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RESEARCH ARTICLE

STUDY OF THE PROCESS OF DESTRUCTION OF HARMFUL MYCOBACTERIA IN SURFACE WATER WITH ENVIRONMENTAL PROBLEMS USING OZONE TECHNOLOGY

Askar Abdykadyrov[a,b], Palvan Kalandarov[b], Sunggat Marxuly[a*], Aruzhan Sabyrova[c], Kanat Zhunusov[a*], Anar Khabay[a], Nurzhigit Smailov[a], Alisher Terek[a]

[a]Department of Electronics, Telecommunications and Space Technologies, Satbayev University, Almaty, Kazakhstan.
[b]Department of Automation and Control of Technological Processes and Production, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers Tashkent, Uzbekstan;
[c]Department of Automation and Control, Almaty University of Power Engineering and Telecommuni-cations named after G.Daukeev, Almaty, Kazakhstan;
**Corresponding Author's E-mail: Sungat50@gmail.com*

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ABSTRACT

The scientific research work is based on the process of destroying harmful microbacteria in surface water with the help of ozone technology, which are exposed to environmental problems. In general, this research paper carried out a comprehensive review of the literature published in scientific journals in the world in recent years on the process of neutralizing surface waters with traditional disinfectant reagents, which are subject to environmental problems. For example, we have highlighted the disadvantages and advantages of oxidizing agents and disinfectant reagents such as chlorine (Cl), chloramin (NH2Cl), chlorine dioxide (ClO2), ozone (O3) and ultraviolet (UV). However, among these reagents, considering the advantages of ozone technology, according to the research work, there is a special Current to ozone technology. The scientific novelty of the research work was the creation of a modern ozonator unit Etro – 02 based on an electric corona discharge with a frequency of 13 kHz, a voltage of 21 kV. For testing the installation, surface water was taken from the Kapshagai and Vyacheslav reservoirs, where aranai was exposed to environmental problems, and expert samples were carried out. The number of microbiological indicators that do not meet the standards found in the composition of water is as follows: total number of microbes 130-160 (1 ml of CFU (Colony-forming unit)), TCB (Thermotolerant coliform bacteria) 270-370 (100 ml of CFU), CCB (Common Coliform Bacteria) 650-800 (100 ml of CFU), coliphages 135-170 (100 ml of PFU (plaque - forming units)). To completely neutralize and clean these bacteria, the amount of ozone consumed per 1m3 of water was enough for 0.5 – 0.8 g/hour of ozone. And it turned out that the decontamination time will be enough 20 – 25 minutes. In addition, the obtained data were used to compile a mathematical model using the programs "Mathcad 14" and "SMath Solver".

KEYWORDS

Electric discharge, ozone, UV radiation, primary water, purified water, sorption.

1. INTRODUCTION

Depending on the human development strategy, it is estimated that by 2030 and 2040, water reserves in 167 countries will be 40% less than today (World Economic Forum, 2022). According to such statistics, water scarcity can have a negative impact on overall economic development (Maddocks et al., 2015). This issue is also relevant for Kazakhstan. After all, in the 1950s in Kazakhstan 120 billion. there are about 100 billion cubic meters of water reserves. there are also assumptions that the Cube was reduced to a meter (UN., 2022). This is because drinking water is obtained in most cases through surface reservoirs. Therefore, it is necessary to protect the environment and restore resources (Estévez et al., 2022). One of the reservoirs affected by environmental problems is Kapshagai and Vyacheslav reservoir (KZ News, 2022). On the shore of the kapshagai reservoir is the "training and drilling test site" of the Satbayev University. Due to the scarcity of drinking water in the landfill, surface water is used for drinking purposes. The content of harmful microbacteria in water is higher than the maximum permissible concentration (MPC) established by sanitary rules and norms [Ministry of Justice of the Republic of Kazakhstan, 2015; Siberian Ecology company, 2022). For example, the total number of microbes (TNM) i.e. the number of colony - forming bacteria in 1 ml 130 – 160 met. Modern articles on the effectiveness of the destruction of such harmful bacteria are currently published in foreign and domestic publications. For example, the effectiveness of technologies for disinfection of harmful bacteria in water by chlorine, ozone and ultraviolet rays is being considered (Diana and Yuly, 2021). However, these mentioned reagents have their own advantages and disadvantages (Figure 1) (Novikov and Prodous, n.d)

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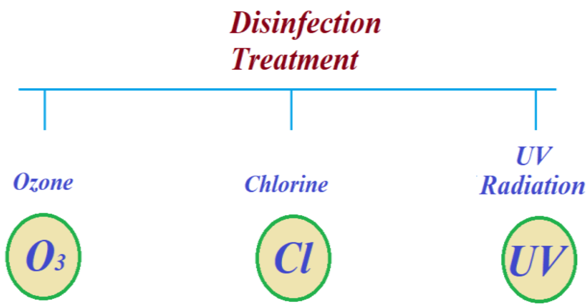


Figure 1: The main types of water disinfection methods

1.1 Chlorination of water

Advantages: effective against many types of microorganisms, widely used in large water treatment systems (Novikov and Prodous, n.d.; Limarenko and Novikov, 2014)

Disadvantages: chlorides and trichloromethane can form, which are dangerous to health. The taste and smell of chlorine in the water will appear (Limarenko and Novikov, 2014).

1.2 UV light treatment

Advantages: effective against bacteria, viruses and simple organisms without chemical additives. Does not change the chemical composition of water (Seleznev et al., 2007).

Disadvantages: does not remove particles and toxins, requires electricity and is effective only under direct radiation.

1.3 Ozone disinfection

Advantages: Ozone is effective against bacteria, viruses, fungi and organic pollution (Dan Kroll, 2007; Draginsky et al., 2007). Leaves no residue in the water.

Disadvantages: ozone requires special equipment to produce. The formation of some nitrogen oxides is possible.

Water disinfection is selected depending on the scope of the task (Bakhir, 2003;2007). Also, by water content and quality requirements (Dan Kroll, 2007 Zheldakova and Tulskaya, 2010). Chlorination is suitable for large water systems, UV treatment is suitable for small water systems and home use, and ozone disinfection is more environmentally friendly than chlorine (Bonnelye and Richard, 1997).

In recent years, there has been significant research and notable advancements in plasma disinfection technologies (Takuya Kuwahara, 2018). Ozone (O_3) is an effective disinfectant in the process of destroying viruses among the reagents mentioned above (Figure 1) (Lin et al., 2007; Wigginton and John 2012). Therefore, it is widely used as a strong oxidizer of water. Ozone is usually formed in a cold plasma (NTP) with a dielectric barrier discharge from oxygen (O2) (Suan Tial and Mistugi, 2022). Therefore, when designing the design of ozonators, it is worth considering the cooling system of the electrodes in it. Considering the unique properties of ozone, we've embarked on a new ozonator project, with a keen focus on integrating ozone technology based on scientific research.

2. Materials And Methods

The elimination of harmful microbacteria contained in surface water, which are subject to environmental problems, by means of an electric discharge is currently under rapid development (Tian et al., 2015; Parpiev et al., 2021). Overall, surface water is vital for supporting life on Earth. However, the existence of microorganisms like bacteria and viruses can endanger human health (Bakhir 2003;2007). Utilizing ozone generated through electric discharge emerges as one of the most efficient methods for eradicating microorganisms in water. (Khainatsky et al., 2018; Abdelaziz, 2016). In a scientific study, we will consider the mechanisms of action of ozone, the tendency of its formation in an electric discharge, and also evaluate the effectiveness of this method in the destruction of microorganisms in water [24]. In order to effectively remove harmful microorganisms contained in water in general with ozone, it is advisable to first thoroughly analyze the solubility and self-distribution of ozone in water.

2.1 The solubility and self-distribution of ozone in water

As ozone dissolves in water, its concentration steadily rises until it reaches the required threshold for a specific condition (Egorova et al., 2015).

The solubility of ozone in water depends on different conditions, i.e. the volume of water (v_{oz}/v_w),), the temperature of the water (T,^{0}C) and the value of *pH* (Draginsky et al., 2007; Lunin, 2015). The concentration volume of dissolved ozone (measured in mg/l) in water is determined by the Bunsen coefficient. (Eike Breitbarth et al., 2004). At the same time, the tendency of ozone to dissolve in water can be explained by Henry's law, which is proportional to the pressure of dissolved ozone and gaseous ozone in solution (Egorova et al., 2015). This pattern is written as:

$$C = \beta \cdot \mathrm{M} \cdot \mathrm{P}\gamma, g/l \quad (1)$$

Where, C is the solubility of ozone in water, g/l; β —Bunsen coefficient, M is the density of ozone 2.14 g/l [16.31], Pγ – is the partial pressure of ozone in the melting gas medium.

The solubility of ozone in water is very high compared to oxygen and nitrogen in the atmosphere (Battino,1983; Wei et al., 2017). Its solubility property in water increases with a decrease in water temperature (Egorova et al., 2015). Such research works Horvath M.L., Bilitrki Land Hutter., W. J. Considered in the experimental research works of Masschelein and B. F. Kogan (Table 1) (Draginsky et al., 2007).

Table 1: Solubility property of ozone in water (Draginsky et al., 2007; Epelle et al., 2022).

T,^{0}C	According to the studies conducted by Horvath M.L., Bilitrki Land Hutter		Research by B. F. Kogan		Research by W. J. Masschelein	
	Solubility, g/l	β (l O_3/ l H_2O)	Solubility, g/l	β (l O_3/ l H_2O)	Solubility, g/l	β (l O_3/ l H_2O)
0	1,13	-	1,09	0,51	1,37	0,64
5	-	-	-	-	1,07	0,50
10	0,87	0,41	0,78	0,38	0,83	0,39
15	-	-	-	-	0,66	0,31
20	0,69	0,32	0,57	0,29	0,51	0,24
25	-	-	-	-	0,41	0,19
30	0,56	0,26	0,40	0,21	0,32	0,15
35	-	-	-	-	0,25	0,12
40	0,45	0,21	0,27	0,15	-	-
50	0,37	0,17	0,19	0,10	-	-

This can be seen from the experimental research work in Table 1 Above: as the water temperature (T,^{o}C) increases, the solubility of ozone in water (g/l) and the Bunsen coefficient β (l O_3/ l H_2O) decrease. Ozone is less soluble in acidic and salt water than in distilled water (Epelle et al., 2022). Sander R. on questions about the stability of Henry's law, from the research work, it was also considered in connection with *pH* (Sander, 2015). In this research paper, the change in Henry's constant due to *pH* at different temperatures can be expressed by the following equation.

$$ln\, H_a = 20.7 - \frac{3547}{T} \ (pH = during\ the\ 2\ )$$

$$\ln H_a = 18.1 - \frac{2876}{T}\ (pH = during\ the\ 7) \quad (2)$$

Where, H_a is the Henry coefficient at the molar amount of ozone; T is the absolute temperature (K). It is observed that at a temperature of 300 K or 27⁰C, the solubility property of ozone in water is very poor. That is, it is determined that LnH_a =8.9 at pH=2 and LnH_a =8.5 at pH=7 (Epelle et al., 2022; Sander, 2015).

During the dissolution of ozone in water, there is not only a tendency to react with chemical (Lim et al., 2022) substances present in the water, but also its own distribution (Yudianto et al., 2023). These two processes occur simultaneously and depend on the water temperature, pH environment (Sofia, 2020; Galdeano, 2018). At this point, it begins to affect microbiological indicators in drinking water (Sofia, 2020).

In general, the rate of propagation of ozone in water can be written as (Draginsky et al., 2007; Li et al., 2022).

$$\frac{-d[O_3]}{dt} = K_p \cdot [O_3] \quad (3)$$

where, K_p is the constant of the rate at which ozone is dissipated in water.

The quantitative characteristic and important feature of dissolved ozone to improve the process of decontamination and purification of surface waters can be seen in some studies (Jin et al., 2022):

$$O_3 + H_2O \rightarrow 2OH^* + O_2 \quad (4)$$

$$O_3 + OH^- \rightarrow O_2^{-*} + HO_2 \quad (5)$$

$$O_3 + OH^* \rightarrow O_2 + HO_2^* \Leftrightarrow O_2^{-*} + H^{\pm} \quad (6)$$

$$O_3 + HO_2^* \rightarrow 2O_2 + OH^* \quad (7)$$

$$2HO_2^* \rightarrow O_2 + H_2O_2 \quad (8)$$

This can be traced to the formation of the OH^* radical and hydrogen oxide from the above expressions.

The electrochemical decomposition of ozone by ozone occurs faster in an alkaline medium than in an acid (Bavasso et al., 2020), the rate of its dissolution under such conditions is expressed as:

$$\frac{-d[O_3]}{dt} = K_p[O_3] = K_a[OH^-]^{1/2} \cdot [O_3]^{3/2} \quad (9)$$

where, K_p and K_a are stability in a wide range of pH in water. The ionic strength of the stabilized phosphate buffer is 0.15(mole/m³) (Judah et al., 2020).

$$K_p = 5.43 \cdot 10^3 \exp\left(\frac{-4964}{T}\right) sec^{-1}; \quad (10)$$

$$K_a = 9.5 \cdot 10^{16} \exp\left(\frac{-10{,}1}{T}\right) l/mole.sec \quad (11)$$

the presence and tendency to decay of OH^- - ions at or below pH=3 does not matter. OH^- - ions have a faster tendency to dissolve in self - water in the region of a value of pH=7÷10. Most often, at such pH values, the ozone propagation time in water is taken into account as about 10 - 25 minutes (Von Sonntag et al., 2012).

Currently, the Staehelin et Hoigne scheme is a scheme that takes into account all the main trends in the dissolution of ozone in water (Figure 2) (Draginsky et al., 2007; Von Sonntag et al., 2012).

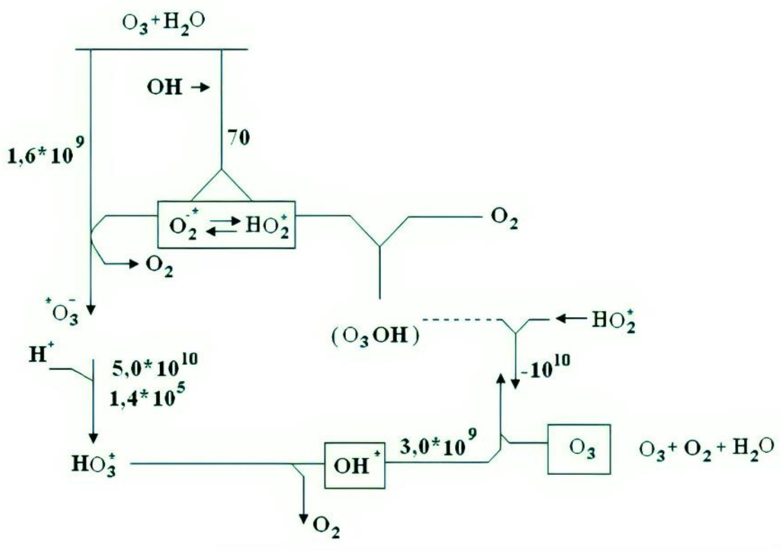


Figure 2: General cyclic scheme of ozone dissolution in water (Draginsky et al., 2007)

The ozone dissociation reaction and the mechanism of interaction with hydrogen at high temperatures hydrogen oxide can accelerate the reaction of self-decomposition of ozone, giving rise to intermediate radical parts (Jian et al., 2023; Yang et al., 2023).

$$H_2O_2 \Leftrightarrow H^+ + HO_2^- \quad (12)$$

$$HO_2^- + O_3 \rightarrow HO_2^* + O_3^* \quad (13)$$

The equilibrium constant is 11.6.

Various solutes interact with ozone and the OH^* radical, at which time the acceleration of the self-decomposition of ozone occurs (Guo et al., 2021).

$$HCOO^- + OH^* \rightarrow H_2O + COO^{-*} K = \quad 3 \cdot 10^9 mole^{-1} sec^{-1} \quad (14)$$

$$COO^{*-} + O_2 \rightarrow O_2^{-*} + CO_2 \quad (15)$$

Given the large number of water pollutants, understanding a fully accurate image of ozone dissolving in water is a difficult task (Abdykadyrov et al., 2023). There is a certain experimental assessment of the main ways of ozone dissolution. In the simplest case, half of the ozone is molecular, and the rest is transformed into OH^* radicals. However, the transformed OH^* radicals act on harmful microorganisms contained in water by different mechanisms.

2.2 Mechanisms of action of ozone by microorganisms

Ozone (O_3) in water is a powerful oxidizing agent capable of destroying the cellular structures of microorganisms (Abdykadyrov et al., 2023). In the process of introducing ozone into water, the oxidation of proteins, lipids and nucleic acids contained in water, as a result of which microorganisms are destroyed (Abdykadyrov et al., 2023; Rangel et al., 2021). This mechanism is an effective solution for disinfecting water with ozone. In general, the effectiveness of the destruction of harmful microorganisms contained in surface water is currently one of the most pressing problems (Gorito et al., 2021). However, in the data of recent scientific publications, the treatment of water with ozone based on an electric discharge provides a high degree of disinfection (Qasim et al., 2022). Efficiency in research work depends on parameters such as ozone concentration, processing time and characteristics of microorganisms (Tao et al., 2021, Xue et al., 2023). The high reactivity of ozone ensures the destruction of a wide range of pathogens, including bacteria, viruses and fungi (Rangel et al., 2021).

The tendency to remove microorganisms with ozone can expose water to oxidizing agents (Rangel et al., 2021; Xue et al., 2023). Which can also affect water quality. Therefore, it is important to balance the ozone concentration and monitor the quality of water after treatment (Spiliotopoulou et al., 2018).

A study of the process of destruction of microorganisms in water using ozone based on electric discharge shows the prospects for this method in ensuring the safety of Water Resources (Abdykadyrov et al., 2023; Qasim et al., 2022). Mechanisms of action and optimization of process parameters help to develop effective and sustainable methods of disinfection of water and other products in various situations (Botondi et al., 2023; Seridou and Kalogeraki, 2021). In general, below is a diagram of the mechanism of action of ozone by microorganisms (Figure 3).

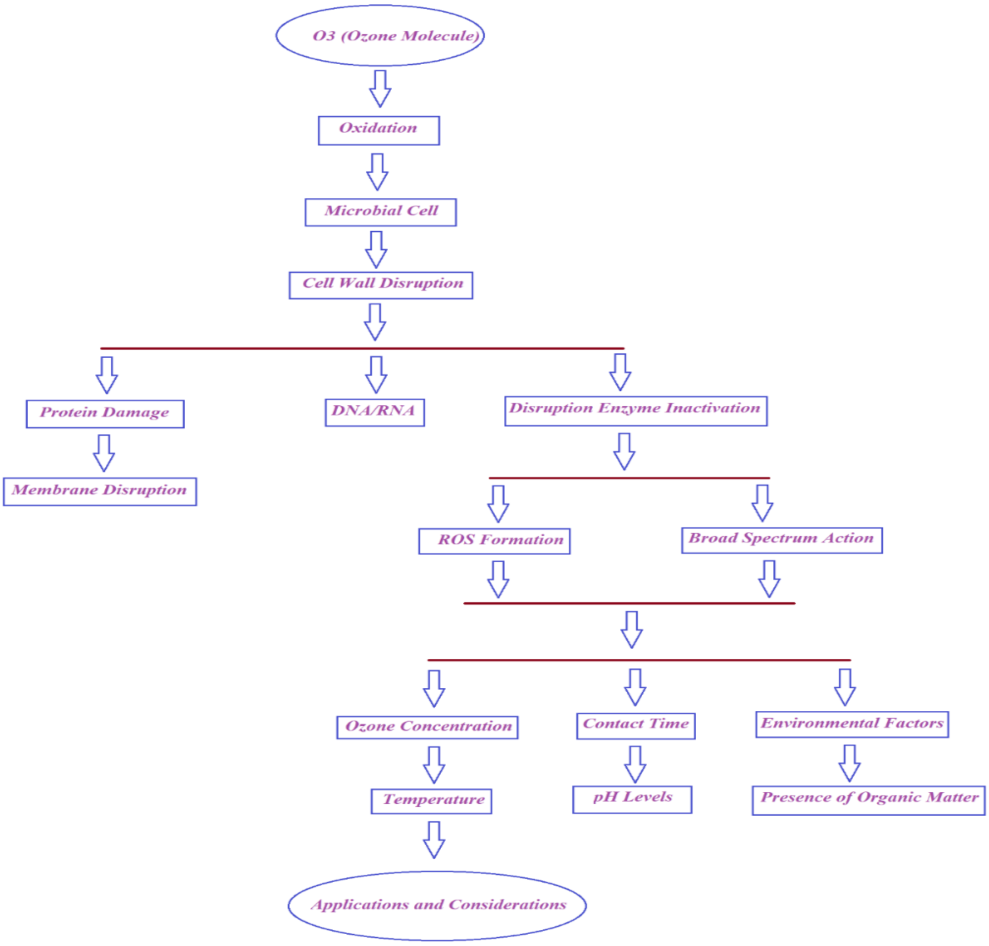


Figure 3: Diagram of the mechanism of action of ozone by microorganisms

As we conclude from the diagram presented in the figure, it can be seen that it is worth paying special attention to the factors that affect the destruction of microorganisms with the help of ozone.

2.3 Factors affecting the destruction of microorganisms using ozone

The effectiveness of ozone in killing microbes is influenced by various factors, including water quality parameters, ozone dose, contact time, and organic matter availability (Rangel et al., 2021; Davidson et al., 2011). The type and concentration of microorganisms also play an important role in determining the effectiveness of ozone treatment (Rangel et al., 2021; Takizawa et al., 2023; Thanomsub et al., 2002). The interaction of these factors and their general tendency to destroy microorganisms can be observed in Table 2 (Epelle et al., 2022).

Table 2: Factors affecting the destruction of microorganisms by ozone (Epelle et al., 2022)

Factor	Destruction of microorganisms by ozone
Mechanism	Ozone acts through oxidation, destroying cell walls and damaging cell components.
Sensitivity of microorganisms	Ozone is very effective in killing microorganisms, including bacteria, viruses and fungi.
Ozone content	A high concentration of ozone usually leads to the effective destruction of microorganisms, but its effectiveness decreases
Contact time	The long exposure time increases the efficiency of ozone, which allows it to interact deeply with microorganisms.
Environmental factors	Temperature and humidity can affect the efficiency of ozone, high temperature and humidity contribute to the good destruction of microorganisms.
PH levels	Ozone is effective in a wide range of *pH* levels, making it versatile in a variety of environmental conditions.
Presence of organic matter	Ozone can react with organic matter in water, making it less accessible to kill germs. It may be necessary to pre-treat the water.
Ozone supply	The way ozone is delivered, gaseous or dissolved in water, can affect its effectiveness in killing microorganisms.

What we can see from this table is that ozone can be a powerful disinfectant, but it is important not to forget that it is essential to use it correctly and that it works optimally. Therefore, before applying in the technological process, it is better to conduct a comparative analysis of ozone technology with traditional methods.

2.4 Comparative analysis of ozone technology with traditional methods

Comparison of ozone treatment with traditional water disinfection methods such as chlorination (Al-Abri et al., 2019). And ultraviolet irradiation, filtration works gives an idea of the benefits and limitations of the destruction of microorganisms by ozone (Soboksa et al., 2020; Cescon and Jiang, 2020; Zinn et al., 2018; Castro et al., 2023). Ozone's ability to quickly inactivate a wide range of microorganisms without leaving harmful byproducts makes it a suitable option for surface water treatment (Castro et al., 2023; García-Araya and Beltrán, 2023). To compare ozone technology with traditional methods, let's divide it into the main categories (Table 3).

Table 3: Comparison of ozone technology with traditional methods (Draginsky et al., 2007; Botondi et al., 2023)

Aspect	Ozonation technology	Traditional methods such as chlorine and UV
Efficiency	It has high efficiency in disinfection and oxidation	Efficiency varies depending on the method (e.g. chlorine, UV).
Waste	Leaves no harmful waste	Residual by-products may remain
Environmental consequences	Ozone is a strong oxidizer, but it can be produced where it has little impact on the environment	Some traditional methods may involve the use of chemicals related to environmental protection
Scope of application	Universal; used to purify water, air and other environments from harmful bacteria	Application may be limited, depending on the specific method
Operating costs	Operating costs can be higher depending on the equipment used to produce ozone	Costs vary depending on the method and current costs (e.g. chemical filling).
Energy consumption	Energy may be needed to produce ozone, but advances in technology increase efficiency	Energy requirements are different for different methods
Health and safety	Ozone can be harmful in high concentrations; it is very important to handle it properly	Some traditional methods involve the use of potentially hazardous chemicals
Resistance to the action of microorganisms	Effective against a wide range of microorganisms, including bacteria and viruses	Efficiency varies; some methods may require a long contact time
Support	Ozone generators require regular maintenance	Maintenance requirements vary depending on the method chosen
Installation	Ozone systems may require special installation	Installation requirements vary; some methods may be easier to install

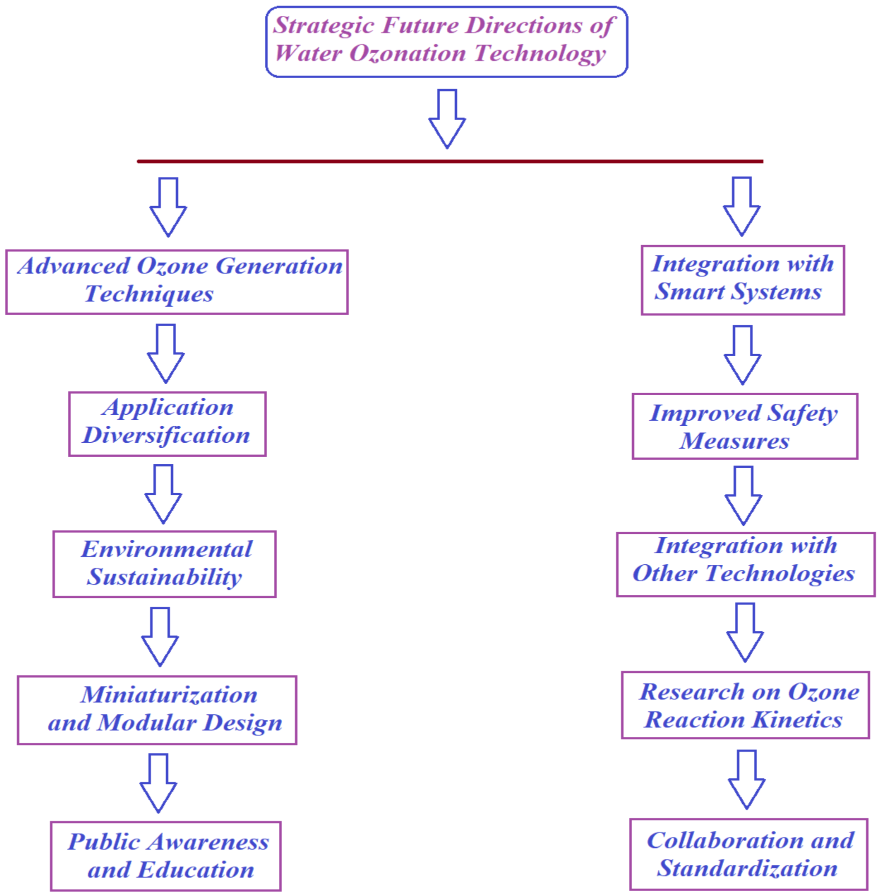


Figure 4: Strategic future directions of water ozonation technology

The table showed a comprehensive comparative analysis of ozonation technology and traditional methods in various aspects (chlorine and UV). What we can see here is the peculiarity of ozone technology. However, special attention should be paid to the strategic future directions of water ozonation technology.

2.5 Strategic future directions of water ozonation technology

Disinfection of water from microbes, ozone has a very high property in the process of purification (Ngwenya et al., 2012; Muzafarov et al., 2021). It also aims to break down organic pollutants and improve the overall water quality (Mouele et al., 2015). The elimination of microorganisms through ozone is a promising method for improving the quality of surface water (Santos et al., 2021). The process contributes to the development of strategies for active water treatment, solving mechanisms and factors. Some research papers consider a solution to the strategy of increasing the activity of photocatalytic ozonation of g-C_3N_4 by halogen doping for water purification (Tan et al., 2022). A diagram of the strategic future directions of total water ozonation technology is presented in Figure 4 below

This figure presents a simplified diagram of the strategic future direction of water ozonation technology. It highlights the interrelated strategic directions of water ozonation technology for the future, highlighting key areas such as the improvement of ozone production, integration with intelligent systems, safety measures, environmental sustainability, integration with other technologies, miniaturization, study of ozone reaction kinetics, public awareness, education and cooperation. Each cell here represents a strategic direction, and the language lines indicate the relationships and influence between these directions.

Taking into account the previously studied scientific information in the above materials and methods, we paid special attention to the process of destroying harmful microbacteria in surface water with the help of ozone technology, which is subject to environmental problems.

3. RESULTS AND DISCUSSIONS

In the process of decontaminating surface water from harmful microorganisms, a number of advantages of ozone (O_3) over traditional methods such as chlorine (Cl) and ultraviolet (UV) radiation have been identified (Summerfelt, 2003). For instance, ozone exhibits a significantly faster effect on harmful microorganisms in water, approximately 15 to 20 times faster than chlorine. Specifically, while ozone at a concentration of 0.45 mg/l can destroy the polio virus within 2 minutes, chlorine requires a dose of 2 mg/l and takes 3 hours to achieve the same result. Consequently, the necessary amount of ozone is approximately 2.5 times less than chlorine. Overall, the advantages of ozone over chlorine and UV radiation are as follows (Ishaq et al., 2018; Voukkali and Zorpas., 2015).

- *High oxidation potential:* Ozone has a high oxidation potential compared to chlorine and ultraviolet radiation. This allows ozone to effectively degrade and oxidize a wide range of organic and inorganic pollutants in water, including bacteria, viruses, and pollutants (Voukkali and Zorpas., 2015).

- *Absence of harmful by-products after the oxidation process:* unlike chlorine, which can form potentially harmful disinfectant by-products when interacting with organic substances, ozone does not form such by-products (Sassi et al., 2005).

- *Effectively destroys pathogens:* Ozone is a more powerful disinfectant than chlorine or ultraviolet radiation, capable of destroying a wide range of pathogens, including bacteria, viruses, and parasites. This makes ozone a reliable solution to prevent water-borne diseases (Ishaq et al., 2018).

- *Lack of residual taste and smell:* Ozone does not give the treated water a residual taste or smell, which is especially effective when treating drinking water, as consumers prefer water with a stable taste and no smell (Voukkali and Zorpas., 2015; Sassi et al., 2005)

- *Wide range of pollution removal:* Ozone effectively decomposes and removes a wide range of pollutants, including organic pollutants, pesticides, and pharmaceutical waste. UV radiation may not be effective against certain types of pollutants, and chlorine may require additional treatment steps for complete removal (Ishaq et al., 2018).

- *Short contact time:* Ozone disinfection usually requires a shorter contact time compared to chlorine. This can lead to more efficient water treatment processes and a shorter overall treatment time, which contributes to energy savings (Voukkali and Zorpas., 2015).

- *PH flexibility:* Ozone remains effective in a wider *pH* range compared to chlorine. This provides flexibility when treating water at different *pH* levels without compromising disinfection efficiency (Sassi et al., 2005).

- *Eco-friendly:* Ozone decomposes into oxygen without leaving harmful waste, making it an environmentally friendly disinfectant. On the contrary, disinfection with chlorine can lead to the formation of chlorinated by-products that can affect the environment. Although UV radiation is effective in disinfection, it does not provide a residual disinfecting effect. Ozone, on the other hand, can have a residual disinfectant effect that provides permanent protection against the regrowth of microorganisms in the distribution system (Draginsky et al., 2007; Sassi et al., 2005).

Thus, the advantages of ozone over chlorine and UV radiation in water treatment include high disinfection capabilities, the absence of harmful by-products, flexibility in the *pH* range and an integrated approach to removing pollutants. These factors contribute to an increase in the preference for ozone in various areas of water preparation.

3.1 The tendency to destroy harmful microorganisms contained in water with ozone

Ozone destruction of microorganisms involves oxidative reactions in which ozone reacts with various components of microbial cells (Martinelli et al., 2017; Rosenblum et al., 2012). Specific chemical reactions can vary depending on the nature of microorganisms and the composition of cells (Ngwenya et al., 2013; Banach et al., 2015). The ozone concentration can be determined according to the stage of the technological process as follows (Chasanah et al., 2019):

$$\frac{d[O_3]}{dt} = -k_1[O_3] \tag{16}$$

Where k_1 is a constant rate due to the decay of ozone.

The concentration of lipids in the total [L] microbial cell membranes can be determined as follows (Barák and Muchová, 2013; Lakey et al., 2017).

$$\frac{d[L]}{dt} = -k_2[O_3][L] \tag{17}$$

Where k_2 is the constant reaction rate between ozone and lipids.

Similarly ,the concentration of proteins in [P] microbial cells can be determined as follows (Cataldo, 20005).

$$\frac{d[P]}{dt} = -k_3[O_3][P] \tag{18}$$

Where k_3 is the constant reaction rate between ozone and proteins.

Reaction equation with nucleic acids (Hoigné and Bader, 1983, Portjanskaja, 2010):

$$\frac{d[NA]}{dt} = -k_4[O_3][NA] \tag{19}$$

Where [NA] is the concentration of nucleic acids (DNA/RNA) in microbial cells. k_4 is a constant reaction rate between ozone and nucleic acids.

Microbial inactivation equation (Brodowska, 2017):

$$\frac{d[M]}{dt} = -k_5[O_3][M] \tag{20}$$

Where [M] refers to the concentration of microorganisms. k_5 is a constant rate of total inactivation of microorganisms by ozone.

These equations describe changes in the concentration of ozone and the concentration of lipids, proteins, nucleic acids and microorganisms over time. Based on these theoretical data, a system for eliminating harmful microorganisms contained in water with ozone was identified below (Figure 5). Let us consider the algarity of the basic system of equations that take into account the reactions in which ozone and various components of microorganisms are involved during the general technological process.

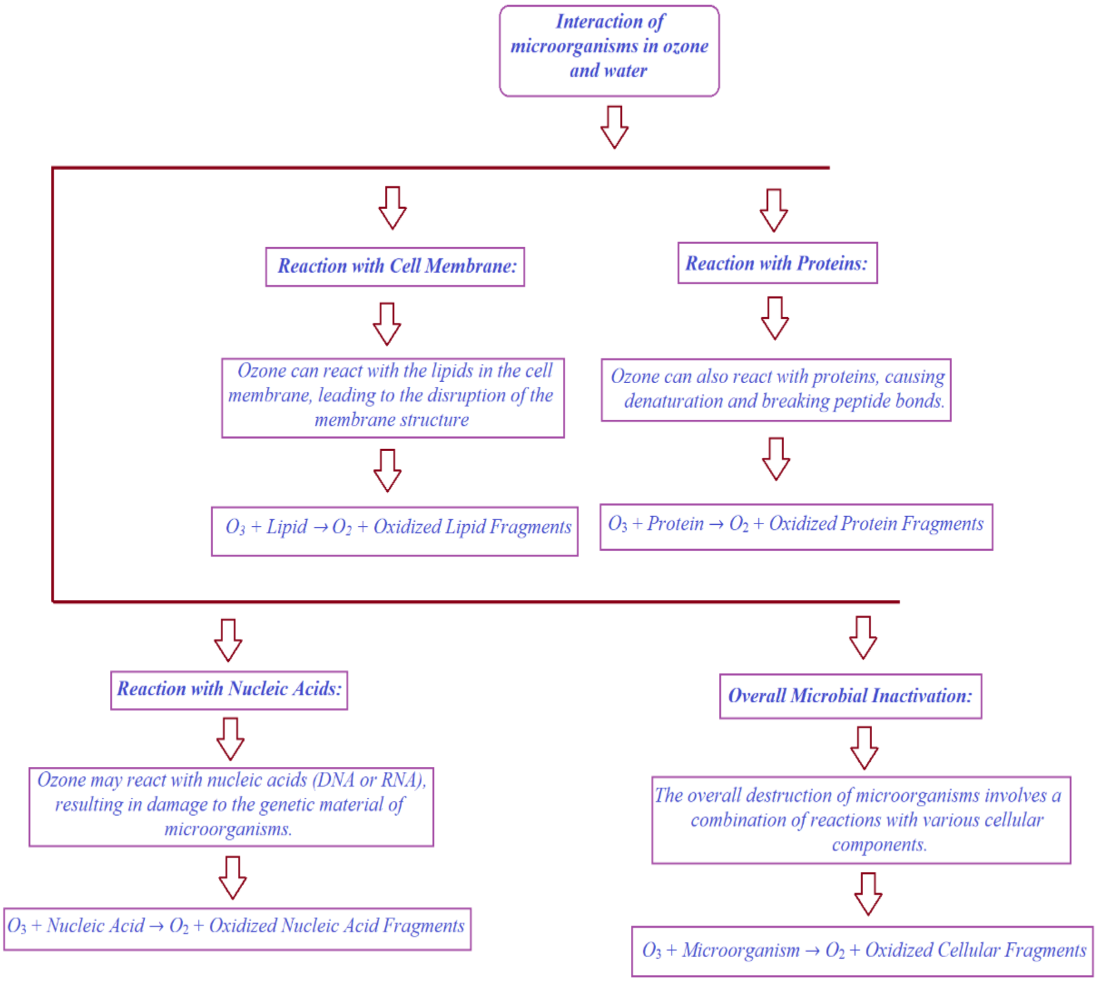
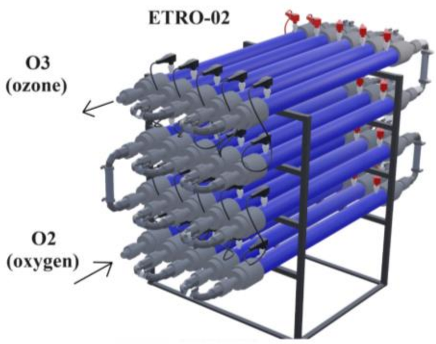


Figure 5: The system of equations of contact of ozone with the destruction of microorganisms.

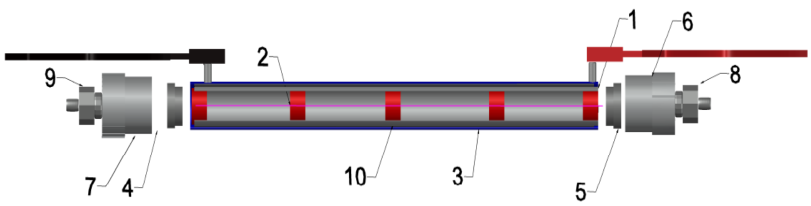
3.2 Design of a new pilot ozonator installation Etro-02

Based on the theoretical data and methodological instructions given in the previous sections, a special installation of the Etro – 02 ozonator was developed at the K. I. Satpayev Kazakh National Research Technical University (KazNRTU) based on an electric corona discharge with a frequency of 13kHz and a voltage of 21 kV (Abdykadyrov et al., 2014). The general sketch scheme of the installation is presented in Figure 6 a,b below. For practical testing, the unit was installed in a scientific laboratory located near the Kapshagai reservoir, which was exposed to environmental problems. There, scientific research was carried out on the process of destroying harmful microbacteria contained in surface water using ozone technology.

The Etro-02 unit belongs to ozone extraction devices and can be used in the field of Ecology, in the treatment and disinfection of drinking water and wastewater, as well as in medicine, water channels, drainage, food industry, etc. The voltage between the corona electrodes in the ozonator is 21 kV, the length of the electrodes in it is 40 m, and the cooling system is carried out using nitrogen or transformer oil. The generator produces an ozone-air mixture with a capacity of 30g/m3 per hour.



a) general image of the ozonator



b) design image (internal image) of the ozonator

electrode (made of nichrome); 3 – dielectric tube (D = 63 mm); 4,5 – dielectric plug made of fluoroplast; 6,7 - dielectric cap; 8.9 – cover made of brass; 10 – space where NO_2,H_2O or transformer oil travels.

Figure 6: Electric Crown discharge-based Etro-02 ozonator unit

The technological scheme for cleaning water from harmful bacteria is based on the Etro – 02 ozonator device operating at a special frequency of 13 kHz and a voltage of 21 KV to carry out the process of disinfection and purification of harmful microorganisms found in the reservoir water (Figure 7).

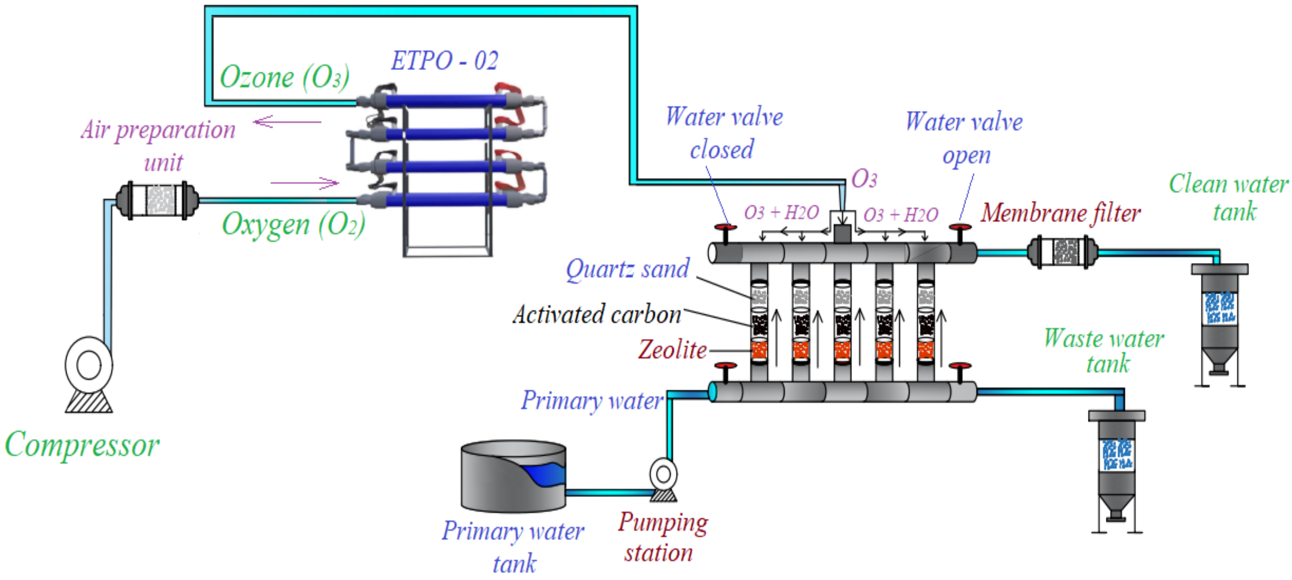


Figure 7: Technological scheme of the process of destruction of harmful microorganisms in water.

With the help of the Etro-02 ozonator, the process of neutralizing and cleaning harmful microorganisms found in surface waters of the Kapshagai and Vyacheslav reservoirs is effective.

The Etro – 02 ozonator unit was used to decontaminate surface water from the warehouse. In the course of the general process, our goal in using ozone in reagents (chlorine and UV radiation, etc.) was to find that the oxidizing and disinfecting properties of ozone are higher than others. This is because it was effective for disinfecting surface water from harmful microorganisms, removing odors, changing the color of water, and removing impurities (Ding et al., 2019; Morrison et al., 2022). For example the elimination of bacteria, spores, germs and viruses in water (inactivation). To do this, a disinfectant reagent (ozone, chlorine, UV, etc.) is usually introduced into the water (Abdykadyrov et al., 2023). The dose of reagent in water treatment processes and disinfectants varies depending on the content of organic matter in the water, the temperature of the water, and the time of active reaction of the water with the disinfectant (Collivignarelli et al., 2018). When using chlorine, the higher the dose, the fewer bacteria will live, but at the same time unpleasant side effects will occur (Morrison et al., 2022). Heavy metals and bactericidal effects with the use of ozone begin when a certain critical dose is reached, equal to 0.3 - 0.6 mg per liter of treated water (Abdykadyrov et al., 2023). In addition, complete inactivation (disinfection) of water occurs.

The mechanism of action of ozone in general consists in the breakdown of bacterial proteins and is carried out by the diffusion of ozone through the cell membrane into the cytoplasm, after which the life centers are damaged. The action takes place quickly-if its required concentration in water is maintained. If ozone has an effective effect on almost all bacteria, then chlorine selectively poisons the life centers of bacteria due to the low rate of diffusion in the cytoplasm (Broséus et al., 2009). The time it takes to reduce the concentration of bacteria to the allowable amount is called the inactivation (disinfection) time. For chlorine, the inactivation time is 30 min. when the chlorine content in water is in the range of 0.05 - 0.2 mg/l. For ozone, this time is 12 min. when the ozone content in water is 0.2 - 0.3 mg/l. In France, a time equal to 4 min is taken for water inactivation (ozone concentration 0.4 mg/l) [16].

According to the technological scheme, the process begins with the formation of ozone. Ozone (O_3) is formed by passing oxygen molecules through a high – voltage electrical discharge(as can be seen in Figure 6 (B)). The ozone then enters the water through a tube using a compressor. That is, at this time, there is a process of neutralization of harmful microorganisms contained in the water. When ozone comes into contact with pollutants in water, such as organic matter, bacteria, viruses, and other impurities, it breaks them down by giving them highly reactive oxygen atoms. This process effectively neutralizes and removes these pollutants. In general, ozone in water not only fights microorganisms, but also helps to remove particles and turbidity. The oxidizing power of ozone causes aggregation of small particles, making them easier to settle or filter during subsequent water treatment steps.

3.3 Testing the unit

For testing the installation, special research works were carried out on the Kapshagai reservoir located on the coast of the city of Kunaev and on the Vyacheslav reservoir located on the coast of Astana (Republic of Kazakhstan) (Wikipedia; ADB, 2021; CAWater-info).

During the technological process, the amount of ozone (0.3 – 0.6 g/hour) is consumed depending on the content of surface water in the warehouse. The treated water from the facility retained a residual ozone concentration ranging from approximately 0.09 to 0.3 mg/l. Presently, ozone technology stands as one of the contemporary approaches to water disinfection and purification. Ozone exerts both organoleptic and chemical effects on harmful bacteria present in water throughout the technological process. Its impact on waterborne microorganisms varies depending on factors such as pH level (pH = 6 - 10) and temperature (ranging from 0°C to 37°C). It's challenging to assert that ozone selectively targets microorganisms in water: initially, it acts on dissolved organic impurities before affecting microorganisms (Abdykadyrov et al., 2023).

Among the methods of surface water disinfection, ozone technology is very effective. For example, it can be observed in Figure 8 and Table 4 below (Draginsky et al., 2007; Abdykadyrov et al., 2023). Table 4 uses various disinfection methods (temperature 22^{0}C. *pH* = 6.8 - 7.0) from microorganisms (E. coli) and viruses can be observed with a decontamination efficiency of up to 97 - 99% percent.

Table 4: The K·T (concentration·time) values of different disinfectants for virus disinfection were compared.

Disinfectant	Unit of measurement	Disinfection 2-log	Disinfection 3-log	Disinfection 4-log
Chlorine (Cl)*	mg ·min/l	3,1	4,08	6,98
Chloramin (NH_2Cl)**	mg ·min/l	639	1058	1398
Chlorine dioxide (ClO_2)***	mg ·min/l	3,9	11,78	24,8
Ozone (O_3)	mg ·min/l	0,6	0,86	1,25
Ultraviolet (UV)	mV · sec/cm²	22	38	-

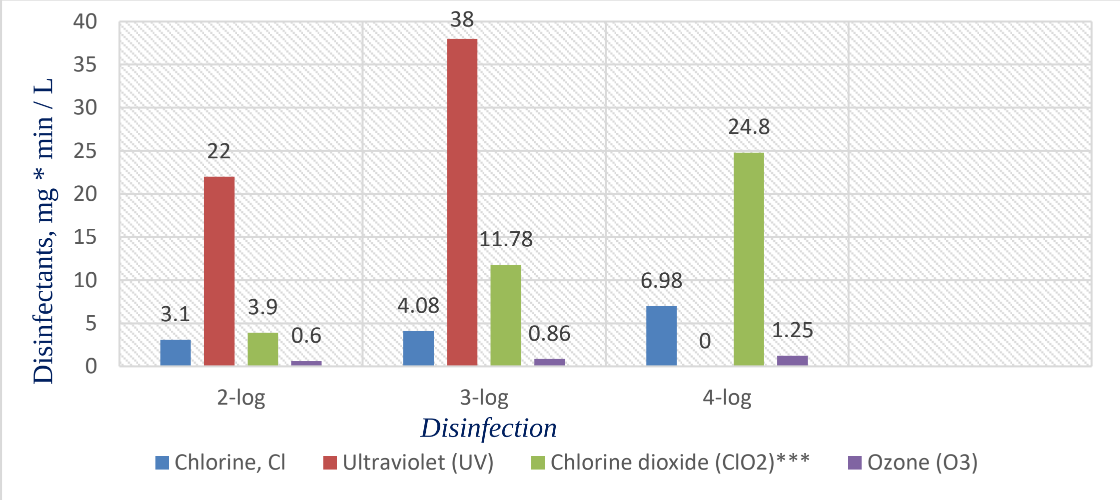


Figure 8: K·T (concentration·time) values of various disinfectants for virus disinfection

*The data here are: * obtained at a temperature of 10°C, in the pH = 6 - 9 range and free chlorine at 0.2 – 0.5 mg/l; * * at 10°C and pH = 8; * * * at 10°C and pH = 6 - 9.*

What we see in Figure 8 is that chlorine is suitable for neutralizing bacteria and viruses, but should not be used to deactivate protozoa. And the process of ozonation is able to destroy all known bacteria and viruses. When ozonating water, first of all, the contact time and the concentration of ozone in the water are taken into account.

Table 5 and Figure 9 below show the disinfection rate of "Giardia cysts". In this table, it can be observed that total chlorine and chloramine have a low K·T (concentration·time) value. In general, ozone is a powerful disinfectant to neutralize the microorganism. The protozoa contained in water (Cryptosporidium) actually react slowly with chlorine and chloramine. The K·T (concentration·time) values for chlorine deactivation are equal to 3000 – 4000 mg·min/l for 1 - log deactivation (90% deactivations.

Table 5: The speed of disinfection of" Giardia cysts " is indicated.

Disinfectant	Disinfection 2,5-log	Disinfection 2 - log	Disinfection 1,5-log	Disinfection 1-log	Disinfection 0,5-log
Chlorine (Cl)*	86,3	68,5	50,9	34,7	16,8
Chloramin (NH_2Cl)**	1438	1227	927,8	613,5	309,7
Chlorine dioxide (ClO_2)***	18,5	14,7	11,2	6,85	3,8
Ozone (O_3)	1,15	0,85	0,68	0,39	0,185

"Giardia cysts" refer to an intestinal infection caused by Giardia parasites, characterized by symptoms such as stomach cramps, bloating, nausea, and episodes of watery diarrhea. This infection arises from a microscopic parasite prevalent worldwide, particularly in regions lacking proper sanitation and having unsafe water sources.

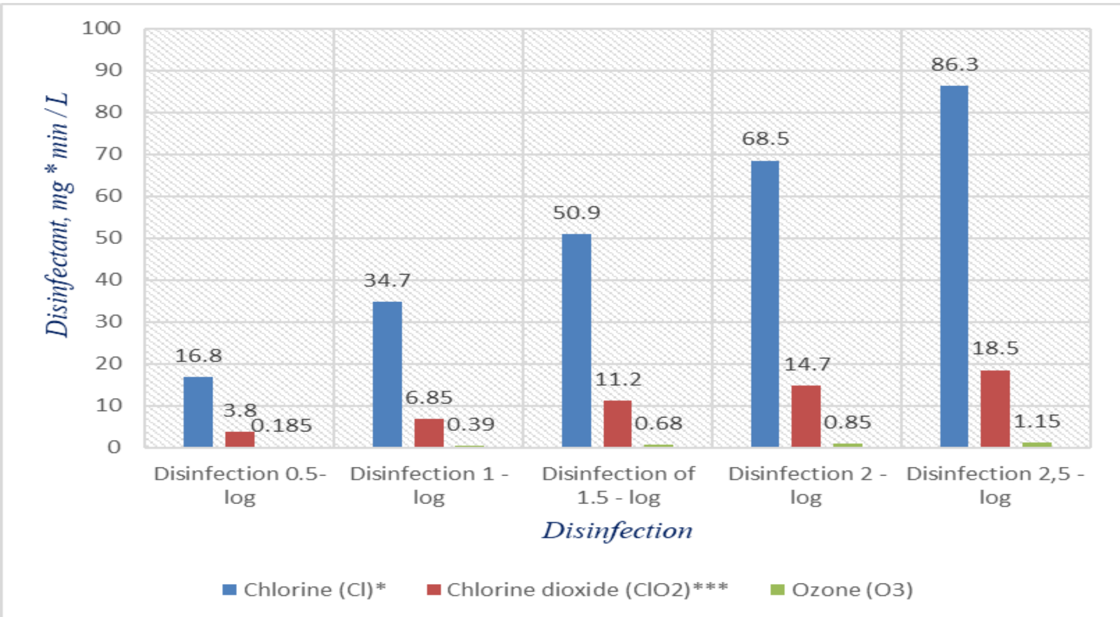


Figure 9: Speed of disinfection of "Giardia cysts" using various disinfectants

The data here. *At 10°C, *pH* 7 and free chlorine equal to or less than 0.4 mg/l; ** taken at 10°C and *pH* 6-9; *** taken at 10°C and *pH* 6

This can be seen in the figures 8 and 9 above, the advantage of ozone. Here ozone has little effect on ph and temperature. However, as the temperature increases, the solubility of ozone decreases, the level of disinfection increases at 10°C, in the range of 0 - 30°C, these two factors reduce each other. in the pH = 6 – 8.5 range, the ozone disinfection rate hardly changes. For some resistant microorganisms (such as Giardia Muris), the disinfection rate increases when the *pH* is high. For other types of microorganisms, the opposite is true.

To determine the efficiency of oxidizing agents and destruction of microorganisms contained in surface water in the warehouse, it was necessary to develop a sanitary reliability criterion, taking into account various reagents, their doses, the length of the water supply network, quality indicators. Such research work has already been adopted in the United States in previous centuries, that is, in the 1960s (Корко, 2020).

According to scientific research, the ozonator plant was tested, special water was removed from the surface reservoirs of Kapshagai (Kunayev city) and Vyacheslav (Astana city), ozonation was carried out. Scientific research was carried out in the "sanitary and hygienic Laboratory" of the RSE (Republican State enterprise) of Almaty and in the scientific laboratories "Astana Su Arnasy" of Astana. The microbial parameters of water quality do not align with the Maximum Permissible Concentration (MPC), as demonstrated in the table provided below (Table 6).

Table 6: Microbiological indicators of primary water content in kapshagai and Vyacheslav reservoirs

№	Microbiological indicators of water content	Standards are not more than (MPC)	Number of microbiological indicators in the composition of primary water	
			Kapshagai reservoir	Vyacheslav reservoir
1	Total number of microbes, 1 ml CFU	<50	130	160
2	Coliphages (100 ml PFU)	0	135	170
3	CCB (100 ml CFU),	0	650	800
4	TCB (100 ml CFU)	0	270	370

This experimental research work, based on the process of complete disinfection and cleaning of harmful microorganisms presented in Table 6, was carried out in two directions:

Option 1. Keeping the decontamination time constant (t = 5 minutes), on the contrary, changed the concentration of ozone to 0.3 – 0.8 g/hour. The results of the research work are presented in Table 7 (Kapshagai reservoir), table 8 (Vyacheslav reservoir) and figures 10 and 11 below.

Table 7: Changes in microbiological indicators of water content in Kapshagai reservoir depending on the amount of ozone

№	Microbiological indicators of water content	Regulations not more (MPC)	The primary water composition includes a specific number of microbiological indicators.	Ozone content in g/h (decontamination time constant t = 5 minutes)				
				0,3	0,4	0,5	0,6	0.8
1	Total number of microbes, 1 ml CFU	<50	130	123	114	38	13	0
2	TCB (100 ml CFU)	0	270	255	237	79	27	0
3	CCB (100 ml CFU),	0	650	615	571	190	65	0
4	Coliphages (100 ml PFU)	0	135	127	118	39	13	0

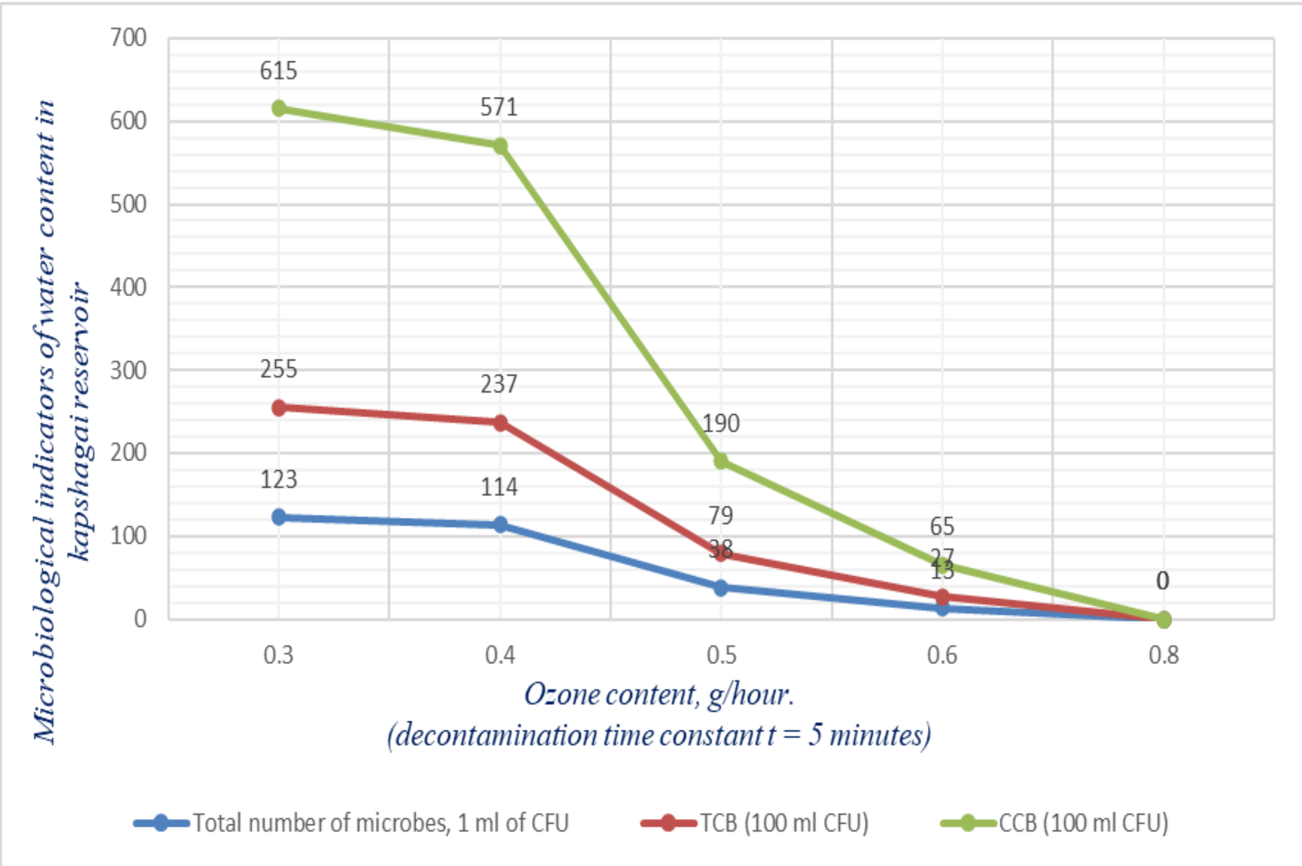


Figure 10: Changes in microorganisms in water depending on the amount of ozone (decontamination time constant t = 5 minutes)

Table 8: Changes in microbiological indicators of water content in the Vyacheslav reservoir depending on the amount of ozone

№	Microbiological indicators serve to gauge the microbial content within water	Regulations not more (MPC)	The composition of primary water typically includes various microbiological indicators, which help assess its microbial content.	Ozone content in g/h (decontamination time constant t = 5 minutes)				
				0,3	0,4	0,5	0,6	0,8
1	Total number of microbes, 1 ml CFU	<50	160	151	140	47	16	0
2	TCB (100 ml CFU)	0	370	350	325	108	37	0
3	CCB (100 ml CFU),	0	800	757	703	235	80	0
4	Coliphages (100 ml PFU)	0	170	161	149	49	17	0

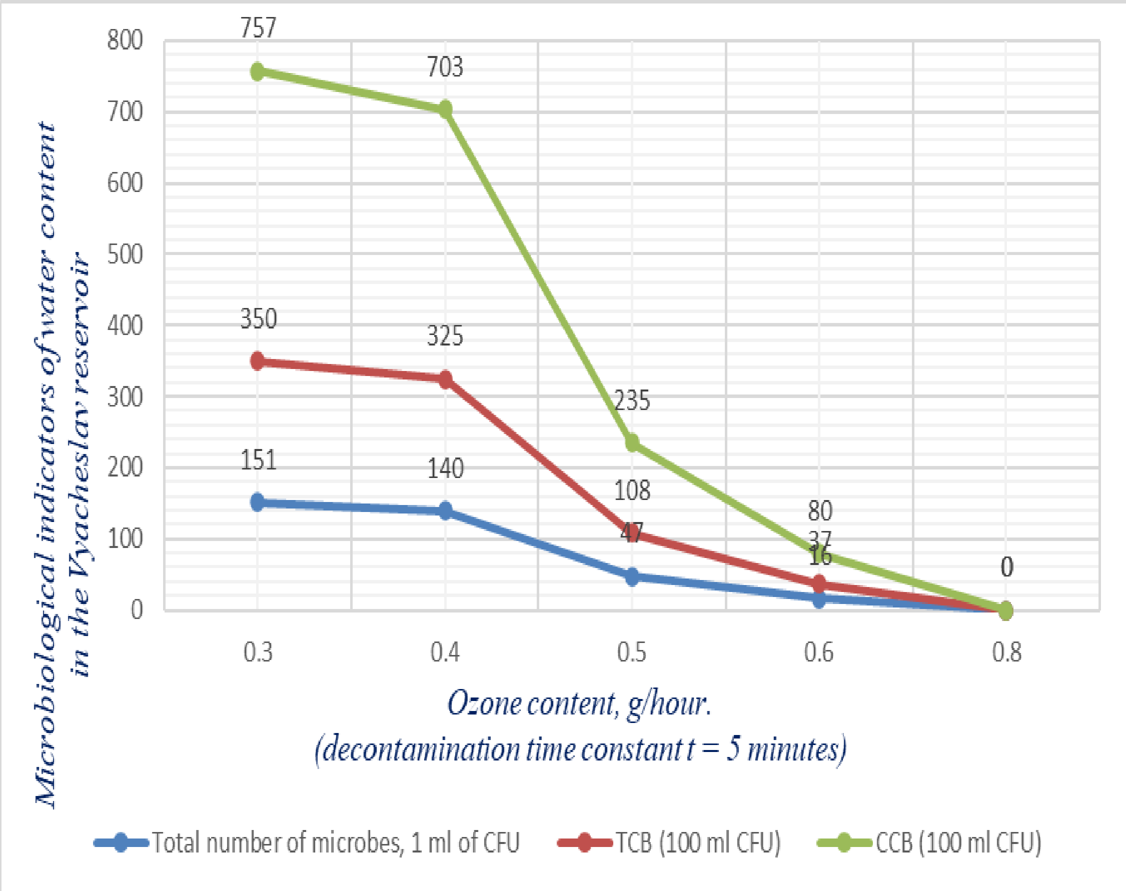


Figure 11: Changes in microorganisms in water depending on the amount of ozone (decontamination time constant t = 5 minutes)

It is evident that the initial water samples contain microbiological indicators within the ranges of 130-160 CFU (total coliform bacteria), 270-370 CFU (thermotolerant coliform bacteria), and 135-170 PFU (coliphages) per 100 ml. Upon introducing varying ozone amounts ranging from 0.3 to 0.8 g/h into the water, there is a gradual reduction in microbiological indicators, as illustrated in Figures 10 and 11. Notably, when the ozone concentration reaches 0.5 to 0.8 g/h, the total microbe count in the water meets the predetermined criteria set by the MPC. This indicates a 99.9% elimination of harmful microorganisms from the water.

Option 2. In this version, we change the decontamination time to 5 – 25 minutes, keeping the ozone concentration constant (C = 0.8 g/hour). The results of the research work are presented in Table 9 (Kapshagai reservoir), table 10 (Vyacheslav reservoir) and figures 12 and 13 below.

Table 9: Changes in microbiological indicators of water content in Kapshagai reservoir depending on time

№	Indicators of microbial presence in water	Regulations not more (MPC)	The count of microbiological indicators present in the composition of primary water.	Decontamination time, minutes (The amount of ozone is constant C = 0.8 g/hour)				
				5	10	15	20	25
1	Total number of microbes, 1 ml CFU	<50	130	123	112	34	13	0
2	TCB (100 ml CFU)	0	270	255	233	71	27	0
3	CCB (100 ml CFU),	0	650	615	562	173	65	0
4	Coliphages (100 ml PFU)	0	135	127	116	35	13	0

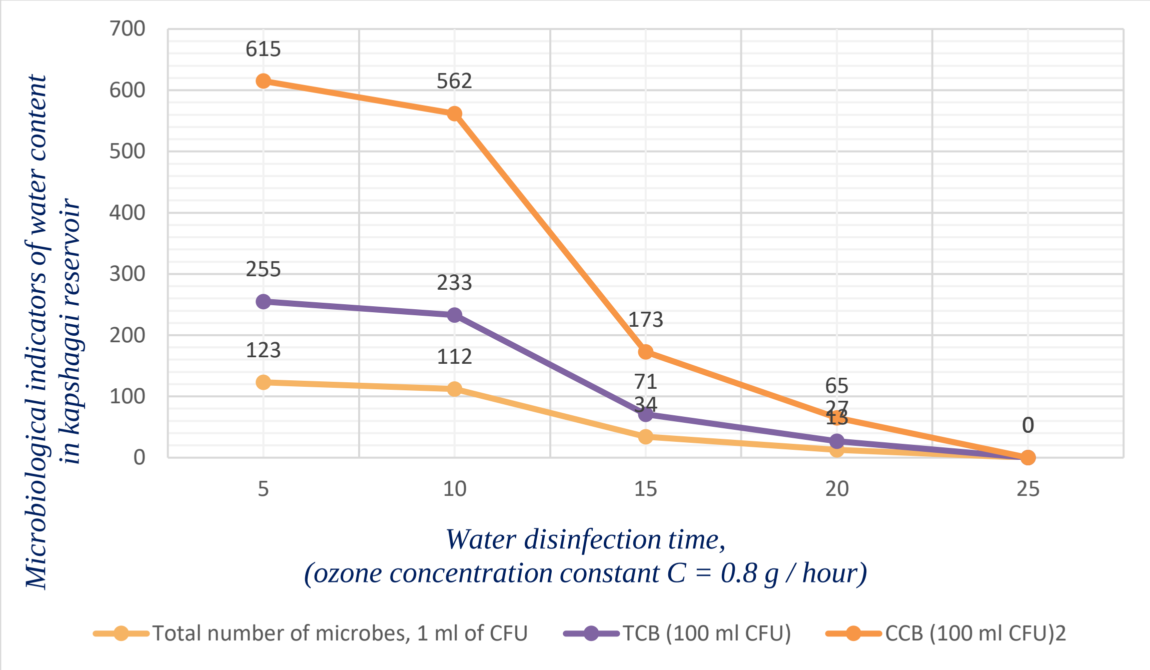


Figure 12: Changes in microorganisms in water depending on the decontamination time (ozone concentration constant C = 0.8 g / hour)

Table 10: Changes in microbiological indicators of water content in the Vyacheslav reservoir depending on time

№	Indicators of microbial presence in water	Regulations not more (MPC)	The count of microbiological indicators present in the composition of primary water	Decontamination time, minutes (The amount of ozone is constant C = 0.8 g/hour)				
				5	10	15	20	25
1	Total number of microbes, 1 ml CFU	<50	160	151	138	42	16	0
2	TCB (100 ml CFU)	0	370	350	320	98	37	0
3	CCB (100 ml CFU),	0	800	757	692	213	80	0
4	Coliphages (100 ml PFU)	0	170	161	147	45	17	0

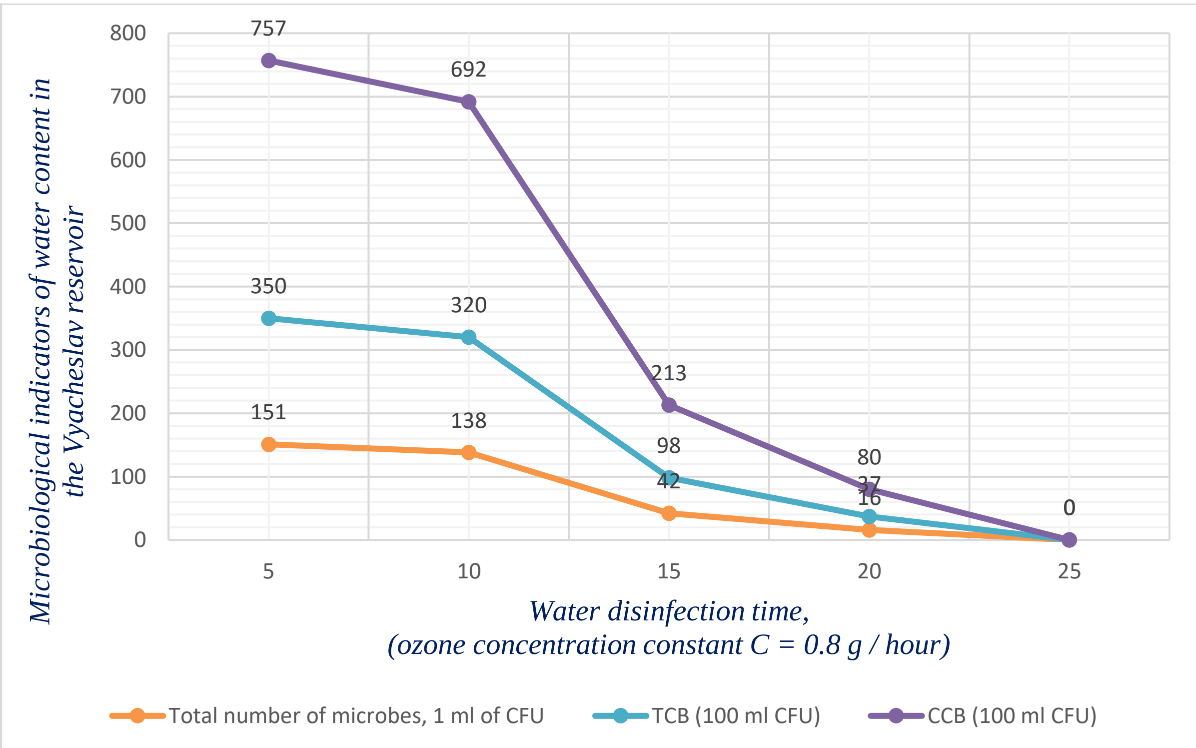


Figure 13: Changes in microorganisms in water depending on the decontamination time (ozone concentration constant C = 0.8 g / hour

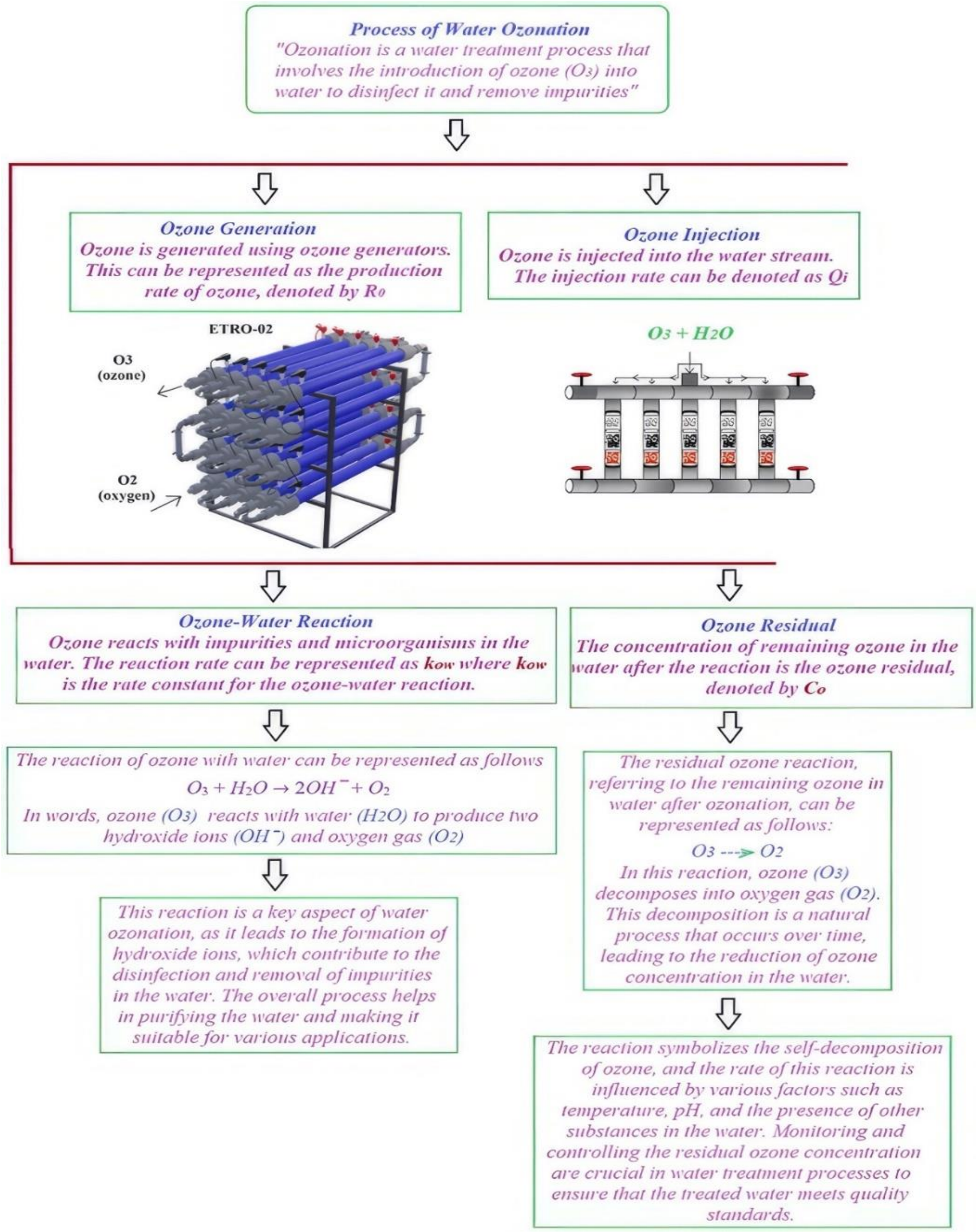


Figure 14: Process of Water Ozonation

Figures 12 and 13 demonstrate that with an ozone concentration of C = 0.8 g/hour, and a decontamination duration of 20-25 minutes, the levels of thermotolerant coliform bacteria (TCB), coliform bacteria (CCB), and coliphages in the water align with the maximum permissible concentrations outlined in the drinking water standard MEST 2.1.4.1074 – 01 [7]. However, for the sake of standardizing experimental procedures and determining ozone consumption per 1m3 of water, it is recommended to develop a mathematical model that incorporates relevant physical parameters (Звонарев, 2019).

3.4 Mathematical model of the technological process

To construct a mathematical representation of the process wherein ozone eliminates harmful microorganisms in surface water it is necessary to first analyze the technology of ozonation of water (Figure 14) (Loeb, 2011). From this figure 14, let's denote the ozone concentration in water as $C_0(t)$, depending on the time. Then the rate of change in ozone concentration ($\frac{dC_0}{dt}$) can be described by the following differential equation (Draginsky et al., 2007; Shin et al., 2020):

$$\frac{dC_0}{dt} = R_0 - Q_i \cdot C_0 - k_{ow} \cdot C_0 \quad (21)$$

Where: *Ro is the rate of ozone formation; Q_i is the rate of ozone injection; k_{ow} is the constant rate of ozone+water reaction.*

Through this (21) expression, one predicts first-order kinetics for the ozone + water reaction, and one can observe the rate at which ozone and injection occur.

The main factors influencing surface water disinfection processes include concentration of disinfectant reagents, mechanical work, time and temperature (Richardson and Postigo, 2012, Pérez-Lucas, 2022). When using disinfectants, you should be guided by the manufacturer's recommendations. For example, when using highly concentrated solutions during the process, it can lead to the formation of insoluble compounds and the activation of corrosive processes (Wei et al., 2017).

High temperatures can lead to chemical decomposition of the active substance, loss of hard water salts, polymerization of proteins and fats (Epelle et al., 2023). But this negatively affects the quality of disinfection. Another important factor in the process of disinfection of vegetables in any agriculture, including drinking water, is the time of contact. For example, the greater the contact time of ozone, the lower the number of microorganisms (Sukarminah et al., 2017).

There are many mathematical models that describe the process of inactivation of microorganisms found in the drinking water and food industries (Hafsan et al., 2023). Difficulties arise when using these models, because it involves complex parameters that are determined experimentally. One of the models used more often than others is the Chika-Watson linear-logarithmic model (Mecha et al., 2020):

$$Log(N_t/N_0) = - \kappa C^n t \quad (22)$$

Or this (22) expression can also be written as:

$$N_t = N_0 e^{-\kappa C^n t} \quad (23)$$

N_t is the number of microorganisms that survived during the process; N_0 this refers to the initial quantity of microorganisms.; k is the constant of the disinfection rate; C this denotes the concentration of the disinfectant.; n is the dilution factor; t is the contact time.

The dilution factor (*n*) here depends on the type of disinfectant. For example, for quaternary ammonium salts *n* = 1. this means that the exposure time must be doubled when the concentration of *n* is halved. For ethanol, *n* = 10, which means that when the ethanol concentration is halved, the processing efficiency decreases by 2^{10}, that is, by 1024 times.

Based on the experimental data presented in figures 10, 11 and 12, 13 of the previous section, mathematical calculations were carried out to determine the amount of ozone consumed per 1m³ of water. Mathematical calculations were performed using the Mathcad 14 and SMath Solver programs (SMath Studio, 2010).

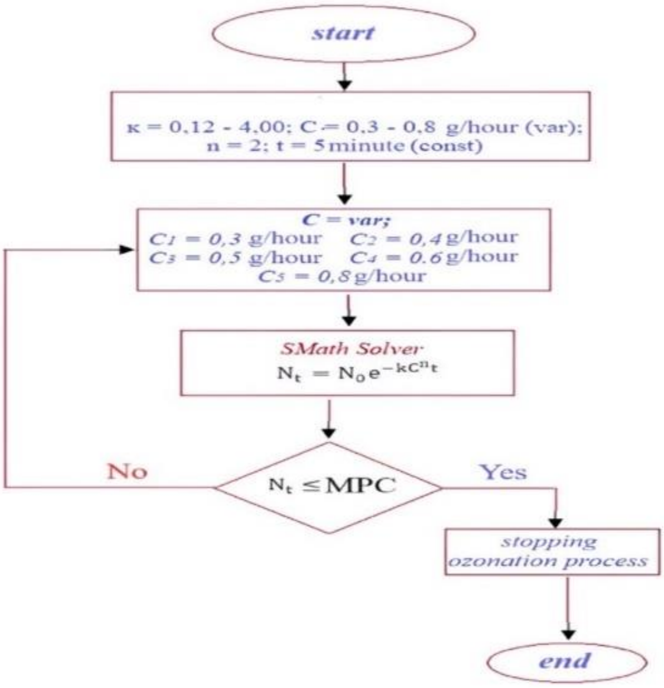
According to the research work, the process of complete disinfection of 1m³ of water from harmful microorganisms was carried out according to two options:

Option 1: according to this option, let's determine the number of survivors of harmful microorganisms during the N_t – process in water by changing the concentration of ozone in the range of C = 0.3 - 0.8 g/hour? Where time constant t = 5 minutes; dilution coefficient *n=2*; disinfection rate constant κ = 0.12 – 4.00; N_0 - the initial number of microorganisms is given in Table 11 below. Based on this data, let's write from the expression (23) the number of microorganisms eliminated by the concentration of ozone (N_t) in Table 11.

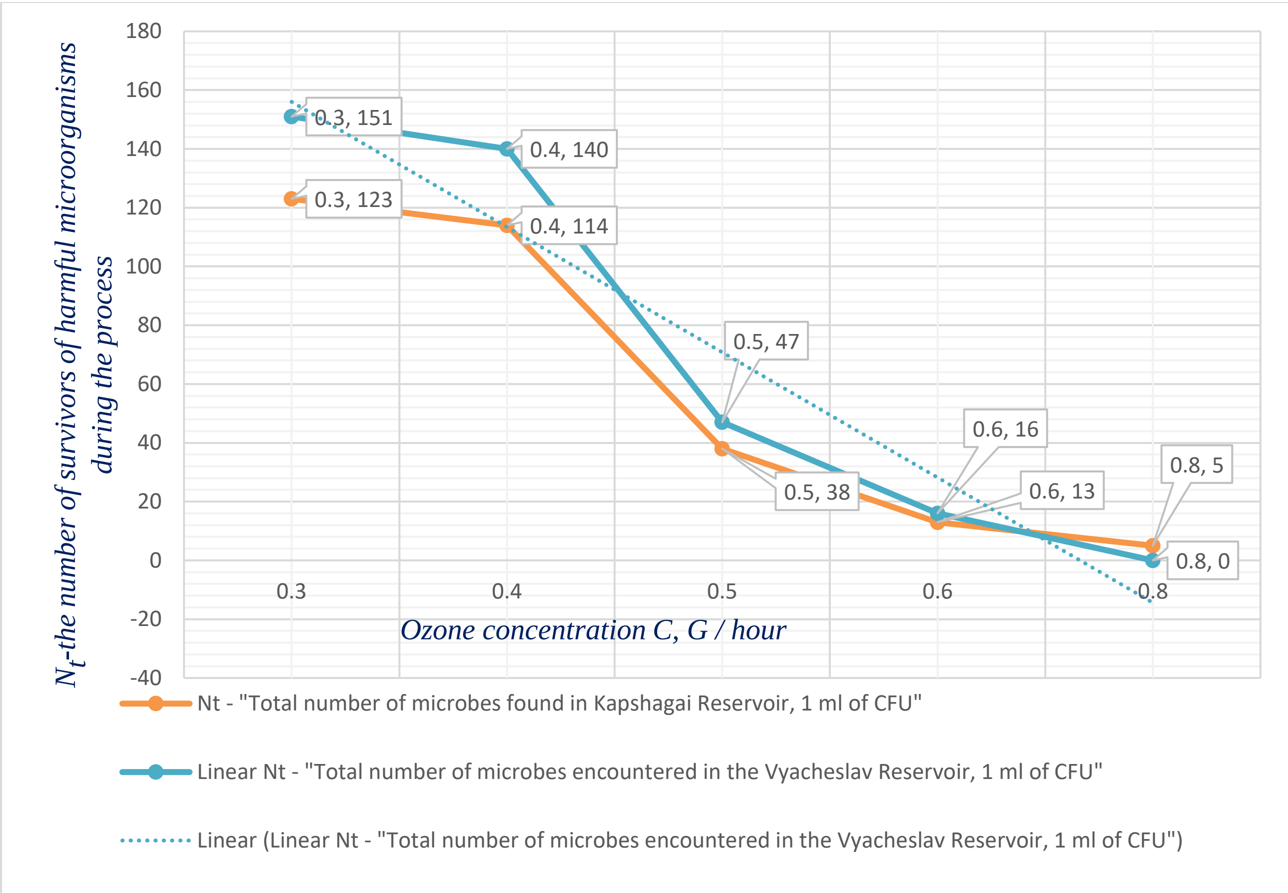
Table 11: Microbiological indicators of water content in Kapshagai and Vyacheslav reservoirs, depending on the amount of ozone (t = const)

№	C, g/hour	t, minute	n	k, minute	N_0	N_t	N_0	N_t	Regulations not more (MPC)
					Kapshagai reservoir		Vyacheslav reservoir		
Total number of microbes, 1 ml CFU									
1	0,3	5	2	0,12	130	123	160	151	<50
2	0,4			0,16		114		140	
3	0,5			0,98		38		47	
4	0,6			1,278		13		16	
5	0,8			4,00		0		0	
TCB (100 ml CFU)									
1	0,3	5	2	0,12	270	255	370	350	0
2	0,4			0,16		237		325	
3	0,5			0,98		79		108	
4	0,6			1,278		27		37	
5	0,8			4,00		0		0	
CCB (100 ml CFU)									
1	0,3	5	2	0,12	650	615	800	757	0
2	0,4			0,16		571		703	
3	0,5			0,98		190		235	
4	0,6			1,278		65		80	
5	0,8			4,00		0		0	
Coliphages (100 мл PFU)									
1	0,3	5	2	0,12	135	127	170	161	0
2	0,4			0,16		118		149	
3	0,5			0,98		39		49	
4	0,6			1,278		13		17	
5	0,8			4,00		0		0	

And now let's draw the destruction of microorganisms contained in water in the interval C = 0.3 – 0.8 g/hour, depending on the amount of ozone, according to the data in Table 11. Where time constant is t = const. The algorithm for the destruction and contact characteristics of microbiological indicators of the water content of 1m³ are presented in figures 15 a and b below.



a) Algorithm for the process of eliminating harmful microorganisms contained in water (t = const)



b) The characteristic between the number of survivors of harmful microorganism during the N_t - process in ozone and water

Figure 15: Tendency to eliminate harmful microorganisms contained in water (t=const

Figure 15 of the aforementioned equation (22,23) illustrates that the method for eliminating harmful microorganisms in water through the algorithm is most effective with an ozone concentration of C = 0.8 g/h. Throughout the technological process, it's feasible to counterbalance the water composition from detrimental compounds by adjusting the time constant at a specific juncture. By maintaining a constant ozone level in the water (C = const) while altering the decontamination duration, we can ascertain the effective time constant.

Option 2: according to this option, let's determine the number of microorganisms that survived during the Nt process by keeping the ozone concentration constant C = 0.8 g/hour, and accordingly changing the decontamination time from T = 5 to 25 minutes? Where the dilution coefficient is n=2; the constant of the disinfection rate is κ = 0.12 – 4.00; N_0 - the initial number of microorganisms is given in Table 12 below. Based on this data, let's write from the expression (23) to table 12 of the number of microorganisms (N_t) that have been removed due to time.

Table 12: Time-dependent (C = const) microbiological indicators of water content in Kapshagai and Vyacheslav reservoirs

№	C, g/hour	t, minute	n	k, minute	N_0	N_t	N_0	N_t	Regulations not more (MPC)
					Kapshagai reservoir		Vyacheslav reservoir		
Total number of microbes, 1 ml CFU									
1	0,8	5	2	0,12	130	123	160	151	<50
2		10		0,16		112		138	
3		15		0,98		34		42	
4		20		1,278		13		16	
5		25		4,00		0		0	
TCB (100 ml CFU)									
1	0,8	5	2	0,12	270	255	370	350	0
2		10		0,16		233		320	
3		15		0,98		71		98	
4		20		1,278		27		37	
5		25		4,00		0		0	
CCB (100 ml CFU)									
1	0,8	5	2	0,12	650	615	800	757	0
2		10		0,16		562		692	
3		15		0,98		173		213	
4		20		1,278		65		80	
5		25		4,00		0		0	
Coliphages (100 ml PFU)									
1	0,8	5	2	0,12	135	127	170	161	0
2		10		0,16		116		147	
3		15		0,98		35		45	
4		20		1,278		13		17	
5		25		4,00		0		0	

And now, according to the data in Table 12, let's keep the ozone content constant C = 0.8 g/hour, and accordingly change the decontamination time t = 5 – 25 minutes. Let's draw an algarite of the destruction of microorganisms contained in the water at this point (fig.16).

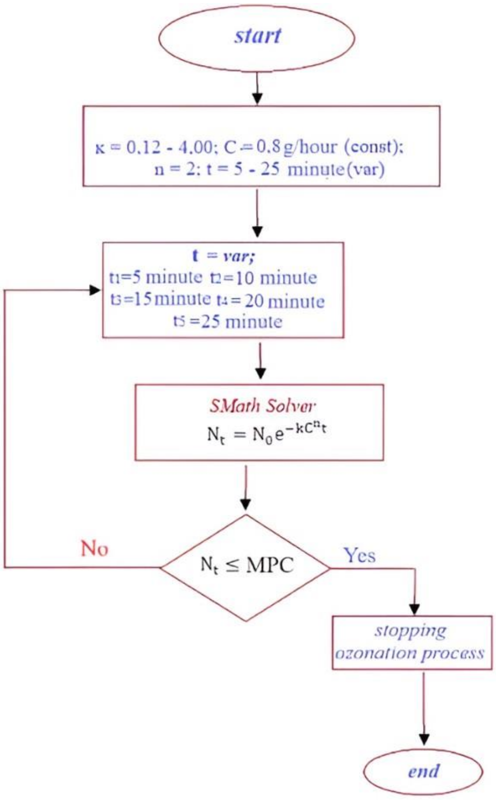


Figure 16: Procedure for eliminating detrimental microorganisms in water (C = const)

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It is possible to determine the time (t, minutes) and the amount of ozone concentration (C, g/hour) of the process of destruction of harmful microorganisms (N_t) in water using the algorithm presented above in figures 15 a, b and 16.

4. Discussion Of Scientific Research Work

Microorganisms present in surface waters can pose various threats to human health. The damage they cause is primarily due to diseases and infections transmitted through water. Here are some common microorganisms found in surface waters and their potential health effects:

Bacteria: pathogenic bacteria like E. coli, Salmonella, and Vibrio cholerae can induce gastrointestinal infections, resulting in symptoms such as diarrhea, abdominal cramps, nausea, and vomiting

Viruses: Intestinal viruses such as norovirus and rotavirus are responsible for viral gastroenteritis. They can cause severe diarrhea, dehydration, and sometimes more serious complications, especially in vulnerable groups such as children and the elderly.

Parasites: Protozoa such as" Giardia lamblia "and" cryptosporidium parvum " can cause gastrointestinal problems. Cryptosporidia, in particular, are resistant to traditional disinfection methods and can lead to long-term diarrhea, especially in people with weakened immune systems.

Algae: Toxic algae can cause harmful algae blooms (HABs) that release toxins into the water. Ingestion or contact of these toxins with the skin can cause various health problems, including respiratory problems, skin irritation, and in severe cases, neurotoxic effects.

Mushrooms: Although some water-carrying fungi are rare in surface water, they can cause infections, especially in people with weakened immune systems. Examples are the species" Aspergillus "and" Fusarium".

The health risks associated with these microorganisms highlight the importance of proper water treatment and disinfection. Contaminated surface water, especially in areas with insufficient sanitation and water treatment facilities, can lead to the widespread spread of waterborne diseases. In addition, extreme weather events such as heavy rain and floods can increase the chances of contamination. However, currently, the main widespread methods of water disinfection are the following methods (figure 17).

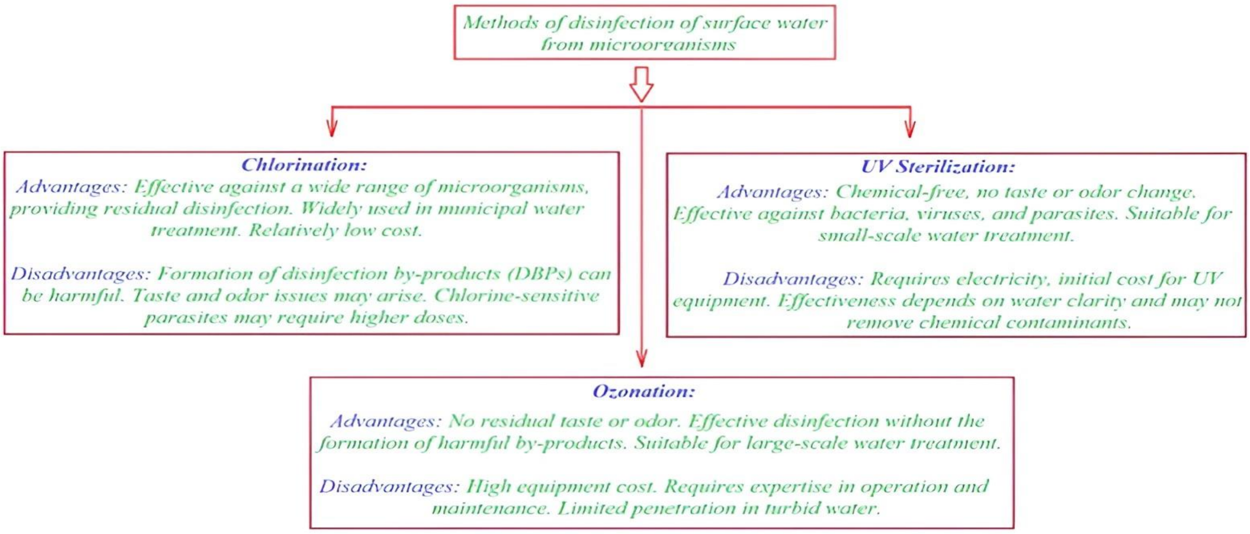

Figure 17: Advantages and disadvantages of methods for disinfection of water from harmful microorganisms

Proper water disinfection methods such as chlorination, UV sterilization or ozonation are very effective in reducing the microbial load in surface water and preventing water-borne diseases. Constant monitoring of water quality and compliance with water safety standards is essential to ensure the health and well-being of communities that use surface water sources.

Among the listed methods, we paid special attention to ozone technology during our scientific research work. Figure 18 below shows the effectiveness of ozone technology in eliminating harmful microorganisms contained in surface water.

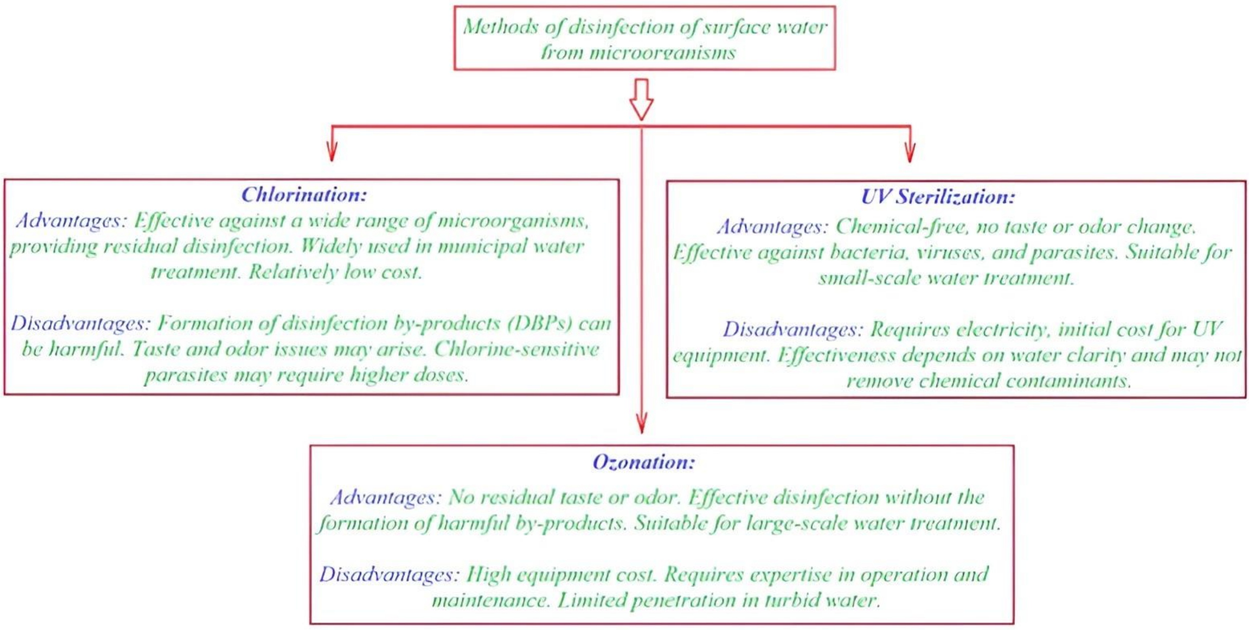

Figure 18: Efficiency of the process of neutralization of harmful microorganisms in water using ozone technology

In Figure 18, the efficacy of ozone technology in neutralizing harmful microorganisms present in water was thoroughly examined. The study also delved into the technological and design aspects of the ozonation process for Kapshagai and Vyacheslav surface waters, utilizing the Etro-02 ozonator unit featuring a pilot, innovative electric Crown discharge of 21 kV with a frequency of 13 kHz. However, a drawback of ozone technology is that water treated with ozone may traverse many kilometers of pipelines before reaching consumers, potentially encountering secondary contamination along the way. To mitigate this issue, a high-quality water filter was incorporated into the technological scheme. Among the filters examined, the research highlighted membrane filters as the most effective option. These filters are safe for human consumption and yield water that can be consumed without further treatment.

5. Conclusions

Over the past 5 years, a comprehensive review of modern scientific literature has been carried out on the process of destroying harmful microbacteria in surface water with the help of ozone technology, which is subject to environmental problems. Based on the review of the scientific literature at the Department of "Electronics, Telecommunications and space technologies" of the Satbayev University, the Etro-02 ozonator unit based on the electric Crown discharge was developed. According to scientific research, the ozonator plant was tested, special water was removed from the surface reservoirs of Kapshagai (Kunayev) and Vyacheslav (Astana), ozonation was carried out. Scientific research was carried out in the "sanitary and hygienic Laboratory" of the RSE of Almaty and in the scientific laboratories "Astana Su Arnasy" of Astana. During the research work, the following results were revealed:

- for testing the installation, surface water was taken from the Kapshagai and Vyacheslav reservoirs, where aranai was exposed to environmental problems, and expert samples were carried out. The number of microbiological indicators that do not meet the standards found in the composition of water is as follows: total number of microbes 130-160 (1 ml of CFU), TCB 270-370 (100 ml of CFU), CCB 650-800 (100 ml of CFU), coliphages 135-170 (100 ml of PFU). To completely neutralize and clean these bacteria, the amount of ozone consumed per 1m^3 of water was enough for 0.6– 0.8 g/hour of ozone. And it turned out that the decontamination time will be enough 20 – 25 minutes;

- There was a decrease in toxicological indicators found in water, i.e. Inorganic compounds with a high toxicity indicator such as nitrates, nitrites, fluorine, etc.;

- Toxicological indicators found in the composition of water were observed in which there was a decrease in organic compounds.

This proposed scientific research work was carried out using the Etro – 02 ozonator unit based on an electric corona discharge with a special frequency of 13 kHz and a voltage of 21 kV. Research work was carried out in the period from 2020 to 2023, and the performance of the unit, its power and other technological indicators were determined.

References

Abdelaziz A.A., Ishijima, T., Seto, T., Osawa, N., Wedaa, H., Otani, Yo., 2016. Characterization of surface dielectric barrier discharge influenced by intermediate frequency for ozone pro-duction. Plasma Sources Science and Technology, 25 (3). URI: http://10.1088/0963-0252/25/3/035012.

Abdykadyrov A, Marxuly S., Kuttybayeva A., Domrachev V., Boranbayeva A, Kasimov A, Yerzhan A, Baibolov N. 2023. Process of determination of surface water by ultraviolet radiations, Water Conservation and Management Edition 7, Release 2, Pages 158 – 167 Doi: 10.26480/wcm.02.2023.158.167

Abdykadyrov A, Marxuly S., Tashtay Y., Kuttybayeva A., Sharipova G., Khabay A., Bazarbay A., Akylzhan P., 2023. Study of the process of cleaning water-containing iron solutions using ozone technology, Water Conservation and Management Edition 7, Release 2, Pages 148 – 157 Doi: 10.26480/wcm.02.2023.148.157

Abdykadyrov A.A., Dagarbek R., Kozhaspayev N.K., Rakhimov D.T., and Turdybek B. 2014. A device for producing an ozone-air mixture "ETRO-02". Innovation patent number: No.28562. Kazakhstan patent database. https://kzpatents.com/0-ip28562-ustrojjstvo-dlya-polucheniya-ozonovozdushnojj-smesi-etro-02.html

Abdykadyrov, A., Marxuly, S., Kuttybayeva, A., Almuratova, N., Yermekbayev, M., Ibekeyev, S., and Bagdollauly, Y. 2023. Study of the Process of Destruction of Harmful Microorganisms in Water. Water. 15 (3), Pp. 503. https://doi.org/10.3390/w15030503

Abdykadyrov, A., Marxuly, S., Mamadiyarov, M., Smailov, N., Zhunusov, K., Kuttybaeva, A., and Orazbekov, A., 2023. Investigation of the Efficiency of the Ozonator in the Process of Water Purification Based on the Corona Discharge //Journal of Ecological Engineering. 24 (2). DOI: https://doi.org/10.12911/22998993/156610

Al-Abri, M., Al-Ghafri, B., Bora, T., Dobretsov, S., Dutta, J., Castelletto, S., and Boretti, A., 2019. Chlorination disadvantages and alternative routes for biofouling control in reverse osmosis desalination. npj Clean Water, 2 (10), Pp. 2. https://www.nature.com/articles/s41545-018-0024-8

Bakhir V.M. 2007. Disinfection of drinking water: analysis and prospects. Journal Drinking water, 3, Pp. 17–19.

Bakhir V.M., 2003. Disinfection of drinking water: problems and solutions. Journal Drinking water, 1, Pp. 17–34.

Banach JL, Sampers I, Haute S, and Fels-Klerx HJ. 2015. Effect of disinfectants on preventing the cross-contamination of pathogens in fresh produce washing water. International Journal of Environmental Research and Public Health, 12, Pp. 8658–8677. doi: 10.3390/ijerph120808658.

Barák I., and Muchová K. 2013. The role of lipid domains in bacterial cell processes //International Journal of Molecular Sciences, 14 (2), Pp. 4050-4065. https://doi.org/10.3390/ijms14024050

Bavasso, I., Montanaro, D., Di Palma, L., Petrucci E., 2020. Electrochemically assisted decomposition of ozone for degradation and mineralization of Diuron. Electrochimica Acta, 331, Pp. 135423. https://doi.org/10.1016/j.electacta.2019.135423

Bocci, Velio, and Velio Bocci. 2011. Physical-chemical properties of ozone–natural production of ozone: the toxicology of ozone. OZONE: A new medical drug. Pp. 1-4. doi: 10.1007/978-90-481-9234-2_1

Bonnelye, V., and Richard, Y., 1997. Changes in ozone demand of water during the treatment process, Ozone: Science and Engineering, 19 (4), Pp. 339–350.

Botondi, R., Lembo, M., Carboni, C., and Eramo, V. 2023. The Use of Ozone Technology: An Eco–Friendly Method for the Sanitization of the Dairy Supply Chain //Foods. 12 (5) Pp. 987. https://doi.org/10.3390/foods12050987

Brodowska, A.J., Nowak, A., Kondratiuk-Janyska, A., Piątkowski, M., and Śmigielski, K., 2017. Modelling the ozone-based treatments for inactivation of microorganisms. International journal of environmental research and public health. 14 (10), Pp. 1196. https://doi.org/10.3390/ijerph14101196

Broséus, R., Vincent, S., Aboulfadl, K., Daneshvar, A., Sauvé, S., Barbeau, B., and Prévost, M., 2009. Ozone oxidation of pharmaceuticals, endocrine disruptors and pesticides during drinking water treatment, Water research., 43 (18). Pp. 4707-4717. https://doi.org/10.1016/j.watres.2009.07.031

Castro, C.M.E., Nafarrate, M.P., Olvera, A.M.B.,and Martínez, C.G. Emerging Technologies in Water Treatment: Recent Advances. – 2023. DOI: 10.5772/intechopen.109063

Cataldo F., 2003. On the action of ozone on proteins //Polymer Degradation and Stability. 82 (1). Pp. 105-114. https://doi.org/10.1016/S0141-3910(03)00170-8

Cescon A., Jiang J. Q., 2020. Filtration process and alternative filter media material in water treatment //Water. 12 (12), Pp. 3377. https://doi.org/10.3390/w12123377

Chasanah, U., Yulianto, E., Zain, A. Z., Sasmita, E., Restiwijaya, M., Kinandana, A. W., and Nur, M., 2019. Evaluation of titration method on determination of ozone concentration produced by dielectric barrier discharge plasma (DBDP) technology. Journal of Physics: Conference Series. – IOP Publishing, 1153 (1), Pp. 012086. **DOI** 10.1088/1742-6596/1153/1/012086

Collivignarelli, M. C., Abbà, A., Benigna, I., Sorlini, S., & Torretta, V. (2017). Overview of the main disinfection processes for wastewater and drinking water treatment plants, Sustainability. 10 (1), Pp. 86. https://doi.org/10.3390/su10010086

Dan Kroll, 2007. Security of National Water Supply, The American Society for Microbiology and ASM Biodefense and Emerging Disease Meeting, Washington D.C.Watch.

Davidson, J., Good, C., Welsh, C., and Summerfelt, S. 2011. The effects of ozone and water exchange rates on water quality and rainbow trout Oncorhynchus mykiss performance in replicated water recirculating systems, Aquacultural Engineering. 44 (3), Pp. 80-96. https://doi.org/10.1016/j.aquaeng.2011.04.001

Diana Vega and Yuly Sánchez. 2021. Analysis of swimming pool water disinfection technologies in the Piscilago Water Park Girardot – Cundinamarca. 2021 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI). DOI: 10.1109/CONIITI53815.2021.9619696

Ding, W., Jin, W., Cao, S., Zhou, X., Wang, C., Jiang, Q., and Wang, Q. 2019. Ozone disinfection of chlorine-resistant bacteria in drinking water. Water research, (160). Pp. 339-349. https://doi.org/10.1016/j.watres.2019.05.014

Draginsky V.L., Alekseeva L.P., and Samoilovich V.G., 2007. Ozonation in water purification processes. Moscow: DeLi print.

Egorova, G.V., Voblikova, V.A., Sabitova, L.V., Tkachenko, I.S., Tkachenko, S.N., and Lunin, V.V., 2015. Ozone Solubility in Water. Moscow University Chemistry Bulletin, 70 (5), Pp. 207–210. DOI: 10.3103/S0027131415050053 https://link.springer.com/article/10.3103/S0027131415050053

Eike Breitbarth, Matthew M. Mills, Gernot Friedrichs, and Julie LaRoche, 2004. The Bunsen gas solubility coefficient of ethylene as a function of temperature and salinity and its importance for nitrogen fixation assays. Limnol. Oceanogr.: Methods 2, Pp. 282–288. https://aslopubs.onlinelibrary.wiley.com/doi/pdf/10.4319/lom.2004.2.282

Epelle E. I. et al. Microbial inactivation: gaseous or aqueous ozonation? //Industrial & Engineering Chemistry Research. – 2022. – Т. 61. – №. 27. – С. 9600-9610. https://doi.org/10.1021/acs.iecr.2c01551

Epelle, E. I., Macfarlane, A., Cusack, M., Burns, A., Okolie, J. A., Mackay, W., and Yaseen, M., 2023. Ozone application in different industries: A review of recent developments. Chemical Engineering Journal. 454, Pp. 140188. https://doi.org/10.1016/j.cej.2022.140188

Epelle, E.I., Macfarlane, A., Cusack, M., Burns, A., Amaeze, N., Richardson, K., Mackay, W., Rateb, M.E., Yaseen, M., 2022 Stabilisation of ozone in water for microbial disinfection Environments. 9 (4) Pp. 45. https://doi.org/10.3390/environments9040045

Eriksson, Margareta. 2005. Ozone chemistry in aqueous solution: ozone decomposition and stabilisation. Diss. KTH. https://www.diva-portal.org/smash/get/diva2:8778/FULLTEXT01.pdf

Estévez, S., González-García, S., Feijoo, G., Moreira, M.T., 2022. How decentralized treatment can contribute to the symbiosis between environmental protection and resource recovery. Science of the total Environment, 812, Pp. 151485. https://doi.org/10.1016/j.scitotenv.2021.151485

Galdeano, M. C., Wilhelm, A. E., Goulart, I. B., Tonon, R. V., Freitas-Silva, O., Germani, R., and Chávez, D. W. H., 2018. Effect of water temperature and pH on the concentration and time of ozone saturation. Brazilian Journal of Food Technology. T, (21). https://doi.org/10.1590/1981-6723.15617

García-Araya J.F., Beltrán F.J. 2023. Photocatalytic Oxidation, Ozonation Processes Catalysts. 13 (2), Pp. 314. https://doi.org/10.3390/catal13020314

Gorito, A.M., Pesqueira, J.F., Moreira, N.F., Ribeiro, A.R., Pereira, M.F.R., Nunes, O.C., and Silva, A.M., 2021. Ozone-based water treatment (O3, O3/UV, O3/H2O2) for removal of organic micropollutants, bacteria inactivation and regrowth prevention. Journal of Environmental Chemical Engineering. 9 (4). Pp. 105315. https://doi.org/10.1016/j.jece.2021.105315

Guo, Y., Zhan, J., Yu, G., and Wang, Y., 2021. Evaluation of the concentration and contribution of superoxide radical for micropollutant abatement during ozonation. Water Research. 194, Pp. 116927. DOI: 10.1016/j.watres.2021.116927

Hafsan, H., Huy, D.T.N., Van Tuan, P., Mahmudiono, T., Dinku, T., Nasirin, C., and Al-Mawlawi, Z.S. 2023. Modelling of inactivation of microorganisms in the process of sterilization using high pressure supercritical fluids //Food Science and Technology. 43, Pp. e111621. DOI: https://doi.org/10.1590/fst.111621

Hoigné J., and Bader H., 1983. Rate constants of reactions of ozone with organic and inorganic compounds in water—II: dissociating organic compounds, Water research. 17 (2), Pp. 185-194. https://doi.org/10.1016/0043-1354(83)90099-4

HY Li, C Deng, L Zhao, CH Gong, MF Zhu, JW Chen., 2022. Ozone water production using a SPE electrolyzer equipped with boron doped diamond electrodes. Water Supply. T, (22), 4. C. Pp. 3993-4005. https://doi.org/10.2166/ws.2022.029

Ishaq, M. S., Afsheen, Z., Khan, A., and Khan, A., 2018. Disinfection methods, Photocatalysts-applications and attributes. Pp. 3-19. DOI: 10.5772/intechopen.80999

Jian, J., Hashemi, H., Wu, H., Jasper, A. W., and Glarborg, P., 2022. A reaction mechanism for ozone dissociation and reaction with hydrogen at elevated temperature, Fuel. 322, Pp. 124138. https://doi.org/10.1016/j.fuel.2022.124138

Jin, X., Zhang, L., Liu, M., Hu, S., Yao, Z., Liang, J., Wang, R., Xu, L., Shi, X., Bai, X., Jin P., Wang XC., Chemosphere., 2022. Characteristics of dissolved ozone flotation for the enhanced treatment of bio-treated drilling wastewater from a gas field, 298, C. 134290. https://doi.org/10.1016/j.chemosphere.2022.134290

Judah, H. L., Liu, P., Zarbakhsh, A., and Resmini, M., 2020). Influence of buffers, ionic strength, and pH on the volume phase transition behavior of acrylamide-based nanogels, Polymers. 12 (11) Pp. 2590. https://doi.org/10.3390/polym12112590

Kapchagay Reservoir. https://en.wikipedia.org/wiki/Kapchagay_Reservoir

Khainatsky, S.A., Hristo, A.I., Shvedov, L.P., 2018. Electric discharge methods of water purification. ISSN 2519-2248 (Online), 2079-0740 (Print). 537.528:66.088. https://core.ac.uk/reader/161785286

KZ News, 2022. Pollution of the Kapchagai reservoir can lead to an ecological disaster. https://24.kz/ru/news/social/item/576083-deputat-zagryaznenie-kapchagajskogo-vodokhranilishcha-mozhet-privesti-k-ekologicheskoj-katastrofe

Lakey, P. S., Wisthaler, A., Berkemeier, T., Mikoviny, T., Pöschl, U., and Shiraiwa, M., 2017. Chemical kinetics of multiphase reactions between ozone and human skin lipids: Implications for indoor air quality and health effects, Indoor air. 27 (4), Pp. 816-828. https://doi.org/10.1111/ina.12360

Limarenko, E.E., and Novikov, M.G., 2014. On the issue of chlorination of water for drinking and household purposes. Journal Water resources and water use, 1 (120), Pp. 10–11.

Lin, Y., Juan, H., and Cheng, Y., 2007. Ozone exposure in the culture medium 249 inhibits enterovirus 71 virus replication and modulates cytokine pro- 250 duction in rhabdomyosarcoma cells. Antiviral Research, 76, 3, 251 pp. 241–251, Dec. 2007. 252

Loeb B. L. 2011. Ozone: Science & Engineering: Thirty-three years and growing //Ozone: Science & Engineering. 33 (4), Pp. 329-342. https://doi.org/10.1080/01919512.2011.584302

Maddocks, A., Young, R.S., Reig, P., 2015. Ranking the World's Most Water-Stressed Countries in 2040, Available online: https://www.wri.org/insights/ranking-worlds-most-water-stressed-countries-2040 (accessed on 24 November 2022).

Mai Kai Suan Tial and Fumiaki Mitsugi, 2022 Characteristics of Water-Cooling Dielectric Barrier Discharge Spraying Nozzle. IEEE Transactions on Plasma Science, 50 (9). DOI: 10.1109/TPS.2022.3195814

Martinelli, M., Giovannangeli, F., Rotunno, S., Trombetta, C.M., and Montomoli, E., 2017. Water and air ozone treatment as an alternative sanitizing technology, Journal of preventive medicine and hygiene. – 2017. – Т. 58. – №. 1. – С. E48.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5432778/

Mecha, A.C., Onyango, M.S., Ochieng, A., and Momba, M.N., 2020. Modelling inactivation kinetics of waterborne pathogens in municipal wastewater using ozone //Environmental Engineering Research. 25 (6) Pp. 890-897. DOI: https://doi.org/10.4491/eer.2019.432

Merouani S., and Hamdaoui O. 2019. Sonolytic ozonation for water treatment: efficiency, recent developments, and challenges. Current opinion in Green and sustainable chemistry, Pp. 98-108. https://doi.org/10.1016/j.cogsc.2019.03.003

Ministry of Justice of the Republic of Kazakhstan, 2015. On approval of Sanitary rules "Sanitary and epidemiological requirements for water sources, places of water intake for household and drinking purposes, household and drinking water supply and places of cultural and domestic water use and safety of water bodies". https://adilet.zan.kz/rus/docs/V1500010774

Morrison, C. M., Hogard, S., Pearce, R., Gerrity, D., von Gunten, U., and Wert, E.C., 2022. Ozone disinfection of waterborne pathogens and their surrogates: A critical review Water Research, 214. Pp. 118206. https://doi.org/10.1016/j.watres.2022.118206

Mouele, E.S.M., Tijani, J.O., Fatoba, O.O., and Petrik, L.F., 2015. Degradation of organic pollutants and microorganisms from wastewater using different dielectric barrier discharge configurations—a critical review //Environmental Science and Pollution Research. 22, Pp. 18345-18362. https://link.springer.com/article/10.1007/s11356-015-5386-6

Muzafarov, S.M., Babaev, A.G., Kilichov, O.G., and Batirova, L.A., 2021. Disinfection of drinking water with ozone by the method of electrodispersion. IOP Conference Series: Earth and Environmental Science, IOP Publishing, 2021. 939 (1) Pp. 012016. doi:10.1088/1755-1315/939/1/012016

Ngwenya N, Ncube EJ, Parsons J. 2013. Recent advances in drinking water disinfection: successes and challenges. Reviews of Environmental Contamination and Toxicology, 222, Pp. 111–170. doi: 10.1007/978-1-4614-4717- 7_4.

Ngwenya N., Ncube E. J., Parsons J. 2012. Recent advances in drinking water disinfection: successes and challenges, Reviews of environmental contamination and toxicology, Pp. 111-170. https://www.health.state.mn.us/communities/environment/water/factsheet/ddbp.html

Novikov, M.G., Prodous. O.A., n.d. Comparative assessment of the effectiveness of water disinfection with various reagents for household and drinking purposes. https://isguru.ru/stati/vodosnabzhenie-i-vodootvedenie/5680-sravnitelnaya-oczenka-effektivnosti/

Parpiev, M.P.; Simonov, A.A.; Kamardin, Aleksey; and Nazarov, Abdulaziz M., 2021. Estimating The Bubbling Process Of Ozone-Containing Gases In The Water, Chemical Technology, Control and Management, 2021 (1), Article 2. DOI: https://doi.org/10.34920/2021.1.11-20

Pérez-Lucas, G., Martínez-Menchón, M., Vela, N., and Navarro, S., 2022. Removal assessment of disinfection by-products (DBPs) from drinking water supplies by solar heterogeneous photocatalysis: A case study of trihalomethanes (THMs). Journal of Environmental Management. 321, Pp. 115936. https://doi.org/10.1016/j.jenvman.2022.115936

Physical-geographic characteristics of the region. Republic of Kazakhstan. http://www.cawater-info.net/bk/water_land_resources_use/english/docs/fiziko_geog_kharack_kazakhstan.html

Portjanskaja E., 2010. Ozone reactions with inorganic and organic compounds in water, Encyclopedia of Life Support Systems. Ozone Science and Technology. https://www.eolss.net/sample-chapters/c07/E6-192-06-00.pdf

Qasim M., Rafique M. S., and Naz R. 2022 Water purification by ozone generator employing non-thermal plasma, Materials Chemistry and Physics. 291, Pp. 126442. https://doi.org/10.1016/j.matchemphys.2022.126442

Rangel, K., Cabral, F. O., Lechuga, G. C., Carvalho, J. P., Villas-Bôas, M. H., Midlej, V., and De-Simone, S.G., 2021. Detrimental Effect of Ozone on Pathogenic Bacteria. Microorganisms 10 (1). https://doi.org/10.3390/microorganisms10010040

Republic of Kazakhstan: Astana Integrated Water Master Plan. https://www.adb.org/sites/default/files/project-documents/51353/51353-001-tacr-en.pdf

Richardson S. D., Postigo C. 2012. Drinking water disinfection by-products //Emerging organic contaminants and human health. Pp. 93-137.

Rosenblum J, Ge C, Bohrerova Z, and Yousef A, Lee J. 2012. Ozonation as a clean technology for fresh produce industry and environment: sanitizer efficiency and wastewater quality. Journal of Applied Microbiology, 113 (4), Pp. 837–845. doi: 10.1111/j.1365-2672.2012.05393.x.

Rubin Battlno, Timothy R. Rettich and Toshihiro Tominaga, 2009. The Solubility of Oxygen and Ozone in Liquids. Department of Chemistry, Wright State University, Dayton, Ohio 45435. https://srd.nist.gov/jpcrdreprint/1.555680.pdf

S Lim, JL Shi, U von Gunten, DL McCurry. 2022. Ozonation of organic compounds in water and wastewater: A critical review. Water research (213), Pp. 118053. https://doi.org/10.1016/j.watres.2022.118053

Sander, R., 2015. Compilation of Henry's law constants (version 4.0) for water as solvent. Atmospheric Chemistry and Physics, 15 (8), Pp. 4399-4981. https://acp.copernicus.org/articles/15/4399/2015/acp-15-4399-2015.pdf

Santos, L.M.C.D., Silva, E.S.D., Oliveira, F.O., Rodrigues, L.D.A.P., Neves, P.R.F., Meira, C. S., and Machado, B.A.S., 2021. Ozonized water in microbial control: analysis of the stability, in vitro biocidal potential, and cytotoxicity, Biology. 10 (6) Pp. 525. https://doi.org/10.3390/biology10060525

Sassi J, Viitasalo S, Rytkonen J, Leppakoski E. 2005. Experiments with ultraviolet light, ultrasound and ozone technologies for onboard ballast water treatment. VTT TIEDOTTEITA. Turku, Finland: Åbo Akademi University; 2005 https://www.vttresearch.com/sites/default/files/pdf/tiedotteet/2005/T2313.pdf

Seleznev, G.M., Lykov S.M. and others. 2007. New technologies and equipment for disinfection of water — an alternative to chlorine. Journal Occupational safety in industry, 2, Pp. 64–66.

Seridou P., and Kalogerakis N. 2021 Disinfection applications of ozone micro-and nanobubbles //Environmental Science: Nano. 8 (12) Pp. 3493-3510. DOI: 10.1039/D1EN00700A

Shin, D., Song, S., Ryoo, S. B., and Lee, S.S., 2020. Variations in ozone concentration over the mid-latitude region revealed by ozonesonde observations in Pohang, South Korea, Atmosphere. 11 (7), Pp. 746. https://doi.org/10.3390/atmos11070746

Siberian Ecology company, 2022. Sanitary rules and regulations 2.1.4.1074-01. Drinking water. Hygienic requirements for the water quality of centralized drinking water supply systems. Quality control.

https://www.sibecolog.ru/informatsiya/81/

SMathStudio.Icons.zip (Дата: 12.04.2010. Размер: 63,74KB)

Soboksa, N.E., Gari, S.R., Hailu, A.B., Donacho, D.O., and Alemu, B.M., 2020. Effectiveness of solar disinfection water treatment method for reducing childhood diarrhoea: a systematic review and meta-analysis //BMJ open. 10 (12), Pp. e038255. https://bmjopen.bmj.com/content/bmjopen/10/12/e038255.full.pdf

Sofia, D. R. 2020. The effect of ozonation on dissolved oxygen and microbiological content in refill drinking water. IOP Conference Series: Earth and Environmental Science. 443, (1). IOP Publishing. DOI 10.1088/1755-1315/443/1/012025

Spiliotopoulou, A., Rojas-Tirado, P., Chhetri, R. K., Kaarsholm, K. M., Martin, R., Pedersen, P. B., and Andersen, H. R., 2018. Ozonation control and effects of ozone on water quality in recirculating aquaculture systems, Water research. (133) Pp. 289-298. DOI:10.1016/j.watres.2018.01.032

Sukarminah, E., Djali, M., Andoyo, R., Mardawati, E., Rialita, T., Cahyana, Y., and Setiasih, I. S., 2017. Ozonization technology and its effects on the characteristics and shelf-life of some fresh foods: A review., KnE Life Sciences. Pp. 459-470. file:///C:/Users/Admin/Downloads/1065-Article%20Text-6210-1-10-20171126%20(1).pdf

Summerfelt S. T., 2003. Ozonation and UV irradiation—an introduction and examples of current applications. Aquacultural engineering. 28 (1-

2), Pp. 21-36. https://doi.org/10.1016/S0144-8609(02)00069-9

Takizawa, F., Domon, H., Hiyoshi, T., Tamura, H., Shimizu, K., Maekawa, T., and Terao, Y., 2023. Ozone ultrafine bubble water exhibits bactericidal activity against pathogenic bacteria in the oral cavity and upper airway and disinfects contaminated healthcare equipment. Plos one. 18 (4) Pp.

Tan, Y., Chen, W., Liao, G., Li, X., Wang, J., Tang, Y., and Li, L., 2022. Strategy for improving photocatalytic ozonation activity of g-C3N4 by halogen doping for water purification, Applied Catalysis B: Environmental. 306, Pp. 121133. https://doi.org/10.1016/j.apcatb.2022.121133

Tao, P., Yang, C., Wang, H., Zhao, Y., Zhang, X., Shao, M., and Sun, T. 2021. Synergistic effects of ultrasonic-assisted ozonation on the formation of hydrogen peroxide //Journal of Environmental Chemical Engineering. 2021. 9 (1) Pp. 104905. https://doi.org/10.1016/j.jece.2020.104905

Thanomsub, B., Anupunpisit, V., Chanphetch, S., Watcharachaipong, T., Poonkhum, R., and Srisukonth, C., 2002. Effects of ozone treatment on cell growth and ultrastructural changes in bacteria. The Journal of general and applied microbiology. 48 (4). Pp. 193-199. https://doi.org/10.2323/jgam.48.193

UN News, 2022. https://news.un.org/ru/story/2022/06/1425862

Von Sonntag C., and Von Gunten U. 2012. Chemistry of ozone in water and wastewater treatment. IWA publishing, file:///C:/Users/Admin/Downloads/external_content.pdf

Voukkali I., and Zorpas A. A. 2015. Disinfection methods and by-products formation, Desalination and Water Treatment. 56 (5), Pp. 1150-1161. DOI: 10.1080/19443994.2014.941010

Wei, C.H., Fengzhen, Z., Yun, H., Chunhua, F., and Haizhen, Wu., 2017. Ozonation in water treatment: the generation, basic properties of ozone and its practical application //Reviews in Chemical Engineering. 33 (1), Pp 49-89.

Wigginton, K.R. and Kohn, T., 2012.Virus disinfection mechanisms: The role 253 of virus composition, structure, and function, Current Opinion Virol, 254, 2, (1), Pp. 84–89.

World Economic Forum, 2022. Ensuring Sustainable Water Management for All by 2030 World Economic Forum. Available online, https://www.weforum.org/impact/sustainable-water-management/ (accessed on 9 January 2023).

Xue W., Macleod J., and Blaxland J. 2023. The Use of Ozone Technology to Control Microorganism Growth, Enhance Food Safety and Extend Shelf

e0284115. https://doi.org/10.1371/journal.pone.0284115

Takuya Kuwahara. 2018. Reduction in Energy Consumption Using Fuel Cells in Nonthermal Plasma-Based Water Sterilization by Bubbling Ozone. IEEE Transactions on Industry Applications, 54, 6. DOI: 10.1109/TIA.2018.2856860

Life: A Promising Food Decontamination Technology. Foods. 12 (4), Pp. 814. DOI: 10.3390/foods12040814

Yang, J., Li, Y., Yang, Z., Ying, G. G., Shih, K., and Feng, Y., 2023. Hydrogen peroxide as a key intermediate for hydroxyl radical generation during catalytic ozonation of biochar: Mechanistic insights into the evolution and contribution of radicals. Separation and Purification Technology. 324, Pp. 124525. https://doi.org/10.1016/j.seppur.2023.124525

Yiping Tian; Xiaoli Yuan; Shujing Xu; Xinying Zhou; and Zhitao Zhang. 2015. Drinking water disinfection based on strong electric field discharge and hydrodynamic cavitation. 2015 IEEE International Conference on Plasma Sciences (ICOPS). DOI: 10.1109/PLASMA.2015.7179534

Yudianto, D., Hariyadi, R.D., Sukarno, S., Nur, M., and Purnomo, E.H. 2023. Characterization of Ozone Distribution in Distilled Water and Coconut Water Produced Using a Double Dielectric Barrier Discharge Machine. Jurnal Biota 9 (2). Pp. 80-96. DOI https://doi.org/10.19109/Biota.v9i2.16714

Zheldakova Z.I., and Tulskaya E.A., 2010. Comparison of the reactivity of disinfectants in relation to aromatic chemical compounds in water. 4. Pp. 37–41.

Zinn, C., Bailey, R., Barkley, N., Walsh, M. R., Hynes, A., Coleman, T., and Haque, U., 2018. How are water treatment technologies used in developing countries and which are the most effective? An implication to improve global health //Journal of Public Health and Emergency, 2 (25), Pp. 1-14. http://dx.doi.org/10.21037/jphe.2018.06.02

Звонарев, С.В., 2019. З 42 Основы математического моделирования: учебное пособие / С.В. Звонарев. — Екатеринбург : Изд - во Урал. ун-та. Pp. 112.

Корко В. С., Челомбитько М. А., 2022. Производство и использование озона в пищевой промышленности и санитарии. 1, Международная научно-практическаяконференция, Pp. 22-23 ноября 2022 г. УДК 554.838.7:631.5 https://rep.bsatu.by/bitstream/doc/17425/1/Korko-V-S-Proizvodstvo-i-ispolzovanie-ozona-v-pishchevoj-promyshlennosti-i-sanitarii.pdf