DOI: 10.23968/2500-0055-2022-7-2-54-65

ASSESSING THE PERFORMANCE OF UNITS FOR THE SYNTHESIS OF OLIGODYNAMIC SOLUTIONS FOR WATER TREATMENT

Andrey Belyaev[1], Elena Kuts[2]*, Vladimir Shabalin[2]

[1]Vyatka State University
Moskovskaya st., 36, Kirov, Russia
[2]Saint Petersburg State University of Architecture and Civil Engineering
Vtoraja Krasnoarmeyskaya st., 4, Saint Petersburg, Russia

*Corresponding author: kouts@yandex.ru

Abstract

Introduction: Fresh water suitable for water supply has been depleted due to production activities. Thus, closed water supply cycles are required at civil infrastructure facilities. The quality of water must meet the requirements on its use for various purposes. It is common knowledge that water is essential in providing adequate health and sanitary conditions for the public. Therefore, issues of water treatment remain in the focus of researchers. Water disinfection is one of the mandatory methods used in water purification and treatment. Currently, chlorination is still the main technology for water disinfection. However, it is responsible for toxic, carcinogenic, and other types of negative effects on the human body. In this paper, we consider the use of oligodynamic solutions as a new, rapidly-developing direction in water treatment. In the course of our study, we addressed a method of swimming pool water disinfection using units of oligodynamic synthesis and examined the results of treated water quality analyses. **Methods**: The study was based on the statistical analysis of water quality indicators in pools with water treated with silver and copper ions. The analysis made it possible to determine the hygienic safety and reliability of products. To assess hygienic safety and reliability, we analyzed the composition and properties of the product (oligodynamic solution) as well as the composition and concentration of impurities in pool water and determined if the disinfecting properties of water are preserved and proper levels of copper and silver ions (not exceeding MAC) in pool water are maintained. **Results:** The paper provides a rationale for procedures to analyze and determine the safety and reliability of small-scale units producing disinfection solutions to ensure optimal swimming conditions in swimming pools. **Discussion:** The obtained results indicate that it is expedient to apply oligodynamic water treatment to ensure the hygienic safety and reliability of swimming pools. The technology suggested fully meets the requirements of sanitary regulations on water quality.

Keywords

Water quality indicators, oligodynamic solutions, oligodynamic synthesis units, hygienic safety and reliability.

Introduction

Our health and longevity depend on our lifestyle. That is why a healthy lifestyle is gaining more and more followers and is promoted at the state level. These circumstances determine trends in the construction and reconstruction of such health and leisure facilities as gyms, stadiums, swimming pools, etc. In their design, particular attention should be paid to the choice of water treatment method and technology. The choice of water purification technology and water purification systems depends on the sanitary and hygienic requirements on swimming pool water, the size of the pumping and filtering unit, the volume of the pool basin, the quality of feed water, technical and economic indicators, and other parameters.

Traditional methods of water disinfection with chlorine and its derivatives have particular negative effects, e.g., sensitizing and carcinogenic effects. Besides, such water may irritate the mucous membranes of the eyes and the respiratory tract and pose a toxic hazard in emergencies (overdose). The chemical transformation of substances contained in the water is of particular relevance since it results in the formation of organic halogen compounds dangerous to human health (Carter and Joll, 2017; Firuzi et al., 2020; Liu et al., 2020; Wyczarska-Kokot et al., 2020; Zhang et al., 2022). In new regulatory documents, significant changes have affected chlorine and chlorination by-products. Unfortunately, these changes are due to the disappointing statistics of mass poisoning in swimming pools. In the prior regulatory document, combined chlorine was not even included in the sanitary inspection program and was mentioned only when referring to the unit on standby. The maximum allowable concentration of residual chlorine has been reduced by 10 times and is equal to 0.2 mg/l (Sanitary Rules SP 2.1.3678-20 (Chief Public Health Officer of the Russian Federation (2020))). The maximum allowable concentration of chloroform has been changed as well, from 0.1 to 0.06 mg/l (Sanitary Rules and Regulations SanPiN 1.2.3685-21 (Chief Public Health Officer of the Russian Federation (2021))).

These new regulations are aimed at improving the safety of swimming pool water (both microbiological and toxicological) due to the use of chlorine-containing agents. Measures taken to gain a more comprehensive understanding of the water safety issue and risk management associated with the use of chlorine comply with the global trends creating a comfortable and safe environment. New regulations require all process participants to make informed decisions during swimming pool design and construction and ensure strict compliance with the maintenance mode during swimming pool operation.

Considering the above, it is required to turn attention to alternative methods of water disinfection to improve hygienic reliability and reduce the number of emergencies in swimming pools, caused by the negative effects of agents used in water disinfection.

In recent decades, new methods of industrial water disinfection by enriching it with metal ions were found. Among those methods, silver and copper electrolysis became the most popular. Those new technologies significantly improved the procedure of pool water treatment and provided particular advantages in terms of hygiene. For instance, silver-copper (oligodynamic) solutions form insoluble compounds with amines and carbamides — substances released by humans into water. The resulting solid sediments can be easily removed from the basin. Proper technological conditions aimed at maintaining the sub-threshold concentrations of these ions in the basin at a constant level can ensure a long-term disinfection effect, and that — in contrast to chlorine and oxidants — is without any chloramines, chloroforms, peroxides, and other derivative compounds prone to chemical transformations and causing negative effects for humans.

The method of water disinfection with silver and copper ions as well as the ions of other metals in the form of oligodynamic solutions (Adelshin and Leonteva, 2011; Allen et al., 2021; Karataev, 2009; Krasovsky et al., 2021) is based on the fact that very low concentrations (below the MAC level) of the positive ions of metals and other substances with high electric potential have an adverse effect on microorganisms. Pure silver and copper ions, which are not bound in salts and with other substances, have the ability to disinfect water. Their bactericidal effect manifests in the amounts significantly lower than the adverse effect and/or the sensation threshold (in terms of turbidity, odor, and water color index). What silver and copper ions have in common in their adverse effect on biological objects is their influence on the concentration of SH groups.

Oligodynamic solutions are aqueous solutions with antimicrobial characteristics due to low concentrations of the ions of mercury, silver, copper, iron, lead, zinc, bismuth, gold, aluminum, and other metals (Voznaya, 1967). This characteristic depends on the availability of the cations of metals with high electric potential (Ag++, Hg++, C++) as well as some non-metallic ions that can inactivate enzymes whose active groups are located on the surface of microbiological substrates (bacteria, cells).

During water treatment with oligodynamic solutions, water is enriched with silver and copper ions to sub-threshold values (bactericidal concentrations), which brings its composition closer to the natural one. The concentration of other constituents depends on feed drinking (tap) water.

The advantages of the method involving the use of oligodynamic solutions (as compared with water chlorination and other methods of water disinfection) should be evaluated not only by economic indicators but also by physicochemical and biological characteristics. It is those characteristics that ensure a hygienic advantage.

To collect and analyze data when evaluating water treatment method effectiveness, we considered AE-1 units for the synthesis of oligodynamic solutions, by AQUA-EFFECT Research and Innovation Enterprise (Units for the synthesis of oligodynamic solutions. Specifications TU 361469-001-30917173-2015 (AQUA-EFFECT Research and Innovation Enterprise (2015a))). Their operation is based on electrolysis using silver and copper electrodes. Water is treated automatically depending on the mode set. The following metals with an oligodynamic effect are used: silver in accordance with the requirements of State Standard GOST 25474-2015; copper in accordance with the requirements of State Standard GOST 767-2020. The unit provides the following rate of metal ion formation: silver — up to 3 g/h; copper — up to 2 g/h. The rated water consumption per unit is 1–5 m^3/h. The equipment is powered by a single-phase general-purpose network.

Based on the established procedure of water treatment, the water flow in the AE-1 unit is divided into two unequal parts. A small part of water (about 20 l/min) goes to an electrolysis reactor, where it is enriched with metal ions. Then it is transferred back to the main flow and goes to the filters.

Despite the apparent advantages of water enrichment with silver and copper, scientific and technical sources contain no objective research data on the safety and reliability assurance necessary to provide required water quality indicators. The Rospotrebnadzor (Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing) has not yet established requirements on swimming pools using methods of oligodynamic water treatment.

Materials and methods

We aimed to evaluate the efficiency of AE-1 units for the synthesis of oligodynamic solutions, used for swimming pool water disinfection. The efficiency, hygienic safety and reliability of AE1 units for oligodynamic synthesis and their products correspond to the ability of equipment in pools to maintain constant sanitary characteristics of water in the basin during the entire operation period in terms of microbiological, organoleptic as well as sanitary and chemical indicators.

To reach the goal, we analyzed studies performed by accredited laboratories for the following six facilities (Izhevsk, Lesnaya Nov, Mitino, Sportivny Park, Chuvashia, and Raduga). In total, we processed 445 laboratory water analysis reports, including 154 sanitary and bacteriological analysis reports, 148 organoleptic indicator analysis reports, and 143 silver and copper ion chemical concentration analysis reports.

Water quality indicators were analyzed in accordance with the requirements of the following regulatory documents: State Standard GOST R 51232-98 (Technical Committee for Standardization, 1998), Sanitary Rules SP 1.1.1058-01 (Chief Public Health Officer of the Russian Federation, 2001) and SP 2.1.3678-20 (Chief Public Health Officer of the Russian Federation, 2020), and Sanitary Rules and Regulations SanPiN 1.2.3685-21 (Chief Public Health Officer of the Russian Federation, 2021).

To evaluate the hygienic reliability of the units, hygienic and technical information blocks were formed. The hygienic information block includes data on the comparison of the laboratory analysis results with hygienic standards. The technical information block includes technical parameters characterizing the performance of the units.

The initial data (properties of water treated, used as dependent variables) were as follows:

- microbiological: total coliforms per 100 ml, etc.
- organoleptic: turbidity, color, odor.
- sanitary and chemical: silver (Ag) and copper (Cu) ion concentration.

The results of laboratory analyses according to Sanitary Rules SP 2.1.3678-20, Sanitary Rules and Regulations SanPiN 1.2.3685-21, and State Standard GOST R 51232-98 shall not exceed regulatory values. Any case when such regulatory values are exceeded can and should be considered an emergency (especially in terms of microbiological indicators), which gives “code red” to hygienic reliability.

Table 1 shows some regulatory values for water quality in swimming pools during water treatment using AE-1 units.

Table 1. Hygienic regulatory values for water quality

Indicator (dependent variables)	Regulatory value	Regulatory document
1. Sanitary water indicators		
1.1. Total coliforms per 100 ml of water	NMT 1	Sanitary Rules SP 2.1.3678-20
1.2. Thermotolerant coliforms per 100 ml of water	0	
1.3. Coliphages per 100 ml of water	0	
1.4. Staphylococcus aureus per 100 ml of water	0	
1.5. Enteric pathogens	0	
1.6. Pseudomonas aeruginosa per 100 ml of water	0	
1.7. Giardia intestinalis cysts per 50 l of water	0	
1.8. Eggs and larvae of helminths per 50 l of water	0	
2. Organoleptic water indicators		
2.1. Turbidity, mg/l	NMT 2.0	
2.2. Water color index, color degrees	NMT 20	
2.3. Odor, points	NMT 3	
3. Metal ions		Sanitary Rules and Regulations SanPiN 1.2.3685-21
3.1. Silver, mg/l	NMT 0.05	
3.2. Copper, mg/l	NMT 1.0	

External influences on the quality of treated water were determined by particular technical characteristics (used as dependent variables):

- Unit service life (days)
- Pool volume, m^3
- Water consumption, m^3/h
- Circulation flow, m^3
- Water change, m^3/h
- Pool attendance (people/day)
- Average swimming time per swimmer (person/hour)
- Electrode replacement time
- Number and diameter of filters

Based on the statistical analysis of the laboratory studies on water quality in six pools over five years, it was established that the following three criteria of the hygienic safety and reliability of AE-1 units shall be distinguished: microbiological, organoleptic, and ionic.

At the first stage of work, the size of a random sample was determined based on the data on nine pools for 230 months of their operation. The calculations were performed by the standard formula for the size of a random sample with three types of error (5%, 10%, and 15%), confidence level: 95%.

Results and discussion

The system used to evaluate the hygienic safety and reliability of synthesis products (pool water) and AE-1 units is based on microbiological, organoleptic, and ionic criteria.

The microbiological criterion is a qualitative indicator of the reliability of products and operating AE-1 units; there shall be no positive results in the detection of pathogenic and conditionally indicative microflora as well as the detection of surface contamination with the eggs of certain helminths. The criterion also determines the epidemiological significance of water treated.

The study of a random sample of 154 microbiological analysis reports for six pools over five years did not reveal a single positive result.

Table 2 lists the basic sanitary indicators of pool water (**microbiological studies**), determined by the applicable regulations (Sanitary Rules SP 2.1.3678-20, Sanitary Rules and Regulations SanPiN 1.2.3685-21). We performed laboratory water quality control by these criteria.

Table 2. Basic indicators of microbiological water safety in pools

Indicator (dependent variables)	Regulatory value
1. Total coliforms per 100 ml of water	0
2. Thermotolerant coliforms per 100 ml of water	0
3. Coliphages per 100 ml of water	0
4. Staphylococcus aureus per 100 ml of water	0
5. Enteric pathogens	0
6. Pseudomonas aeruginosa per 100 ml of water	0
7. Giardia intestinalis cysts per 50 l of water	0
8. Eggs and larvae of helminths per 50 l of water	0

All the microbiological analysis reports drawn up over five years show only negative results. Other methods of water disinfection cannot ensure such a result since there is always a possibility of microbial contamination (Cherkasova, 2007; Karataev, 2009; Krasovsky et al., 2020, 2021; Tul'skaya, 2012). That can be explained by the equipment configuration and the specifics of the process. If bacteriological studies show no positive results, therefore, no statistical analysis can be conducted for the system used to evaluate the hygienic reliability of AE-1 units. Thus, to develop the system, we will consider an alternative: "positive results—no positive results". That can be explained by the specific duration of the bactericidal effect of silver ions and the fact that, in terms of composition, oligodynamic solutions bring water close to the category of drinking water while maintaining disinfection properties. The analysis of data makes it possible to define the microbiological criterion of the safety and reliability of AE-1 units as "a qualitative indicator indicating the absence of harmful microflora in pool water" during the guaranteed service life (5 years (Sanitary Rules SP 2.1.3678-20)). The criterion is aimed at diagnosing the potential danger of infection transmission (taking epidemic control measures). Thus, the first criterion of the hygienic safety and reliability of AE-1 units is no positive results of microbiological studies. In case any indicative microorganisms are detected in water of pools equipped with AE-1 units, that should be considered an emergency requiring immediate response: from a detailed inspection of the units to water draining and disinfection of the basin and other.

The existing system for the hygienic evaluation of microbiological indicators of pool water in view of using electrolysis technologies for water treatment needs to be improved: the list of indicative microorganisms as well as methods of sampling for sanitary and bacteriological studies shall be defined more accurately (to the point of automating the identification of prioritized microorganisms).

The **hygienic evaluation of organoleptic characteristics** of water refers to turbidity, water color index, odor and other impurities. This evaluation is subjective since the ability to distinguish and evaluate odors depends on various external causes (air motion, other microclimatic conditions, etc.).

Table 3 and Fig. 1 show the summary indicators of descriptive statistics for the organoleptic factor. The sets of data cover an interval of 468 days and include the results of analyses performed with the use of new spectrophotometers.

Table 3. Statistics for organoleptic water characteristics

Indicator name	Interval (days)	Turbidity (mg/l)	Water color index (color degrees)	Odor (points)
1	*2*	*3*	*4*	*5*
Regulatory value =		NMT ≥ 2.0	NMT ≥ 20	NMT ≥ 3
Mean =	467.8	0.511	2.446	0.568
Error of the mean (set of data) =	75.5	0.132	0.260	0.130
Variance =	*193,377.5*	*0.592*	*2.302*	*0.577*
Standard deviation =	*439.8*	*0.769*	*1.517*	*0.759*
Mode No. =	9	0.1	2.4	0
Median =	378	0.325	2.2	0
Maximum =	1454	1.7	7.3	2
Minimum =	1	0.1	0.3	0
Amplitude =	*1453*	*1.6*	*7*	*2*

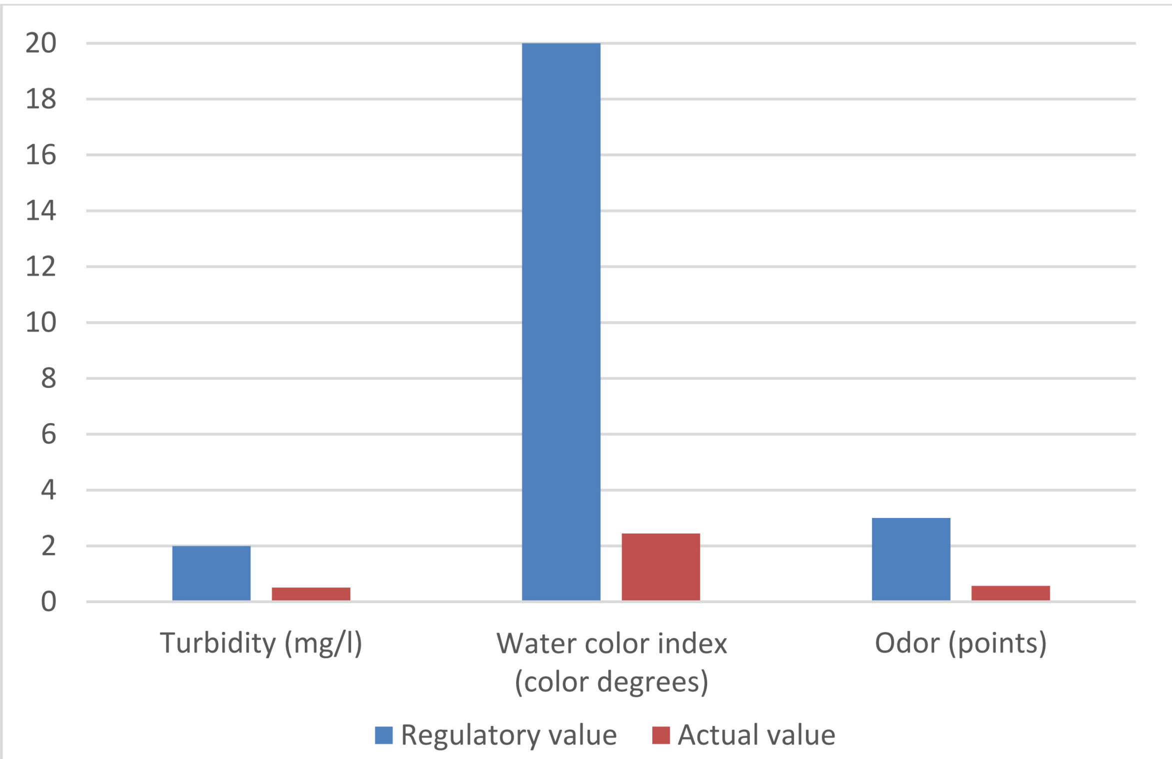

Fig. 1. Summary indicators of descriptive statistics for the organoleptic factor

The mean values of turbidity, water color index, and odor do not exceed the regulatory values. The monotonicity of the series also manifests in scattering indicators, shifts in the median as well as in modal values, showing the most frequently encountered number in a set of values analyzed.

Based on Table 3, we established the relationship between changes in the organoleptic water characteristics and service life.

The calculations showed the following:

- the relationship between turbidity and the service life of AE-1 units is inverse (the longer the service life, the less turbidity) and weak: Rxy = –0.287 units (correlation) and Dt = 8.2% (explained variance). (Rxy is the correlation coefficient showing relationships between the variables analyzed, Dt is the correlation coefficient characterizing the value of “linkage” between the variables in percent (Aivazyan et al., 1989; Förster and Rönz, 1983).
- the relationship between the water color index and the service life of AE-1 units is inverse (the longer the service life, the lower the water color index), not significant (almost no relationship): Rxy = –0.041 units (correlation) and Dt = 0.2% (explained variance).

The described algorithm to evaluate relationships between organoleptic indicators and service life can be used to measure the hygienic reliability of AE-1 units in other cases.

When the regulatory values indicated are exceeded, this means that, based on subjective evaluation, water is not suitable for swimming or may point to water disinfection procedure violation or AE-1 unit malfunctions. In this case, it is required to perform a detailed inspection of the units and a search for causes behind the overall and specific (microbial) contamination of the pool.

Organoleptic water indicators are semi-quantitative (mainly subjective) and, therefore, cannot always be used in statistical studies. Oligodynamic water disinfection requires the improvement of methods used to determine corresponding indicators and minimization of subjectivity as far as the procedure and analysis results are concerned.

Over five years, the pools studied did not show any signs of substandard water quality in the basin (elevated turbidity and water color index, odor).

The third reliability criterion, the **ionic** criterion, is the most complex one. Its distinctive feature is that there are no directions regarding the frequency of control over silver and copper concentrations in water in the applicable sanitary regulations. Besides, the residual amounts of these substances in the analyzed laboratory control materials never exceed the specified MACs (they are always 15–20% lower).

The disinfection characteristics (the **ionic quality criterion**) of AE-1 units are determined by the technology of obtaining and using silver and copper ions. This disinfection procedure is a new special technology. It might be that silver and copper concentrations in water will serve as the most relevant sign of safety and reliability.

The procedure implies water enrichment with silver and copper ions. When bactericidal ions enter the water, most of them bind to the microflora, and the rest of them remain in the solution. The latter can persist in water for a long time and should be classified as those “in the form of residual (background) concentrations”.

Table 4 shows statistics of changes in silver and copper concentrations in the collected water samples, where the total number of sampling days is equal to 68,740.

According to the analysis of the reports, the mean background concentrations do not exceed the MAC levels (Sanitary Rules and Regulations SanPiN 1.2.3685-21):

- silver: 0.024 ± 0.03 mg/l with a regulatory value of NMT 0.05 mg/l;
- copper: 0.221 ± 0.014 mg/l with a regulatory value of NMT 1.0 mg/l.

Therefore, the most frequent modal values are as follows: for the first series of 647 days, silver — 0.011 mg/l and copper — 0.22 mg/l. The amplitude of the series in absolute values is as follows: silver — 0.22 mg/l, copper — 0.92 mg/l (at the MAC levels of NMT 0.05 and 1.0 mg/l, respectively).

Based on the studied set of analyses, the most significant mean residual (background) concentrations are as follows (mg/l):

- silver — 0.0005 (minimum), 0.024 (mean), 0.224 (maximum);
- copper — 0.001 (minimum), 0.221 (mean), 0.92 (maximum).

The relevance of the ionic criterion is determined by the following:

- silver and copper ions are responsible for the main function of oligodynamic solutions, which is disinfection (bactericidal effect);
- the persistence and/or the residual amount of ions ensure the antimicrobial characteristics of water;
- ion concentration control means the evaluation of the antimicrobial characteristics of water in the pool basin and, therefore, requires monitoring.

However, despite the comprehensive statistical data, Table 4 does not give a full picture for the hygienic evaluation of variations in ion concentrations. Therefore, we will try to analyze relationships between the obtained concentration series and the number of unit operation days (sampling days) as well as the corresponding relationships for silver and copper concentrations. In fact, we need to resolve the following question: Is there a relationship

Table 4. Statistics of changes in residual concentrations of silver and copper by sampling days

Indicator name	Sampling days	Silver ions	Copper ions
Total operation days	68,740	2.593	24.035
Mean (background concentration)	630.6	0.024	0.221
Error of the mean	*33.8*	*0.003*	*0.014*
Variance	*124,441.0*	*0.001*	*0.022*
Standard deviation	*352.8*	*0.035*	*0.147*
Mode No. =	220	0.009	0.17
Median =	647	0.011	0.22
Maximum	1464	0.224	0.92
Minimum	1	0.0005	0.001
Amplitude	1463	0.2235	0.919

between the service life (equipment wear) and silver and copper concentrations in solutions?

The calculations of the sampling days / ion concentration correlation coefficients (a sample with n = 143) showed the following: silver ions — Rxy = –0.103 units (Dt = 1%), copper ions — Rxy = –0.109 units (Dt = 1%).

The obtained values indicate that there is almost no correlation between the service life and concentrations. Despite the problematic relationship with this indicator, an inverse correlation is observed: the greater the consumption of silver, the lower the consumption of copper (and vice versa). This circumstance requires further research.

In 143 samples of water from pools equipped with AE-1 units, the MAC levels were not exceeded. The dynamics of changes in residual (background) ion concentrations in the case under consideration may be the result of periodic procedures performed during electrode replacement. No rigid correlations between ion concentrations and the service life were established in the analyzed statistical material. Besides, considering the similarity of dynamics with regard to organoleptic indicators and metal concentrations, we can assume that they depend on the load, i.e., the number of visitors per day (sampling day). This circumstance can serve as a reference point when determining the sampling term. However, given the results of studies on metal concentrations and organoleptic evaluations, it is possible to recommend sampling for residual ion concentrations at a frequency of once per month (approval from local Rospotrebnadzor (Federal Service for Surveillance on Consumer Rights Protection and Human Wellbeing) authorities is mandatory).

The analysis of ion concentration dynamics makes it possible to select silver and copper ion concentrations as the third criterion of the hygienic reliability of equipment. The obtained statistics for the mean metal concentrations can be used as a temporary hygienic reference point.

The obtained mean metal concentrations in the samples analyzed (Table 4) can serve as temporary reference regulatory values, which can be used to evaluate the hygienic safety and reliability of the products of AE-1 units for the synthesis of oligodynamic solutions.

The method used to calculate the **composite index** for the relationships in the set of "regulatory value – actual value" pairs with different dimensions has such an advantage as the possibility to take into account both cases when regulatory values are exceeded and cases when sub-threshold values are observed (Aivazyan et al., 1989; Förster and Rönz, 1983).

This characteristic is determined by the reduction of arrays of heterogeneous information in relation to the corresponding standards in a weighted Euclidean space. For instance, the "regulatory value – actual value" pairs are measured in dB, lx, mg/l, etc. Using a computational procedure, they can be combined into a single numerical estimate showing how an entire set of indicators differs from the regulatory values: ≥ 1.0 — the array includes cases when regulatory values are exceeded ≤ 1.0 — sub-threshold values prevail in the array (Aivazyan et al., 1989; Gnedenko et al., 1965).

In **Table 5**, along with the absolute mean (background) values of turbidity and water color index (line 2), composite estimates are shown (line 3). It can be seen that the composite indices of turbidity and water color index and the total index (0.490 ± 0.1, 0.137 ± 0.04, and 0.344 ± 0.02) are less than 1.0 relative units.

Therefore, the regulatory values of turbidity and water color index are not exceeded, and no such cases are expected. If relevant data are available, the same calculations can be performed for other organoleptic characteristics.

As for odor, the composite index was not calculated due to the highly monotonous series, all the more so as no cases when regulatory values are exceeded were observed.

Table 6 presents the actual and composite estimates for the concentration of residual ions in water. It can be seen that regulatory values in terms of the mean values and composite estimates were not exceeded (0.917 ± 0.014 for silver and 0.137 ± 0.04 for copper, respectively).

The total composite estimates for all four reliability characteristics (two organoleptic and two ionic) are shown in **Table 7.** The total composite estimate calculated for a sample of 594 reports is equal to 0.904 units, which indicates that there were no cases when regulatory values were exceeded in the analyzed set of 594 “regulatory value – actual value” pairs.

The method used to obtain composite estimates confirms the conclusions previously made, indicating no cases when regulatory values were exceeded in terms of organoleptic and ionic criteria. The values of the composite indices show that such cases cannot be possibly observed.

Conclusions

The paper addressed procedures to analyze and determine the safety and reliability of small-scale units producing disinfection solutions to ensure optimal swimming conditions in swimming pools.

We studied AE-1 units for the synthesis of oligodynamic solutions, used for water disinfection in swimming pools of any type. Their operation is based on silver and copper electrolysis, since the ions of these metals have a bactericidal effect. As compared with other units (UV, ozone, and other oxidation systems) and methods of water treatment (chlorination), the units under consideration have a number of advantages: for instance, they form solid copper-coagulated compounds (that can be easily removed from water) with amines introduced into the pool basin by swimmers; there are no chemical transformations of disinfection agents as in the case of chlorination, etc.

We performed the statistical analysis of five-year laboratory studies on the water in six pools equipped with synthesis units, which showed that the criteria of hygienic reliability are as follows:

- microbiological criterion (qualitative), which requires that there shall be no positive results in the detection of indicative microflora during the entire period of operation;
- organoleptic criterion (turbidity, water color index, and odor), which requires that

Table 5. Composite estimates for hygienic characteristics of organoleptic indicators

Indicator	Turbidity	Water color index	Total index
1	*2*	*3*	*4*
Regulatory value	NMT ≥ 2.0 mg/l	NMT ≥ 20 color degrees	X
Absolute value	0.404 ± 0.1	2.4 ± 0.02	X
Composite index	0.490 ± 0.1	0.137 ± 0.04	0.344 ± 0.02

Table 6. Composite estimates for background silver and copper concentrations

Indicator	Concentration	
	Silver	Copper
1	*2*	*3*
Maximum allowable concentration, mg/l	0.05	1.0
Absolute value	0.21 ± 0.01	0.73 ± 0.01
Composite index	0.92 ± 0.01	0.14 ± 0.04

Table 7. Total composite estimates for background indicators of organoleptic characteristics and mean silver and copper concentrations

Indicator name	Turbidity	Water color index	Silver	Copper	Total
1	*2*	*3*	*4*	*5*	*6*
Absolute value	0.4 ± 0.1	2.4 ± 0.02	0.21 ± 0.01	0.73 ± 0.01	X
Composite index	0.5 ± 0.1	0.14 ± 0.04	0.92 ± 0.01	0.14 ± 0.04	0.904

regulatory values shall not be exceeded during the entire life cycle of the facility;
- sanitary and chemical (ionic) criterion, which requires that silver and copper concentrations shall not exceed the MAC levels during the entire period of AE-1 unit operation.

The hygienic safety of the units is determined by zero cases when regulatory values are exceeded. For instance, the analysis of 143 reports over five years showed the following mean concentrations (Table 6, at the following MAC levels: silver — NMT ≥ 0.05 mg/l in terms of the sanitary and toxic index, copper — NMT ≥ 1.0 mg/l in terms of the organoleptic index):

• silver — 0.0005 (minimum), 0.024 (mean), 0.224 (maximum);

• copper — 0.001 (minimum), 0.221 (mean), 0.92 (maximum).

The indicated mean ion concentrations based on the statistics of laboratory analyses can be considered temporary reference points that can be used for water quality control in the pool basin.

The results of the statistical analysis of laboratory control indicators in a random sample of reports with the use of six AE-1 units for the synthesis of oligodynamic solutions over five years and calculations of ion intake from pool water indicate their sufficient efficiency as well as hygienic safety and reliability in terms of requirements of Articles 18, 19, and 24 of Federal Law No. 52-FZ dated March 30, 1999 (State Duma of the Russian Federation, 1999).

References

Adelshin, A. B. and Leonteva, S. V. (2011). The main technological parameters influenced on selection of water-conditioning scheme of swimming-pools. *News of the Kazan State University of Architecture and Engineering*, Issue 3 (17), pp. 114–121.

Aivazyan, S. A., Buchstaber, V. M., Yenyukov, I. S., and Meshalkin L.D. (1989). *Applied statistics. Classifications and reduction of dimensionaility.* Moscow: Finansy i Statistika, 607 p.

Allen, J. M., Plewa, M. J., Wagner, E. D., Wei, X., Bollar, G. E., Quirk, L. E., Liberatore, H. K., and Richardson, S. D. (2021). Making swimming pools safer: does copper–silver ionization with chlorine lower the toxicity and disinfection byproduct formation? *Environmental Science & Technology*, Vol. 55, Issue 5, pp. 2908–2918. DOI: 10.1021/acs.est.0c06287.

AQUA-EFFECT Research and Innovation Enterprise (2015a). *Units for the synthesis of oligodynamic solutions. Specifications TU 361469-001-30917173-2015.* Kirov: AQUA-EFFECT.

AQUA-EFFECT Research and Innovation Enterprise (2015b). *Operation manual for the AE-1 unit for the synthesis of oligodynamic solutions*. Kirov: AQUA-EFFECT.

Carter, R. A. A. and Joll, C. A. (2017). Occurrence and formation of disinfection by-products in the swimming pool environment: a critical review. *Journal of Environmental Sciences*, Vol. 58, pp. 19–50. DOI: 10.1016/j.jes.2017.06.013.

Cherkasova, O. A. (2007). The influence of the quality of swimming pools water on the health of their visitors. *Vestnik of Vitebsk State Medical University*, Vol. 6, No. 4, pp. 148–155.

Chief Public Health Officer of the Russian Federation (2001). *Sanitary Rules SP 1.1.1058-01. Arrangement and assurance of in-process control over compliance with sanitary regulations and the implementation of sanitary and epidemic control (preventive) measures.* [online] Available at: https://docs.cntd.ru/document/901793598 [Date accessed 15.02.2022].

Chief Public Health Officer of the Russian Federation (2020). *Sanitary Rules SP 2.1.3678-20. Sanitary and epidemiological requirements for the operation of premises, buildings, structures, equipment, and transport, as well as conditions for the operation of economic entities selling goods, performing works, or rendering services.* [online] Available at: https://docs.cntd.ru/document/573275590?marker=6560IO [Date accessed 07.06.2022].

Chief Public Health Officer of the Russian Federation (2021). *Sanitary Rules and Regulations SanPiN 1.2.3685-21. Hygienic standards and requirements for ensuring safety and/or harmlessness of environmental factors for humans.* [online] Available at: https://docs.cntd.ru/document/573500115 [Date accessed 24.03.2022].

Firuzi, P., Asl Hashemi, A., Samadi Kafil, H., Gholizadeh, P., Aslani, H. (2020). Comparative study on the microbial quality in the swimming pools disinfected by the ozone-chlorine and chlorine processes in Tabriz, Iran. *Environmental Monitoring and Assessment*, Vol. 192, Issue 8, 516. DOI: 10.1007/s10661-020-08470-4.

Förster, E. and Rönz, B. (1983). *Methods of correlation and regression analysis. A guidebook for economists.* Moscow: Finansy i Statistika, 302 p.

Gnedenko, B. V., Belyaev, Yu. K., and Solovyov, A. D. (1965). *Mathematical methods in the theory of reliability.* Moscow: Nauka, 524 p.

Karataev, O. R. (2009). The comparative assessment of chlorinating preparations in swimming-pools water processing. *News of the Kazan State University of Architecture and Engineering*, Issue 1 (11), pp. 221–225.

Krasovsky, V. O., Yakhina, M. R., and Belyaev, A. N. (2020). About advantages of the oligodynamic method disinfectings of water of swimming pools. *National Science Journal*, No. 62-3, pp. 16–20.

Krasovsky, V., Yakhina, M., and Belyaev, A. (2021). Water purification of swimming pools cations copper and silver and their improving effect (short state-of-the-art review of literature). *The Scientific Heritage*, No. 58-2, pp. 19–28. DOI: 10.24412/9215-0365-2021-58-2-19-28.

Liu, X., Chen, L., Yang, M., Tan, C., and Chu, W. (2020). The occurrence, characteristics, transformation and control of aromatic disinfection by-products: a review. *Water Research*, Vol. 184, 116076. DOI: 10.1016/j.watres.2020.116076.

State Duma of the Russian Federation (1999). *Federal Law No. 52-FZ on the sanitary and epidemiological welfare of population, dated March 30, 1999 (amended as of July 2, 2021).*

State Duma of the Russian Federation (2002). *Federal Law No. 184-FZ on technical regulation, dated December 27, 2002.* [online] Available at: https://docs.cntd.ru/document/901836556 [Date accessed April 28, 2019].

Technical Committee for Standardization (1998). *State Standard GOST R 51232-98. Drinking water. General requirements for organization and quality control methods.* Moscow: Gosstandart Rossii, 18 p.

Tul'skaya, E. A. (2012). Comparative safety of water disinfection means. *Public Health and Life Environment*, No. 11 (236), pp. 22–24.

Voznaya, N. F. (1967). *Water chemistry and microbiology*. Moscow: Vysshaya Shkola, 324 p.

Wyczarska-Kokot, J., Lempart-Rapacewicz, A., Dudziak, M., and Łaskawiec, E. (2020). Impact of swimming pool water treatment system factors on the content of selected disinfection by-products. *Environmental Monitoring and Assessment*, Vol. 192, Issue 11, 722. DOI: 10.1007/s10661-020-08683-7.

Zhang, D., Dong, S., Chen, L., Xiao, R., and Chu, W. (2022). Disinfection byproducts in indoor swimming pool water: Detection and human lifetime health risk assessment. *Journal of Environmental Sciences*, in press. DOI: 10.1016/j.jes.2022.05.003.

ОЦЕНКА ЭФФЕКТИВНОСТИ УСТАНОВОК СИНТЕЗА ОЛИГОДИНАМИЧЕСКИХ РАСТВОРОВ В ТЕХНОЛОГИИ ВОДОПОДГОТОВКИ

Андрей Николаевич Беляев[1], Елена Владиславовна Куц[2]*, Владимир Владимирович Шабалин[2]

[1]Вятский государственный университет
ул. Московская, 36, Киров, Россия
[2]Санкт-Петербургский государственный архитектурно-строительный университет
2-ая Красноармейская ул., 4, Санкт-Петербург, Россия

*E-mail: kouts@yandex.ru

Аннотация

Сокращение пригодной для целей водоснабжения пресной воды, связанное в первую очередь с производственной деятельностью, обуславливает необходимость использования замкнутых циклов водообеспечения объектов гражданской инфраструктуры. При этом качество воды должно соответствовать требованиям к её использованию для различных целей. Общеизвестна роль воды в обеспечении здоровья населения и создании санитарных условий его жизнедеятельности. Поэтому вопросам исследования методов водоподготовки уделяется большое внимание. Процесс обеззараживания воды относится к обязательным методам, применяемым в очистке и водоподготовке. Основной применяемой технологией для обеззараживания воды продолжает оставаться хлорирование несмотря на то, что является причиной токсического, канцерогенного и других видов негативного воздействия на организм человека. Использование олигодинамических растворов – одно из новых и активно развивающихся направлений в системах водоподготовки. В статье рассмотрен метод обеззараживания воды плавательных бассейнов с использованием установок олигодинамического синтеза, а также проведено исследование результатов анализа показателей качества обработанной воды. **Методы:** Исследования базируются на методах статистического анализа показателей качества воды бассейнов с обработкой ионами серебра и меди, который позволяет охарактеризовать гигиеническую безопасность и надежность продукции для здоровья пользователей. Гигиеническая надёжность и безопасность оценивается составом и свойствами производимого продукта (олигодинамический раствор), составом и содержанием примесей в воде в бассейне, сохранением обеззараживающих свойств воды и исключением ситуаций повышенных уровней ионов меди и серебра (превышение ПДК) в воде бассейна. **Результаты:** В работе обоснованы методические приёмы анализа и прогноза соответствующей надёжности и безопасности малогабаритных установок, производящих дезинфицирующие растворы для обеспечения оптимальных условий занятий плаванием пользователей бассейнов. **Обсуждение:** Полученные результаты обосновывают целесообразность использования олигодинамической обработки воды для обеспечения гигиенической надежности и безопасности плавательных бассейнов. Предлагаемая технология полностью обеспечивает требования санитарных регламентов по качеству воды.

Ключевые слова

Показатели качества воды, олигодинамические растворы, установки олигодинамического синтеза, гигиеническая безопасность и надежность.