ANALYSIS OF THE NEED TO EXAMINE CYANURIC ACID LEVELS IN SWIMMING POOLS

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ABSTRACT

This study analyses the necessity of monitoring cyanuric acid levels in swimming pools in Bulgaria, with a focus on its impact on chlorine efficiency in pool disinfection. Current Bulgarian regulations, as outlined in Instruction No. 34 on the hygiene of sports facilities and equipment, issued by the Ministry of Public Health on October 24, 1975 (last updated in March 2002), do not mandate testing for cyanuric acid, despite its widespread use in pool maintenance. A dataset of 1675 records from the period 2019 - 2023, collected from state health inspections in Sofia, reveals frequent non-compliance with chlorine residual standards. Statistical analysis indicates significant differences in chlorine levels between indoor and outdoor pools, with higher instability observed in outdoor pools due to UV degradation. Cyanuric acid acts as a stabilizer, slowing chlorine degradation and extending its effectiveness. However, excessive accumulation above 100 ppm can inhibit chlorine activity, increasing the risk of microbiological contamination. Given its critical role in water quality, routine monitoring of cyanuric acid is recommended to optimize disinfection efficiency and minimize health risks.

Keywords: pools, cyanuric acid, health care, contamination, disinfection.

INTRODUCTION

This study examines the mechanism of action of cyanuric acid in the context of swimming pool disinfection, analysing data from both outdoor and indoor pools in the city of Sofia during the period 2019 - 2023.

The quality of swimming pool water in Bulgaria, from a chemical and microbiological perspective, is regulated by Article 18 of Instruction No. 34 on the hygiene of sports facilities and equipment, issued by the Ministry of Public Health on October 24, 1975 (last updated in March 2002). According to Article 18, the chemical composition of swimming pool water must meet the following criteria [1]:

Radiological indicators: Must comply with drinking water standards:

Residual chlorine: 0.2 - 0.6 mg dm^{-3}

Regarding microbiological water quality, the regulations require that the water ensures epidemiological safety and effective disinfection, with the standards summarized in Table 2.

Table 1. Criteria for the chemical composition of water in swimming pools.

pH level	6.5 to 8.5
Permanganate oxidizability:	No more than 3.0 mg dm^{-3}
Absence of nitrites and ammonia	
Iron and manganese content:	No more than 0.1 mg dm^{-3} each
Toxic substances:	Should not exceed more than twice the limits established for drinking water

Table 2. Standards for microbiological quality of water in swimming pools.

Escherichia coli and total coliform count	More than 100 mL
Microbial count:	Up to 100 colonies
Staphylococcal count:	More than 10 mL
Enterococcal count:	More than 50 mL

Cyanuric acid is not currently monitored in Bulgaria, as evident from the above regulations.

Cyanuric acid has a key role in maintaining effective chlorine disinfection in swimming pools, but it also requires careful control due to potential health risks [2]. The application of cyanuric acid in swimming pool disinfection processes is as a chlorine stabilizer [3]. It protects free chlorine from degradation under the influence of UV rays of the sun. In the presence of cyanuric acid, free chlorine interacts with it, increasing its resistance to UV radiation. However, excessively high levels of cyanuric acid reduce the effectiveness of chlorine, i.e. disinfection deteriorates despite normal chlorine levels [4].

In various European countries, different standards are applied to swimming pool water quality. For example, in Germany, it is recommended that the free chlorine level be maintained between 0.3 and 1.0 mg L^{-1} to ensure water safety for swimmers [5]. However, the level of cyanuric acid, used to stabilize chlorine, can affect the disinfection efficiency. Cyanuric acid forms stable chlorine compounds that are more resistant to degradation by UV light, thereby extending the chlorine's effectiveness in the pool [6]. However, high concentrations of cyanuric acid (above 200 mg L^{-1}) can reduce the chlorine's disinfection efficiency, leading to what is called "chlorine lock" [7].

EXPERIMENTAL

However, state health inspections of swimming pools in Sofia have reported numerous violations, including cases where residual free chlorine was undetectable (Table 3) [8].

Table 3. Cases of undetected residual free chlorine.

Year	Outdoor	Indoor
2019	3	4
2020	-	2
2021	3	1
2022	2	3
2023	-	-

In 2023 there is no pools in which residual free chlorine is absent.

Sampling procedure

Water samples were taken from various indoor and outdoor pools intended for public use in: kindergartens, schools, sanatoriums, beaches, sports centers, etc. Samples were taken on a schedule consistent with the requirements of the State Health Control, as follows: twice a season for all types of pools; mandatory triple sample when filling outdoor pools at the beginning of the season.

All samples were taken by employees of the Sofia Regional Health Inspectorate (SRHI). Chemical and microbiological tests were performed according to the methodology developed in the SRHI Water Sampling Procedure, and the results were compared with the mandatory standards.

All samples were taken in containers provided by the SRHI laboratory, and for microbiological samples, the containers were sterilized.

Samples from the pools are taken during an active hour of the day, with the residual chlorine being determined in advance. Samples are taken from the beginning of the steps or corners of the pool.

Samples for chemical analysis were taken in 1 L bottles 30 cm below the surface, with the bottles closed under water.

For microbiological analysis, about 300 - 500 mL samples were taken in sterile bottles 20 - 30 cm below the surface, with the bottles closed above the water.

The recommendation not to touch the inside of the caps with hands was also observed. For the results of the samples to be correct, their transportation and storage are of particular importance.

The bottles with the samples are placed in special cassettes with partitions for the purpose of their transportation, and the clean and sterile bottles are not mixed with the bottles with the samples taken and those with preservatives.

The transportation of the samples to the laboratory is organized so that their testing can be carried out within 6 h after sampling. In case this is impossible for any reason, the test can be carried out within 24 h, provided that the samples are stored at a temperature of 5 - 8ºC.

The samples for microbiological analysis are transported in refrigerated bags at a temperature of 2 - 8ºC, and those for chemical analysis at a temperature of 1 - 5ºC.

Identification of the samples

After taking the samples, the sampling inspector from the SRZI draws up a sampling protocol and fills out a label, which describes: the name of the person who took the samples, the date and time of sampling, type of pool, the specific name and location of the site, sampling point, sampling protocol number, result of on-site analysis, additional notes regarding meteorological conditions or unusual events that occurred, type of test, reason for sampling and location of sampling.

Each bottle is labelled with a serial number that corresponds to the number in the protocol and contains the following information: date and time of sample collection; protocol number; sample quantity; sample name; object from which the sample was taken; name of the sampler; interested person or authorized representative.

The tests were performed according to the standards and no deviations, exceptions and additions to the test methods were allowed. The tests were performed in compliance with all requirements for specific laboratory conditions. The reported expanded uncertainty of the study is expressed as the standard uncertainty of measurement, multiplied by a confidence factor of 2, with a normal distribution of values and a probability of the confidence interval of 95 %.

Data collection and analysis

This article presents evidence that this phenomenon may be due to the interaction between cyanuric acid and chlorine.

Information processing

The data from each protocol with the results of individual tests are recorded in an annual database in Microsoft Excel, where the following are filled in: the specific pool, the date of the test, the person who conducted the laboratory test, the test results for each indicator. The data from the texts in the annual databases in Excel from the columns “mismatch of chemical indicator/value.” and “mismatch of microbiological indicator/value.” are extracted and processed using a large language model, developed and specially trained for data extraction and analysis.

For the cleaning, aggregation and visualization of the data, the Python programming language and its panda’s library were used, which allows fast and efficient work with tabular data. It allows generating data for all values that do not match the chemical and microbiological indicators that are of interest to us.

Data scaling

Where data scaling was applied, a Min-Max scaler was used, which means that the lowest observed value is represented as 0, the highest as 1, and intermediate values are linearly scaled according to the largest and smallest.

Hypothesis testing (Z-Test)

For indicators for which hypothesis testing for the significance of the difference between levels was used, a Z-test for the difference between mean values was applied. Null and alternative hypotheses are created, testing the difference: p-value with a significance level ($\alpha = 0.05$).

Data collected

A total of 1675 records were collected for the years 2019 - 2023 from state health inspections conducted in Sofia by the Sofia Regional Health Inspectorate. The distribution of data by year is presented in Table 4.

Out of 1675 pools, 422 were indoor, and 1253 were outdoor.

Compliance with Instruction No. 34: 797 pools met the required standards, while 878 did not (Table 5).

60 % of outdoor pools met the standards, compared to only 48 % of indoor pools.

A one-sided Z-test for proportions was conducted

Table 4. Distribution of data by year.

Year	Number of records
2019	376
2020	273
2021	146
2022	246
2023	611

Table 5. Compliance based on pool type.

Pool type	Compliant	Non-Compliant
Indoor	624	629
Outdoor	254	168

to test whether indoor pools fail compliance more often than outdoor pools.

The p-value was 0.0001, which is lower than the significance level ($\alpha = 0.05$), allowing us to reject the null hypothesis and accept the alternative hypothesis that indoor pools are more likely to be non-compliant.

Residual chlorine analysis

555 out of 1675 records (33 %) had residual chlorine levels outside the acceptable range.

The mean chlorine level was 0.78 mg dm^{-3}, with a standard deviation of 0.58 and a median of 0.84.

The lowest recorded chlorine level was 0, while the highest was 3.2 mg dm^{-3}, observed in Kindergarten 39, Ovcha Kupel, in 2023 (Table 6).

Indoor pools had higher average chlorine levels.

A Z-test for mean difference showed a statistically significant difference (p-value = 0.012, $\alpha = 0.05$) between indoor and outdoor pools (Table 7).

The lowest average chlorine level was in 2021 (0.47 mg dm^{-3}), and the highest was in 2023 (1.04 mg dm^{-3}).

The biggest decrease (- 27 %) occurred between 2020 and 2021.

The biggest increase (+ 86 %) occurred between 2022 and 2023.

Table 6. Residual chlorine by pool type (only non-compliant cases).

Year	Residual chlorine	Relative change
2019	0.69	0 %
2020	0.64	- 7 %
2021	0.47	- 27 %
2022	0.56	+ 19 %
2023	1.04	+ 86 %

Table 7. Residual chlorine levels by year

Metric	Indoor Pools	Outdoor Pools
Number of cases	440	115
Mean chlorine level	0.80	0.68
Standard deviation	0.6	0.48
Minimum	0	0
25th percentile	0.29	0.23
Median (50th percentile)	0.86	0.80
75th percentile	1	1
Maximum	3.2	2.15

RESULTS AND DISCUSSION

Chlorination is the most used disinfection method for swimming pools. However, chlorine decomposes quickly due to factors like UV radiation from sunlight, which significantly reduces its disinfection efficiency [9]. Cyanuric acid stabilizes chlorine and extends its effectiveness [4].

These chemical interactions between chlorine and cyanuric acid are of particular importance, as they can affect water quality and swimmer safety. As highlighted in a study by the European Journal of Environmental Sciences, high cyanuric acid levels may necessitate the use of significantly higher chlorine concentrations, which increases costs and risks of unwanted reactions. Therefore, it is essential to seek solutions for optimizing water chemical treatment in swimming pools.

Structure of cyanuric acid

Cyanuric acid ($C_3H_3N_3O_3$) is a symmetrical heterocyclic compound derived from 1,3,5-triazine (Fig. 1). It contains three hydroxyl groups attached to the carbon atoms of the triazine ring, forming a stable tautomeric enol structure (Fig. 1).

The molecular structure of cyanuric acid, showing the 1,3,5-triazine ring with three hydroxyl (OH) groups symmetrically attached to the carbon atoms. The molecule exists primarily in its enol tautomeric form.

Oxidation of cyanuric acid

Under strong oxidative conditions (e.g., with hydrogen peroxide or chlorine), cyanuric acid can undergo ring cleavage and complete oxidation according to Eq. (1).

$$C_3H_3N_3O_3 + [O] \rightarrow 3\ CO_2 + 3\ NH_3 \qquad (1)$$

This reaction leads to full mineralization of the compound into carbon dioxide and ammonia. A general reaction showing the oxidation of cyanuric acid under strong oxidative conditions, resulting in complete breakdown of the ring structure to form carbon dioxide (CO_2) and ammonia (NH_3).

Cyanuric acid and chlorine interaction

Cyanuric acid can interact with chlorine, forming chlorinated compounds that reduce chlorine's disinfectant properties. Studies show that high levels of cyanuric acid can diminish chlorine's effectiveness in killing pathogens, highlighting the need to maintain optimal cyanuric acid levels in pools [10]. To address this issue, regular monitoring of cyanuric acid and chlorine levels is essential. It may be necessary to use alternative disinfection methods or adjust chemical additives depending on the test results [11].

Chlorine stabilization: cyanuric acid forms chemical complexes with chlorine, slowing down its decomposition under UV light [12].

Reduced photolysis: cyanuric acid decreases the rate at which sunlight breaks down chlorine, reducing the need for frequent chlorine additions [13].

Cyanuric acid is an organic compound essential in:

Pool disinfection (stabilizing chlorine)

Pesticide production (precursor for chlorpyrifos)

Resin and plastic stabilizers (UV protection)

Risks and toxicity

Cyanuric acid plays a key role in chlorine disinfection of swimming pools, but its levels must be controlled due to health risks.

Cyanuric acid can accumulate over time, leading to chlorine lock at levels above 100 ppm, increasing microbiological contamination risks.

Decomposition releases toxic gases (cyanides, ammonia).

Improper disposal can cause environmental pollution [14].

CONCLUSIONS

Cyanuric acid is essential for stabilizing chlorine, but its levels must be controlled (20 - 50 ppm). Indoor pools have higher chlorine levels than outdoor pools. One in three pools had non-compliant chlorine levels.

State health monitoring should consider adding cyanuric acid testing to prevent chlorine inefficiency and microbiological risks.

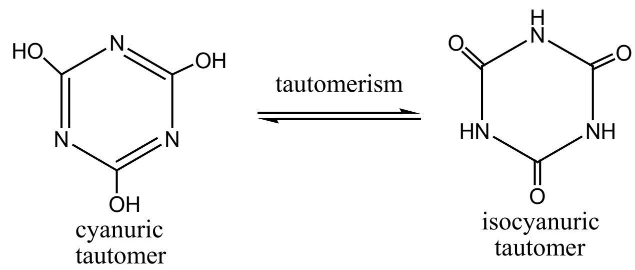

Fig. 1. Cyanuric acid structure and tautomerism transformation

This study highlights the necessity of regulating cyanuric acid in Bulgaria's swimming pools to ensure effective and safe disinfection.

***Authors' contribution**: M.D.: Data analysis and discussion.*

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