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ASSESSMENT OF KEY APPROACHES TO THE HYGIENIC REGULATION OF BIOCIDAL PRODUCTS FOR WATER TREATMENT IN THE EU AND UKRAINE

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THE OBJECTIVE of this study was to analyze the key approaches to the hygienic regulation of biocidal products for water treatment in the EU and Ukraine to prevent their adverse effects on human health. The study graphically presents the classification of biocides used for water treatment, outlines challenges in implementing European requirements for their hygienic regulation and highlights the necessity of defining safe and optimal conditions for their use. It concludes that it is currently relevant to improve Ukrainian legislation concerning the procedure for the state registration of biocidal products, taking into account the requirements of EU Regulation No. 528/2012 of 22 May 2012 on the making available on the market and use of biocidal products — particularly those intended for drinking water treatment — and the quality standards for drinking water under Directive 2020/2184/EU on the quality of water intended for human consumption. These improvements will contribute to the implementation of stricter requirements for the composition and properties of biocidal products for water treatment, promote the dissemination of more efficient water purification technologies, reduce microbiological risks, and protect human health.

KEYWORDS: *water purification, algaecides, disinfectants, drinking water.*

ОЦІНКА ОСНОВНИХ ПІДХОДІВ ДО ГІГІЄНІЧНОЇ РЕГЛАМЕНТАЦІЇ БІОЦИДНИХ ПРОДУКТІВ ДЛЯ ОБРОБКИ ВОДИ В КРАЇНАХ ЄС ТА УКРАЇНІ

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МЕТОЮ ДОСЛІДЖЕННЯ було провести аналіз основних підходів до гігієнічної регламентації біоцидних продуктів для обробки води з метою попередження їх негативного впливу на здоров'я людей в країнах ЄС та Україні. У роботі графічно представлена класифікація біоцидів для обробки води, описано проблеми у аспекті впровадження європейських вимог до їх гігієнічної регламентації та акцентовану увагу на необхідності визначення як безпечних, так і оптимальних умов їх використання. Зроблено висновок про те, що на сьогодні є актуальним удосконалити вимоги законодавства України із загального порядку державної реєстрації біоцидних продуктів, гігієнічної оцінки продуктів, що призначені для обробки питної води, вимог до якості питної води з врахуванням європейських підходів (Регламенту (ЄС) № 528/2012 від 22 травня 2012 року щодо забезпечення доступності на ринку та використання біоцидних продуктів, Директиви 2020/2184/ЄС щодо якості води, призначеної для споживання людиною). Зазначене сприятиме впровадженню жорсткіших вимог до складу та властивостей біоцидних продуктів для обробки води, а також поширенню ефективніших технологій водоочищення з метою зниження мікробіологічних ризиків і захисту здоров'я людей.

КЛЮЧОВІ СЛОВА: *водоочищення, альгіциди, дезінфікуючі засоби, питна вода.*

INTRODUCTION

Drinking water often requires effective treatment with biocidal products, the selection of which depends on the water's composition and type, treatment conditions, target water quality, required efficacy, the risk of by-product formation, the volume of water to be treated, and associated costs [1, 2]. Biocidal products used for water treatment primarily include algaecides and disinfectants.

Algaecides are chemical substances used to control various types of aquatic vegetation in pools, ponds, aquariums, and similar environments. According to EU Regulation No. 528/2012 of 22 May 2012 on the availability and use of biocidal products [3], algaecides fall under main group 1 — disinfectants, product-type 2 — disinfectants and algaecides not intended for direct application to humans or animals. These products are more effective when used in combination with other agents, such as chlorine, bromine, or active oxygen for pool water disinfection. Algaecides disrupt the cell structures of cyanobacteria (e.g., membranes and enzyme systems), suppressing their life cycle. This enhances the effectiveness of subsequent disinfectant action, such as that of chlorine, which ultimately eliminates unwanted microorganisms. The combined use of algaecides and disinfectants creates a synergistic effect, contributing not only to the efficient suppression of algae but also providing antimicrobial activity, particularly against viruses and bacteria.

The most common algaecides are based on copper sulfate and quaternary ammonium compounds. The most used disinfectants are chlorine-based formulations. In Ukraine, as in most EU countries, chlorination is the primary method used for treating drinking water, either alone or in combination with other methods (ozonation, ultraviolet irradiation, potassium permanganate, ultrafiltration). Alternatives include chloramination and chlorine dioxide treatment [4]. Compared to chlorine, chlorine dioxide offers several advantages [5, 6], including greater bactericidal, virucidal, and protozoocidal activity. However, it also presents drawbacks: disinfection by-products such as toxic chlorites and chlorates may form in treated water, which, if present above permissible levels, require specific mitigation measures.

In general, biocidal products may exhibit varying levels of toxicity depending on their composition, concentration, and application method. Their use — either during or after application — can pose risks to human health and therefore requires specific handling and disposal instructions [7–9]. Given this, advancing scientific research into the hygienic regulation of biocidal products for water treatment is a public health priority.

The objective of this study was to analyze the key approaches to the hygienic regulation of biocidal products for water treatment in the EU and Ukraine to prevent their adverse effects on human health.

MATERIALS AND METHODS

To assess health risks, the study analyzed the requirements of European legislation (EU Regulation No. 528/2012 of 22 May 2012 concerning the market availability and use of biocidal products [3]) and Ukrainian legislation related to the general procedure of state registration of biocidal products. A comparative evaluation was performed between the requirements of Directive 2020/2184/EU on the quality of water intended for human consumption [1] and national regulatory acts from 22 EU countries regarding drinking water standards.

To identify safety criteria for the use of disinfectants and to establish a balance between microbiological and chemical risks, we analyzed the results of a field experiment conducted at the chemical laboratory of the Dnipro Water Treatment Plant in Kyiv. The research was carried out using standard laboratory methods. The composition of drinking water in the distribution network was assessed daily based on sanitary-chemical and microbiological parameters from 2021 to April 2023. Reagent dosages (chlorine dioxide, ferrous chloride, aluminum sulfate, and an anionic flocculant based on polyacrylamide) were also determined once per day. Chlorine dioxide was dozed twice (before the mixer and after rapid filters). An Italian-made T70 G 4000 series generator was used for producing chlorine dioxide from sodium chlorite and hydrochloric acid. The system operated in an automated mode using proportional generation and dosing based on water flow rates (see *Fig. 1*).

The following research methods were applied in this study: comparative analysis, analytical methods, risk assessment, chemical, microbiological, and mathematical methods.

RESULTS

Based on their chemical nature and mechanism of action, biocidal products used for water treatment (algaecides and disinfectants) can be classified into two main types: oxidizing and non-oxidizing agents. Among algaecides, some function by altering the water's acidity (pH regulators), while others act as metabolic inhibitors that disrupt algal life processes, leading to their elimination. Biocidal products of natural origin can also be included in this category — for example, pine extract, which biologically suppresses the growth of algae and microorganisms.

Almost all disinfectants used for water treatment can also serve as algaecides. These include chlorine dioxide, ozone, sodium or calcium hypochlorite, and monochloramine, among others (see *Fig. 2*).

According to Regulation (EU) No. 528/2012 of 22 May 2012 on the making available on the market and use of biocidal products [3], and Directive 2020/2184/EU on the quality of water intended for human consumption [1], all products intended for the treatment of drinking water must undergo a specific evaluation based on established criteria.

There are several key methods for studying the properties of biocidal products for water treatment, which can be conventionally divided into:

- *Laboratory methods* (determining composition, characteristics, and properties, including efficacy according to approved protocols),
- *Field methods* (or operational/production testing),
- *Combined methods* (where laboratory tests help select the most effective biocide and field tests define its optimal concentration).

As of today, hygienic evaluation of biocidal products for water treatment through laboratory testing

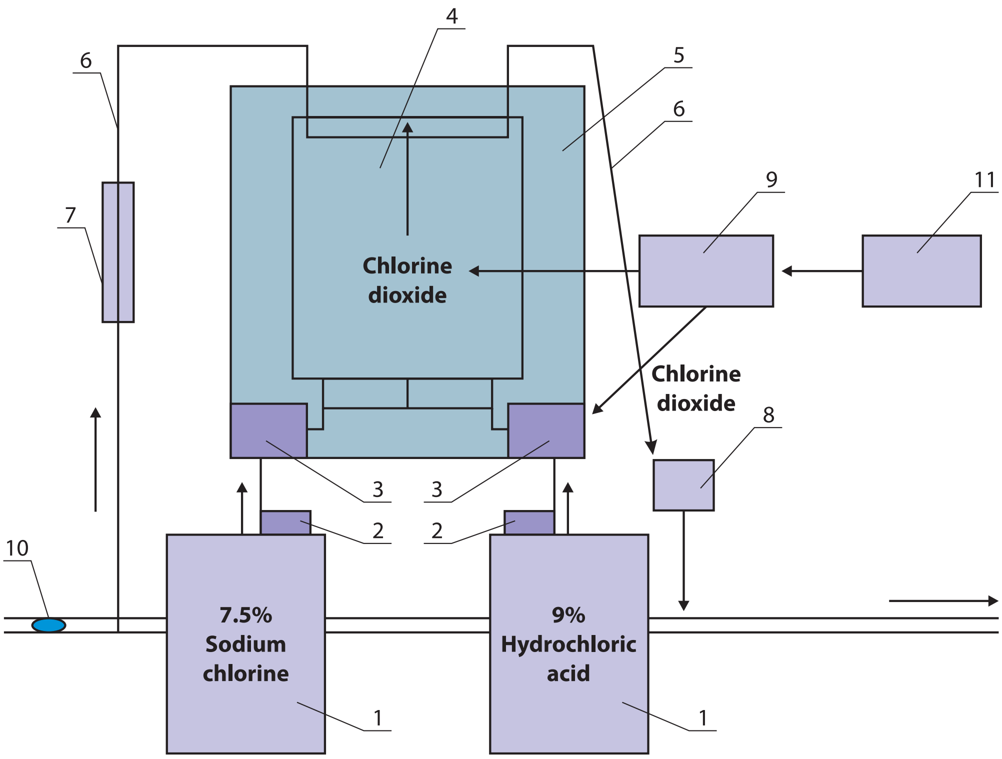

Fig. 1. Schematic diagram of the chlorine dioxide (ClO_2) production process using the T70 G 4000 series generator: *1* — reagent tanks; *2* — tank sensors; *3* — dosing pumps; *4* — ClO_2 generator; *5* — wall-mounted control panel; *6* — bypass line; *7* — rotameter; *8* — device for injecting ClO_2 solution into the water stream; *9* — microprocessor control unit; *10* — flow meter; *11* — ClO_2 concentration sensor in water; *12* — pipeline for supplying ClO_2-treated water into the water conduit.

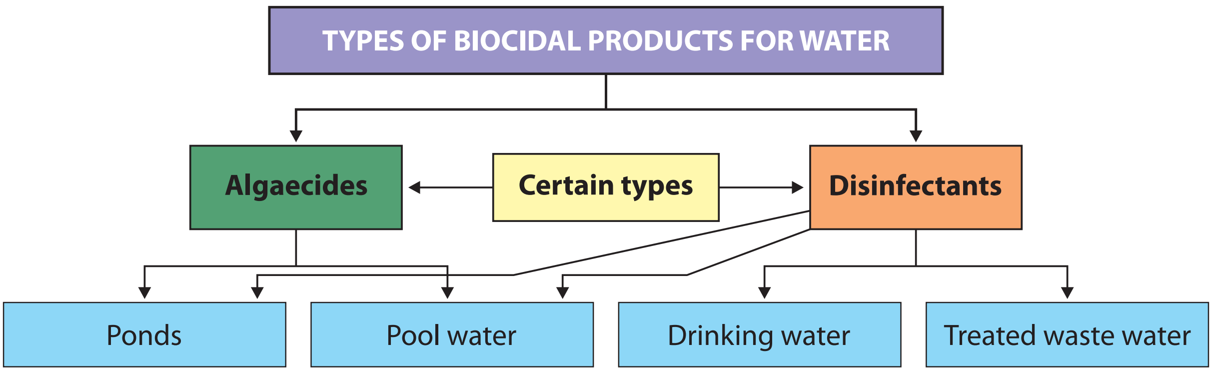

Fig. 2. Types of biocidal products for the treatment of water with which humans directly come into contact

is not conducted in Ukraine, and state registration of such products is not implemented. Instead, the properties of disinfectants used in water treatment are assessed through in situ experiments at water treatment facilities. During such studies, drinking water is analyzed for microbiological indicators, residual disinfectant concentrations (*Table 1*) [7], and disinfection by-products (*Table 2*).

As can be seen from *Tables 1* and *2*, the drinking water quality requirements in Ukraine are, for most indicators, stricter or equivalent to those approved in EU countries. Two indicators related to the content of disinfection by-products are present in Directive 2020/2184/EU on the quality of water intended for human consumption [1] but are absent from the Ukrainian national standard for drinking water (DSanPiN 2.2.4-171-10 [10]).

To ensure compliant drinking water quality, each water supply enterprise in Ukraine develops an individual treatment technology. For example, at the Dnipro Water Treatment Station in Kyiv, approximately 300,000 m^3 of water are treated daily using facilities such as a mixer, horizontal sedimentation tank with integrated reaction cham-

Table 1. **Permissible Residual Levels of Disinfectants in Ukraine and EU Countries According to National Regulatory Standards**

Disinfectants	Sampling Points	Compound Type	Permissible Levels, mg/L	
			Ukraine*	EU countries**
Chlorine-based	After disinfection	Free	≥ 0,3 ≤ 0,5 (after 30 min contact)	≥ 0,1 ≤ 1,0 (after 30 min contact)
		Combined	≥ 0,8 ≤ 1,2 (after 60 min contact)	—
	Consumer tap water	Free	≤ 0,5	≤ 0,05–1,0 (≥ 0,2 ≤ 0,6 — Portugal)
		Combined	≤ 1,2	≤ 2,0-3,0
		Total	—	≤ 0,5
Chlorine dioxide	After disinfection	—	≥ 0,1 (after 30 min contact)	—
	Consumer tap water	—	≥ 0,1	— (≤ 0,2 — Slovakia) (≥ 0,1 ≤ 0,4 — Portual)
Ozone	After disinfection	—	0,1–0,3 (after 4 min contact)	—
	Consumer tap water	—	—	≤ 0,05

Notes: * According to State Sanitary Rules and Regulations (DSanPiN) 2.2.4-171-10 [10]. ** Based on aggregated data from the regulatory documents of 22 EU countries regarding the quality of water intended for human consumption. Directive 2020/2184/EU on the quality of water intended for human consumption [1] does not establish parametric values for the indicators listed in the table (chlorine, chlorine dioxide, and ozone).

Table 2. **Requirements of Directive 2020/2184/EU [1] and Ukraine's DSanPiN 2.2.4-171-10 [10] Regarding Disinfection By-products in Tap Water**

Indicator	Permissible Levels		
	Ukraine	EU CountriesЄС	Directive 2020/2184/EU
Sum of Trihalomethanes (THMs), μg/l	≤ 100	≤ 30-100	≤ 100
Chloroform, μg/l	≤ 60	— (≤ 30 — Czech Republic)	—
Dibromochloromethane, μg/l	≤ 10	—	—
Bromates, mg/l	—	≤ 0,01	≤ 0,01
Chlorites, mg/l	≤ 0,2	≤ 0,05-0,7	≤ 0,25 (0,7)**
Chlorates, mg/l	≤ 20*	≤ 0,05-0,7	≤ 0,25 (0,7)**
Sum of Chlorites and Chlorates, mg/l		— (≤ 0,05 — Denmark, ≤ 0,25 — Czech Republic, ≤ 0,7 — Poland)	
Haloacetic Acids, μg/l	—	≤ 60	≤ 60

Notes: * According to the «Hygienic Standards for Water Quality of Surface Water Bodies Used for Drinking, Domestic and Other Needs of the Population», approved by Order of the Ministry of Health of Ukraine No. 721 dated May 2, 2022, and registered with the Ministry of Justice of Ukraine on May 16, 2022, No. 524/37860 (as per section 3.6 of the State Sanitary Rules and Regulations DSanPiN 2.2.4-171-10 [10], the requirements of this document apply to drinking water quality). ** The parametric value of 0.70 mg/l should be applied when the disinfection method used results in the formation of chlorite, such as chlorine dioxide. Where it is feasible and without compromising disinfection efficacy, EU Member States should strive for lower levels.

ber, rapid sand filter, and clean water reservoir. The applied treatment methods include oxidation, coagulation, flocculation, and final disinfection.

Our research conducted at the Dnipro Water Treatment Station (Kyiv, Ukraine) during 2021–2023 shows that the disinfection technology introduced in 2020 — which includes dual chlorine dioxide treatment (*Fig. 3*), ferric chloride ($FeCl_2$) dosing to minimize chlorite levels in drinking water (average coagulant-to-chlorine dioxide dose ratio ~15:1), aluminum sulfate, and sodium hypochlorite in the distribution network during warm periods — has enabled the facility to abandon the use of liquid chlorine with pre-ammonization.

Thus, when chlorine dioxide is applied in the initial stage of drinking water treatment, the potential health risk from its use depends significantly on the subsequent stages of reagent-based treatment.

According to mathematical modeling of chlorite formation in the distribution network of the Dnipro Water Treatment Station (*Fig. 3*), the risk of chlorite occurrence remains within an acceptable level (≤1.0) when the total chlorine dioxide dose does not exceed 3.5 mg/l, and the hygienic standard for chlorites is ≤0.2 mg/l (*Table 2*). If the hygienic standard for chlorites is increased to ≤0.7 mg/l (*Table 2*), the risk of exceeding permissible levels in drinking water significantly decreases — to 0.4 (*Fig. 4*) [11].

This indicates that the use of biocidal products for water treatment requires a thorough understanding of potential human health risks, to maintain a balance between microbiological and chemical hazards that may arise during storage, transportation, application, and from subsequent human exposure to treated water.

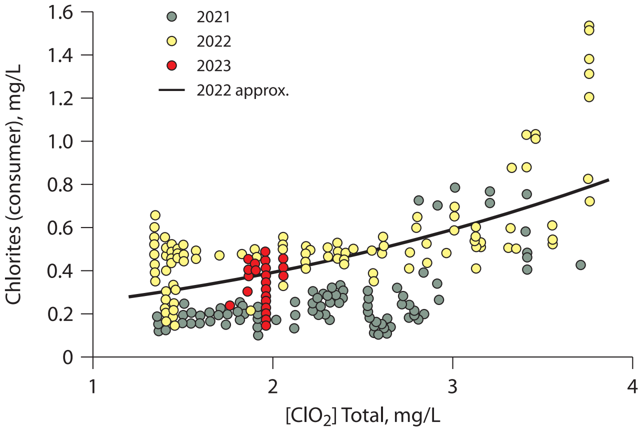

Fig. 3. Relationship Between Chlorite Concentration in the Distribution Network Water and the Total Chlorine Dioxide Dose [11]

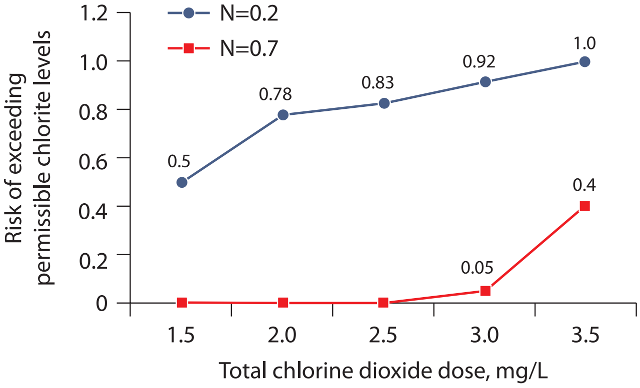

Fig. 4. Relationship Between the Risk of Exceeding Permissible Chlorite Levels in Distribution Network Water and the Total Chlorine Dioxide Dose [11]

CONCLUSIONS

1. At present, it is necessary to improve Ukrainian legislation concerning the state registration of biocidal products intended for water treatment, including their hygienic and toxicological evaluation — particularly the assessment of all potential risks to human health. It is also necessary to revise drinking water quality standards in line with European legislation to clarify the rules for biocide use. These measures would facilitate the implementation of stricter requirements for the composition and properties of water-treatment biocides and promote the adoption of more effective purification technologies aimed at reducing both microbiological and chemical risks and protecting public health.

2. Prior to their use in drinking water supply systems, biocidal products must undergo laboratory testing to determine their composition, characteristics, properties, and effectiveness (for commercial products), as well as long-term field testing — including during the warm season — to establish optimal and safe conditions for their application with respect to human health protection.

3. The level of health risks associated with the use of biocidal products in water treatment may depend on the composition and properties of the biocides, their storage duration and conditions, specific application practices, the chemical makeup of the treated water, and the nature of its subsequent treatment, transport, and storage.

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Автори заявляють про відсутність конфлікту інтересів.

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CONFLICT OF INTEREST

The authors declare the absence of a conflict of interest.

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