | 0.42 (0.41–0.44) | 0.43 (0.42–0.44) | 0.43 (0.42–0.44) | 0.44 (0.43–0.45) | 0.44 (0.43–0.45) | 0.45 (0.44–0.45) | 0.46 (0.45–0.47) |
| pH | – | $Ca(OCl)_2$ | 6.79 (6.45–6.92) | 6.86 (6.74–6.93) | 6.88 (6.78–6.94 | 6.90 (6.84–6.97) | 6.91 (6.79–6.98) | 6.90 (6.82–7.01) | 6.89 (6.75–8.02) |
| | | $ClO_2$ | 7.80 (7.67–7.88) | 7.87 (7.79–7.98) | 7.86 (7.81–7.97) | 7.81 (7.66–7.96) | 7.88 (7.80–8.02) | 7.91 (7.77–7.92) | 7.92 (7.79–8.03) |

Table 2
Pearson correlation matrix between the water quality indicators and the experiment parameters

| | Time | Disinfectant concentration | Number of people | Mesophilic bacteria | Psychrophilic bacteria | Fungi | Oxidizability | N–$NO_3$ | N–$NH_4$ | N–org | Conductivity | pH | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | | –0.90 | 0.76 | 0.57 | 0.52 | 0.57 | 0.66 | 0.36 | 0.71 | 0.86 | 0.37 | 0.81 | Variant 2 ($ClO_2$) |
| Disinfectant concentration | –0.53 | | –0.72 | –0.40 | –0.34 | –0.41 | –0.66 | –0.34 | –0.65 | –0.79 | –0.36 | –0.68 | |
| Number of people | 0.75 | –0.42 | | 0.66 | 0.64 | 0.16 | 0.15 | 0.14 | 0.48 | 0.76 | 0.26 | 0.62 | |
| Mesophilic bacteria | 0.53 | –0.25 | 0.59 | | 0.94 | 0.00 | 0.09 | –0.10 | 0.09 | 0.61 | 0.33 | 0.63 | |
| Psychrophilic bacteria | 0.58 | –0.30 | 0.65 | 0.83 | | –0.02 | 0.03 | –0.10 | 0.10 | 0.54 | 0.27 | 0.57 | |
| Fungi | 0.71 | –0.27 | 0.47 | 0.36 | 0.27 | | 0.58 | 0.54 | 0.40 | 0.32 | 0.18 | 0.49 | |
| Oxidizability | 0.84 | –0.49 | 0.52 | 0.51 | 0.45 | 0.66 | | 0.25 | 0.68 | 0.55 | 0.37 | 0.49 | |
| N–$NO_3$ | 0.51 | –0.30 | 0.13 | 0.16 | 0.14 | 0.33 | 0.71 | | 0.30 | 0.25 | 0.13 | 0.24 | |
| N–$NH_4$ | 0.55 | –0.38 | 0.54 | 0.47 | 0.69 | 0.24 | 0.45 | 0.17 | | 0.54 | 0.14 | 0.37 | |
| N–org | 0.44 | –0.18 | 0.07 | 0.12 | –0.02 | 0.36 | 0.60 | 0.59 | –0.21 | | 0.49 | 0.70 | |
| Conductivity | 0.31 | –0.26 | 0.33 | 0.01 | 0.08 | 0.16 | –0.02 | –0.31 | 0.05 | –0.15 | | 0.34 | |
| pH | –0.03 | 0.01 | –0.30 | –0.17 | –0.18 | –0.09 | –0.06 | 0.19 | –0.21 | 0.05 | 0.12 | | |
| Variant 1 ($Ca(OCl)_2$) | | | | | | | | | | | | | |

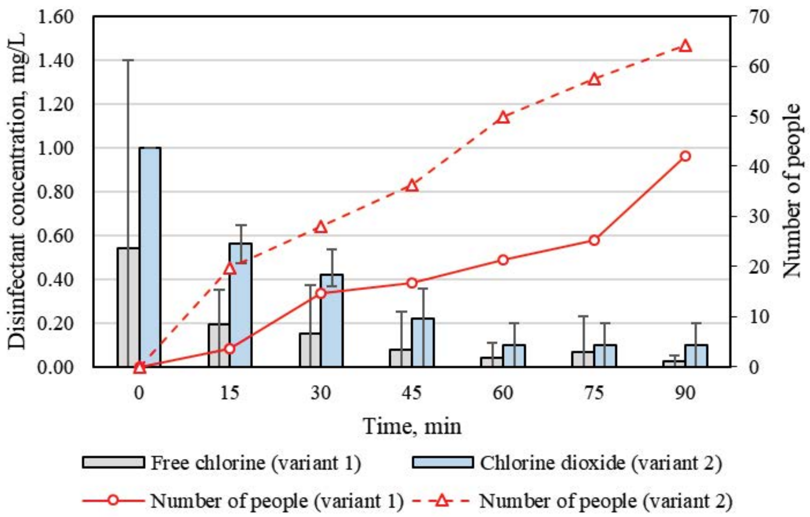


Fig. 1. Disinfectants concentration in the footbath over time and the number of people passing through the footbath.

amount of microorganisms observed in Variant 1, these were definitely lower values (about 73.5% in the case of psychrophilic bacteria and 70% in the case of mesophilic bacteria). However, due to the rapid disinfectant consumption in Variant 1 and 2, water in the footbath was not efficiently protected against the microbial contamination. These results are similar to those obtained in experiments carried out in 2004, aimed at comparing the possibilities of the water disinfection with chlorine dioxide and free chlorine, in which the more effective inactivation of heterotrophic bacteria with chlorine dioxide was obtained [24]. The comparison of the average number of fungi in the water samples from the footbath basin disinfected with $Ca(OCl)_2$ and $ClO_2$ indicated the similar contamination in both variants. The average values of the tested parameter increased from 7 CFU/mL at the beginning of the experiment to 953 CFU/mL after 90 min for Variant 1, and from 30 to 935 CFU/mL for Variant 2. There were strong positive correlations between the time and the number of microorganisms in the water samples from the footbath basin, as well as between the number of people who passed through the footbath and the number of microorganisms. In Variant 1, the correlation between time and mesophilic bacteria was 0.53, in the case of psychrophilic bacteria $r$ = 0.58, and in the case of fungi $r$ = 0.71. In Variant 2 these correlations were 0.57, 0.52 and 0.57, respectively. Gousiaa at al. [25] showed similar observations between the number of bacteria in swimming pool water and the number of users. The correlations between the number of people and mesophilic bacteria, psychrophilic bacteria, and fungi were, respectively, 0.59, 0.65, and 0.47 in Variant 1; and 0.66, 0.64, and 0.16 in Variant 2. While the correlations between the number of microorganisms and the concentration of disinfectant were negative and slightly weaker than the above. In Variant 1, they were –0.25, –0.30, and –0.27, while in Variant 2, –0.40, –0.34, and –0.41, respectively, for mesophilic and psychrophilic bacteria and fungi. Such results may indicate that the increase in the number of microorganisms in the footbath water may be caused not only by too low concentration of disinfectant, but mainly by the continuous inflow of microbial contaminants carried on the feet of the users of the swimming pool. This indicates the need for a regular exchange of water with the appropriate concentration of disinfectant. To better understand the changes of the number of microorganisms in the water of the footbath basin, the multiple linear regression analysis was performed. The obtained models showing the mathematical relations between the number of microorganisms and the key factors controlling it (the disinfectant concentration, the number of people passing through the footbath, and the time of the experiment). The models are presented in Table 3.

As the analysis showed, in Variant 2 ($ClO_2$) all analyzed parameters were statistically significant in the models for predicting the number of mesophilic and psychrophilic bacteria in the water of the footbath basin. However, contrary to expectations, the coefficients obtained for the disinfectant concentration were positive. In the models for mesophilic and psychrophilic bacteria for Variant 1, the only statistically significant factor was the number of people. This factor is also the only one that significantly influences the number of fungi in Variant 2. While in Variant 1, only the time of the experiment significantly influences the number of fungi in water in the footbath basin. However, the obtained values of $R$-squared do not exceed 0.49, which indicates a not very good match of predictive models. Modeling showed that in almost all cases (except fungi in Variant 1) the number of people was a factor significantly influencing the water microbiological quality in the footbath basin. Therefore, it should be recommended to replace the water in a footbath basin, basing on the number of people who have passed through it, and not on the time or the disinfectant concentration.

Besides the microbiological parameters and the concentrations of disinfectants, the concentrations of the pollutants brought by users and the products of their oxidation were also analyzed. These parameters give a broader picture of the water quality and the dynamics of the disinfectant consumption and reactions. Passing through a footbath basin, people release the organic pollutants (with sweat and dirt) and increase a load of organic matter in water (measured

Table 3
Linear equations describing the total number of microorganisms in water of the footbath basin

| | Number of microorganisms = $a + b \cdot D + c \cdot P + d \cdot T$<br>$D$ – disinfectant concentration; $P$ – number of people; $T$ – time of experiment | | | | |
|---|---|---|---|---|---|
| | $a$ | $b$ | $c$ | $d$ | $R^2$ |
| | Variant 1 ($Ca(OCl)_2$) | | | | |
| Mesophilic bacteria | –12,429.7 | 7,799.5 | 791.7* | 260.1 | 0.31* |
| Psychrophilic bacteria | –10,461.7 | 4,008.8 | 950.7* | 264.1 | 0.39* |
| Fungi | –251.8 | 223.8 | –2.7 | 12.0* | 0.48* |
| | Variant 2 ($ClO_2$) | | | | |
| Mesophilic bacteria | –19,561.4* | 19,667.9* | 201.5* | 217.1* | 0.49* |
| Psychrophilic bacteria | –43,913.2* | 45,053.6* | 436.1* | 435.0* | 0.49* |
| Fungi | –2,326.0 | 2,135.6 | 59.9* | 4.6 | 0.43* |

*significant with $p < 0.05$.

as oxidizability). In chemical terms, the human body fluids content primarily the nitrogen compounds – ammonium nitrogen and amino acids (organic nitrogen). The disinfectant present in water oxidizes nitrogen-containing organic compounds to nitrate nitrogen – the final oxidation product of these compounds, which is also a kind of indicator of the water age and the need for its replacement, and indirectly the consumption of the disinfectant. Chlorides are another inorganic compound that can be a similar indicator. They are formed mainly as a result of the reduction of free chlorine, and a simple method to assess their presence is to measure the conductivity. It can be noticed that pollutants transported on the feet of swimming pool users can significantly change the water quality also in these regards. In the case of oxidizability, which is an indicator of the water pollution with organic matter, the correlation coefficient with the number of people who passed through the footbath was 0.52 for Variant 1 and 0.15 for Variant 2. Despite the weak correlation between oxidizability and the number of people in Variant 2, in this case, a strong correlation was observed between organic nitrogen and the number of people ($r = 0.76$). Nitrogen compounds are good indicators of the swimming pool water contamination as they are components of human body fluids. For this contamination, the relatively strong correlations between the ammonium nitrogen content and the number of people were noticed for both variants ($r = 0.54$ for Variant 1 and $r = 0.48$ for Variant 2). The correlation coefficient of 0.45 for Variant 1 and 0.68 for Variant 2 between oxidizability and $N–NH_4$ may indicate the pollution of the footbaths with organic matter originating mainly from human body fluids. The weak correlations between the number of people and nitrate nitrogen were observed (0.13 for Variant 1 and 0.14 for Variant 2); moderate in a case of conductivity ($r = 0.33$ and 0.37 for Variant 1 and 2, respectively) and pH ($r = –0.30$ and 0.62, respectively).

### 3.2. Flat surfaces

The results of microbiological tests of the flat surfaces, before and after the footbath basin are presented in Table 4.

The scientific reports confirm that people regularly using public swimming pools are exposed to various bacterial and fungal diseases, especially as a result of the contact of bare feet with contaminated flat surfaces of swimming pools [23]. Therefore, monitoring the cleanliness of these surfaces is a key issue. The most important conclusion from these results is the fact that the total numbers of microorganisms, staphylococcus bacteria, and fungi were higher on the flat surfaces on the side of the changing room (before the footbath) than on the side of the swimming pool (after the footbath). Comparing the disinfectants, it can be concluded that the chlorine dioxide used to disinfect water in the footbath gives better disinfection effects in the cleanliness of flat surfaces in the swimming pool hall. Analyzing, the influence of the tested disinfectants on the individual groups of microorganisms, a particularly high level of the total number of microorganisms was noted. In Variant 1 ($Ca(OCl)_2$) this parameter was uncountable after 15 min for the flat surfaces both before and after the footbath; while in Variant 2 ($ClO_2$) it was uncountable after 30 min for the flat surfaces before the footbath and after 90 min for the flat surfaces after the footbath. In the case of the total number of staphylococcus bacteria, in Variant 1 uncountable plates were observed after 30 min for the surfaces before the footbath, and after 45 min for the surfaces after it (however, it was only in one measure series). In the most of measurement series the uncountable result was obtained for at least 60 min of experience, while in the time from 0 to 45 min, the average amount of staphylococcus bacteria on the surface after the footbath increased from 0 to 120 CFU/cm$^2$. In Variant 2 for staphylococcus bacteria, similarly as in the case of a total number of microorganisms, chlorine dioxide used to disinfect water in the footbath proved to better protect the surfaces from microbial contamination than calcium hypochlorite. For this variant, the total number of staphylococcus bacteria before the footbath was uncountable after 45 min of the experiment, whereas after the footbath it was obtained only for one measurement series after 90 min of the experiment. For the shorter times, the average total number of staphylococcus bacteria increased from 0 CFU/cm$^2$ at the beginning of the experiment to 12 CFU/cm$^2$ after 75 min.

In comparison with the other studied groups of microorganisms, the fungal counts on the flat surfaces of the swimming pool were the lowest. Total number of fungi on

Table 4
The average number of microorganisms on the flat surfaces before and after the footbath, obtained by using RODAC contact plates

| | Time, min | Total number of microorganism, CFU/cm² | | | | | | | | Total number of staphylococcus bacteria, CFU/cm² | | | | | | | | Total number of fungi, CFU/cm² | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Surface before footbath | | | | Surface after footbath | | | | Surface before footbath | | | | Surface after footbath | | | | Surface before footbath | | | | Surface after footbath | | | |
| Variant 1 ($Ca(OCl)_2$) | 0 | 2 | 1 | 2 | 15 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 2 | 1 | 0 | 0 | 1 |
| | 15 | uc.* | 60 | uc. | 2 | uc. | 40 | uc. | 4 | 12 | 21 | 12 | 14 | 2 | 12 | 9 | 7 | 6 | 0 | 0 | 2 | 1 | 0 | 0 | 1 |
| | 30 | uc. | uc. | uc. | uc. | uc. | uc. | uc. | 9 | uc. | 43. | uc. | 30 | 62 | 16 | 32 | 10 | uc. | 2 | 2 | 2 | 4 | 1 | 2 | 2 |
| | 45 | uc. | uc. | uc. | uc. | uc. | uc. | uc. | 20 | uc. | uc. | uc. | 58 | 31 | 22 | uc. | 10 | uc. | 4 | 7 | 4 | 6 | 1 | 4 | 2 |
| | 60 | uc. | uc. | uc. | uc. | uc. | uc. | uc. | 78 | uc. | uc. | uc. | uc. | uc. | uc. | uc. | 8 | uc. | 7 | 6 | 12 | 4 | 1 | 1 | 2 |
| | 75 | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | 10 | uc. | 12 | 10 | 14 | 12 | 2 | 4 | 12 |
| | 90 | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | uc. | 12 | uc. | 14 | 21 | 14 | 10 | 2 | 9 | 10 |
| Variant 2 ($ClO_2$) | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 15 | 32 | 34 | 3 | 1 | 5 | 12 | 1 | 1 | 14 | 3 | 4 | 1 | 1 | 2 | 1 | 1 | 7 | 7 | 1 | 1 | 1 | 1 | 1 | 1 |
| | 30 | uc. | uc. | 3 | 11 | 4 | 21 | 3 | 6 | 38 | 10 | 1 | 9 | 2 | 1 | 1 | 1 | 8 | 8 | 1 | 12 | 1 | 1 | 1 | 1 |
| | 45 | uc. | uc. | 12 | uc. | 5 | 5 | 4 | 6 | uc. | 1 | 1 | uc. | 4 | 1 | 1 | 0 | 10 | 12 | 1 | 2 | 2 | 1 | 1 | 1 |
| | 60 | uc. | uc. | uc. | uc. | 5 | 15 | 5 | 10 | uc. | uc. | 8 | uc. | 12 | 14 | 2 | 1 | 18 | 13 | 4 | 7 | 2 | 1 | 1 | 1 |
| | 75 | uc. | uc. | uc. | uc. | 7 | 20 | 14 | 10 | uc. | uc. | uc. | uc. | 24 | 7 | 1 | 16 | 16 | 12 | 5 | 6 | 2 | 1 | 2 | 8 |
| | 90 | uc. | uc. | uc. | uc. | 10 | uc. | 20 | uc. | uc. | uc. | uc. | uc. | uc. | 2 | 2 | 22 | 23 | 15 | 14 | 2 | 5 | 1 | 4 | 11 |

Average number of microorganisms on the surfaces before and after the footbath, obtained by using RODAC contact plates.
*uc. – uncountable.

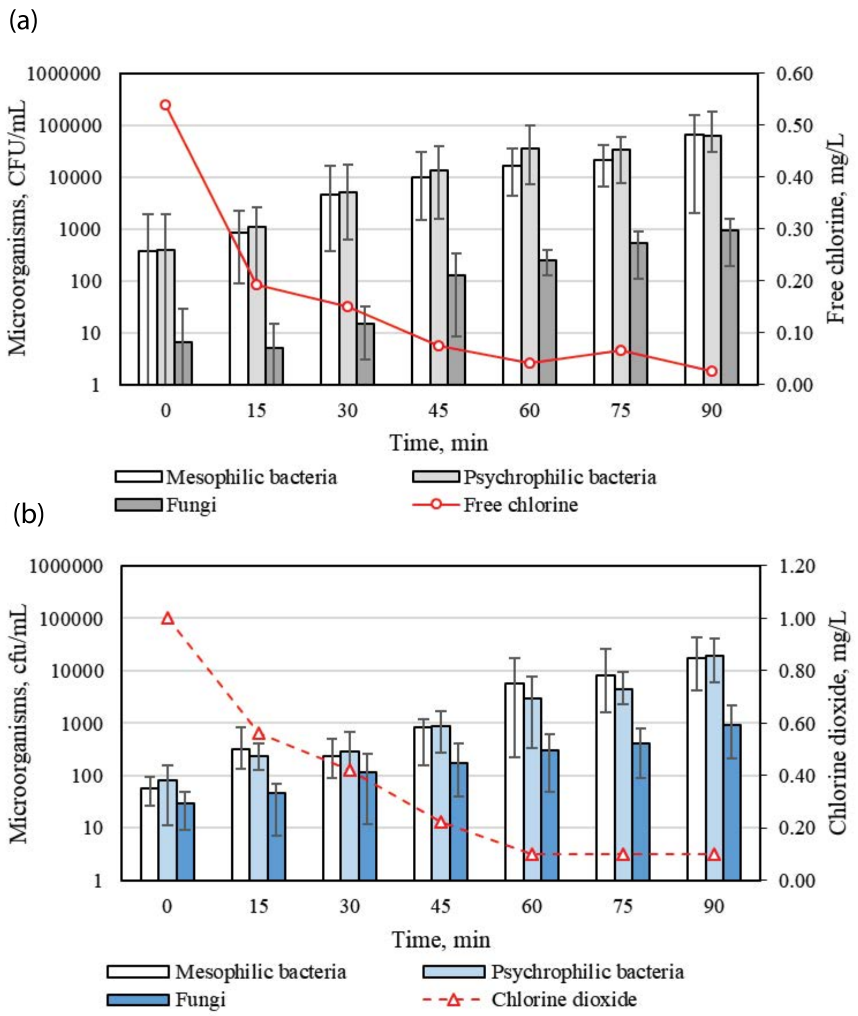


Fig. 2. Total number of microorganisms in the water samples taken from the footbath water: (a) disinfected with calcium hypochlorite (variant 1) and (b) disinfected with chlorine dioxide (variant 2).

the surface after the footbath filled with water disinfected with chlorine dioxide was 5 CFU/cm$^2$ after 90 min; while in the case of calcium hypochlorite, it was 8 CFU/cm$^2$. Also in this case, the chlorine dioxide proved to be the more effective disinfectant, even though a similar effect was not observed in a case of water in the footbath basin (Fig. 2). Fungi was one and only group of microorganisms for which all countable results were obtained by using RODAC plates, and thanks to that it was possible to present fungal counts on surface and disinfectants concentration in footbath water (Fig. 3).

The analysis of Pearson's correlation shows that between the disinfectant concentration in water and fungal counts on the surface there is a moderate negative correlation ($r$ = –0.30 for Variant 1 and $r$ = –0.45 for Variant 2). The moderate positive correlation between the number of people who entered the swimming pool was obtained for Variant 2, in which water was disinfected with $ClO_2$ ($r$ = 0.30). In Variant 1, in which $Ca(OCl)_2$ was used for the disinfection of water in the footbath, the strong correlation was obtained ($r$ = 0.62). This may indicate that chlorine dioxide plays a disinfectant role more efficiently than calcium hypochlorite. The high humidity and high temperature in indoor swimming pools are factors that favor the development of the pathogenic organism, which was confirmed by the observed strong correlations between fungal counts and time of the experiment ($r$ = 0.69 for Variant 1 and $r$ = 0.61 for Variant 2). The confirmation of the wide occurrence of fungal species in the swimming environment, such as *Aspergillus*, *Penicillium*, *Mucor*, and *Risopus*, easily grown in moist and warm conditions, were reported in many scientific papers [23–25]. Rafiei et al. [26] showed that footbath basins can be a source of fungi from the dermatophyte group, that is, *Trichophyton mentagrophytes*, *T. rubrum*, *T. verrucosum*, and *Epidermophyton floccosum*, which can cause serious foot skin diseases. The main task of footbaths is to increase the cleanliness of flat surfaces in the swimming pool hall. With the experiment presented in the article, it was observed that the disinfectant, which is carried out with water on the feet of people leaving the pool hall, could also affect the disinfection of flat surfaces. As chlorine dioxide is a better disinfectant, therefore on the surfaces from the changing room side (before the footbath) for the variant with this disinfectant a smaller

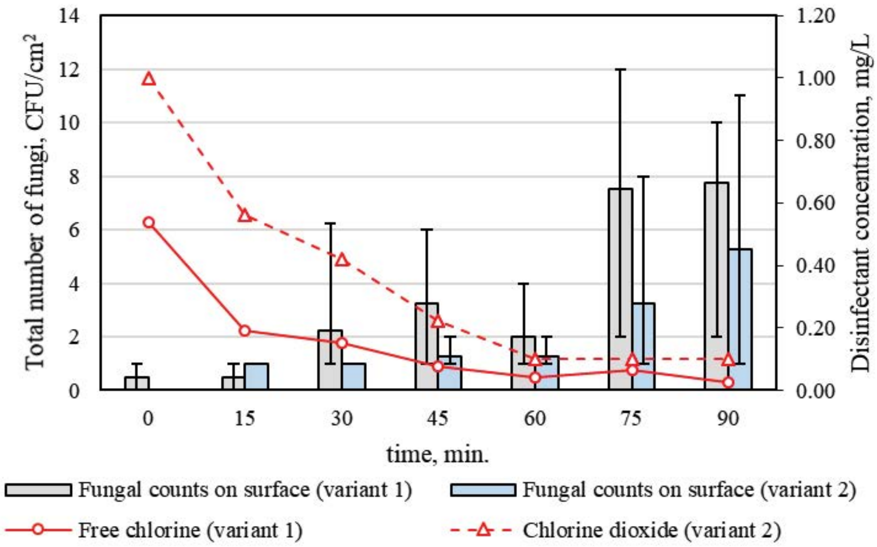


Fig. 3. Total number of fungi on the surface after the footbath and the disinfectants concentration in the footbath water.

number of microorganisms was observed than in the case of calcium hypochlorite, used for disinfection of water in the footbath (Variant 1).

## 4. Conclusions

Footbaths can be an important element in the process of maintaining appropriate sanitary and hygienic conditions in swimming pools. However, to effectively play this role, it is necessary to monitor the level of pollution and disinfectant in footbath water. The results from the conducted research showed the main problems with maintaining the required level of disinfectant and the high microbiological contamination both in the footbath and flat surfaces. Over time, the quality of water deteriorated and the number of microorganisms on the surfaces increased, both before and after the footbath. However, the measurements of the cleanliness of the flat surfaces have shown the footbath can be the barrier against microbial contamination brought by users of the swimming pool because the number of microorganisms before the footbath was visibly higher than after it. It has been also found that the type of applied disinfectant is significant – in the case of chlorine dioxide, the number of microorganisms was lower both in the water filling the footbath and on the flat surfaces, in comparison with calcium hypochlorite. The presented research results confirm the important role of footbaths and show that while maintaining the appropriate concentration of the disinfectant, they can be a disinfection barrier against the inflow of microorganisms to the swimming pool area. The results suggest the need to control the quality of water in footbaths and generally to constantly supervise them.

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