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RESEARCH ARTICLE

RESEARCH ON THE PROCESS OF DISINFECTING AND PURIFYING PATHOGENIC BACTERIA AND VIRUSES IN DRINKING WATER USING OZONE TECHNOLOGY

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ABSTRACT

Introduction: The safety of drinking water is a crucial issue for human health. Pathogenic bacteria and viruses in poor-quality water contribute to the spread of dangerous diseases such as dysentery, typhoid fever, and poliomyelitis. Ozone technology is increasingly recognized as an eco-friendly and effective method for disinfecting water from pathogens. The aim of the study is to investigate the efficiency of disinfecting pathogenic bacteria and viruses in drinking water using ozone technology and to determine the inactivation of pathogens depending on ozone concentration and exposure duration. **Materials and Methods:** The study used 11 strains of typhoid bacteria and 36 strains of dysentery bacteria. To disinfect with ozone, 14 mg/L of ozone was added to the water for 5 minutes, and the inactivation levels of the pathogens were studied. The sensitivity of poliomyelitis and Coxsackie viruses to ozone was also evaluated. **Scientific Results of the Study**: The results of the study showed that ozone inactivated typhoid bacteria by up to 99.95% and dysentery bacteria by up to 99.99%. The poliomyelitis virus was eliminated by 99.99% within 6 minutes, and the Coxsackie virus was inactivated by 99.7% to 99.9% within 15 minutes. The disinfection efficiency was high when the residual ozone concentration was approximately 0.15 - 0.2 mg/L. **Conclusion:** The study demonstrated that ozone technology is an eco-friendly and effective method for disinfecting pathogenic microorganisms in drinking water. The research also showed that higher ozone concentrations and longer exposure times significantly improve pathogen elimination efficiency.

KEYWORDS

Ozone technology, pathogenic microorganisms, bacteria and viruses, disinfection process, oxidizing agent, combination methods, drinking water purification process.

1. INTRODUCTION

Drinking water safety is one of the crucial aspects of ensuring human health. According to the World Health Organization, more than 2 billion people worldwide consume water from unsafe sources, leading to the spread of various infectious diseases (Mack and Choffnes, 2009) . The primary danger of poor-quality water lies in the presence of pathogenic bacteria and viruses, which can cause severe illnesses such as dysentery, cholera, hepatitis, and others (Muryani, E., 2021). While there are various methods for water purification, ozone technology is emerging as one of the most effective and environmentally friendly options (Askar Abdykadyrov et al., 2024; Abdykadyrov et al., 2023). Ozone (O_3), being a strong oxidizing agent, efficiently and rapidly destroys pathogens (Tripathi and Hussain 2022).

The advantages of ozone disinfection include its high effectiveness and the ability to provide chemical-free, clean disinfection (Premjit et al., 2022). Additionally, ozone not only eliminates bacteria and viruses but also breaks down organic compounds, odor-causing substances, and colorants (Kozhaspaev et al., 2016; Draginsky et al., 2007). However, precise control of ozone dosage is essential, as excessive ozone can have adverse effects on human health (Nuvolone et al., 2018).

Ozone-based water disinfection technology is widely used in various countries today, and its effectiveness has been confirmed by several scientific studies (Pichel et al., 2019; Kalandarov et al., 2024; Kalandarov et al., 2024). Unlike traditional chlorination methods, ozone disinfects without altering the chemical composition of the water or leaving harmful residue (Tripathi and Hussain, 2022). It dissolves in water and disrupts the cellular structures of pathogenic organisms, rendering them harmless (Uhm et al., 2009). Moreover, ozone naturally decomposes into O_2 molecules, making the process environmentally friendly (Bagdollauly et al., 2024).

In Kazakhstan, the issue of drinking water quality is of great importance, particularly in rural areas where access to safe drinking water is a pressing issue (Omarova et al., 2019; Bekturganov et al., 2016). As a result, studies on water purification using ozone technology are becoming more widespread, and its effectiveness is being researched (Abdykadyrov et al., 2024). This technology not only meets ecological safety standards but is also economically viable in Kazakhstan.

The objective of this study is to examine the effectiveness of disinfecting pathogenic bacteria and viruses in drinking water using ozone technology. The data obtained will contribute to improving methods used to ensure safe water. Enhancing water quality can improve public health (Holden et

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al., 2017). The key components of this study include determining the disinfection effects of ozone, its duration, and concentration in water (Bekturganov et al., 2016).

Throughout the research, the sensitivity of various pathogens to ozone will be identified, and recommendations for improving the disinfection process will be provided (Abdykadyrov et al., 2024). Additionally, a comparative analysis of ozone's efficiency relative to other methods will be considered (Holden et al., 2017). The study aims to highlight the importance of implementing ozone technology to improve drinking water quality.

Thus, this study is directed toward solving the urgent issue of obtaining high-quality, pathogen-free drinking water through the use of ozone technology. The strong oxidizing properties of ozone make it one of the most effective and safe methods for water disinfection (Draginsky et al., 2007;Duan et al., 2021). Therefore, researching the potential of this technology for protecting water sources and safeguarding public health is of great significance. The findings of this study will help develop new technological solutions aimed at making drinking water safer.

In this context, the use of new methods of ozone disinfection should be explored to ensure the efficient use of water resources and provide ecologically clean and safe drinking water sources.

2. Materials and Methods

For several decades, research on the disinfection of pathogenic bacteria and viruses in drinking water using ozone technology has been conducted intensively (Draginsky et al., 2007; Qadri Alam, 2024). Ozone is a powerful oxidizing agent that destroys pathogenic microorganisms by disrupting their cell walls and membranes. This method effectively disinfects bacteria, viruses, fungi, and other microorganisms. Ozone was first used for water disinfection in 1906 in Nice, France, and since then, it has gained popularity. One of the main advantages of ozone is that it leaves no residual substances in the water after disinfection, making it environmentally safe (Ahmad and Azam, 2019; Manasfi, 2021).

Compared to traditional methods such as chlorination, ozone has a much higher ability to eliminate bacteria and viruses (Lanrewaju et al., 2022). Moreover, chlorine residues can form harmful compounds to human health, whereas ozone does not produce such compounds (Srivastav et al., 2020; Ding et al., 2019). Studies have shown that ozone is highly effective in eliminating E. coli, Salmonella, Vibrio cholerae, and many types of viruses. The ozonation method not only targets pathogenic microorganisms but also breaks down both organic and inorganic pollutants in drinking water (Wang and Chen, 2020). Comparative results from the research are presented in Table 1 below.

Table 1: Comparison of Water Disinfection Methods: Chlorination and Ozonation

Characteristics	Chlorination	Ozonation
Mechanism of action	Chlorine disrupts the cell membranes of microorganisms, stopping their function.	Ozone directly interacts with microorganisms, destroying their DNA and RNA structures.
Effectiveness in killing bacteria and viruses	High, but may be less effective against certain resistant microorganisms (e.g., some viruses and cysts).	Very high, effective against most bacteria, viruses, spores, and pathogens.
Residual compounds	Chlorine residues form harmful compounds for human health, such as trihalomethanes (THMs).	Ozone breaks down quickly into oxygen, leaving no harmful residues.
Impact on taste and odor	Chlorine may negatively affect the taste and odor of water.	Ozone improves the taste and odor of water, removing unpleasant smells.
Residual chemical levels	Chlorine residues can remain in the water for a long time.	Ozone is unstable and quickly decomposes, leaving no residuals.
Application scope	Commonly used in water treatment systems, cost-effective, but requires longer contact time for disinfection.	Widely used but more expensive and requires continuous system monitoring.
Safety	Excessive chlorine during treatment can pose risks.	Ozone breaks down quickly, but high concentrations can be dangerous if not controlled.
Additional effects	Chlorine reacts with organic substances, forming harmful by-products.	Ozone breaks down both organic and inorganic pollutants.
Environmental impact	Chlorine can accumulate in natural water systems and negatively affect ecosystems.	Ozone is environmentally friendly and does not harm ecosystems.

In Table 1, the key differences between chlorination and ozone treatment are compared. While chlorination is effective in eliminating microbes, it can produce harmful residues, whereas ozone is environmentally friendly but comes with higher operational costs. Ozone enhances the taste and odor of water and does not negatively affect the ecosystem, making it one of the most efficient modern disinfection methods.

One of the main drawbacks of ozone is its rapid decomposition in water, which limits its disinfection effect to a short duration. Therefore, researchers are exploring ways to enhance ozone's effectiveness by combining it with other technologies. For instance, when used in combination with ultraviolet (UV) radiation or ultrasound, the disinfection effect of ozone is significantly increased. Thus, combining ozone with other methods can provide more effective protection of water from pathogens (Draginsky et al., 2007; Hossen et al., 2090; Beltrán et al., 2019). The benefits of integrating ozone with other methods are summarized in Table 2 below.

Table 2: Advantages of Combining Ozone with Other Methods

Combination Methods	Advantages
Ozone + Chlorination	Enhances chlorination effectiveness and reduces harmful residues.
Ozone + Ultraviolet Light	Increases disinfection efficiency and eliminates microorganisms.
Ozone + Filtration	Effectively removes contaminants and improves water quality.
Ozone + Biological Methods	Enhances the breakdown of organic matter and reduces environmental impact.
Ozone + Chemical Coagulation	Improves the removal efficiency of polluted particles and enhances water clarity.

Table 2 outlines the advantages of combining ozone with other disinfection methods. These combined approaches enhance disinfection efficiency, reduce harmful residues, and improve water quality. Such combinations also help minimize environmental impact and improve the removal of pollutants.

Research is also investigating the potential of combining ozone with nanotechnology. Nanomaterials can stabilize ozone molecules, allowing them to remain active for longer periods. This approach helps improve the effectiveness of ozone in water disinfection and encourages its broader use in water treatment plants. Additionally, reducing the cost of ozone disinfection is one of the critical challenges, and ongoing studies aim to make this technology more affordable by using new methods (Li et al., 2008; Amin et al., 2014). Table 3 below presents the potential of combining ozone with nanotechnology.

Table 3: Potential of Combining Ozone with Nanotechnology	
Research Aspects	Content
Role of Nanomaterials	Enables stabilization of ozone molecules
Long-Term Activity	Ability to maintain ozone's activity over an extended period
Effectiveness	Enhances the effectiveness of ozone in water disinfection
Application Scope	Facilitates widespread use in water treatment plants
Cost Reduction	Ongoing research aimed at reducing the cost of ozone disinfection

Table 3 highlights the potential of combining ozone with nanotechnology. Nanomaterials stabilize ozone molecules, allowing them to remain active for longer, thus enhancing the efficiency of water disinfection. Additionally, research aimed at reducing the cost of ozone disinfection is focused on introducing new methods that expand its use in water treatment plants.

Another advantage of using ozone for water disinfection is its ability to eliminate unpleasant tastes and odors in the water (as shown in Table 4). This is particularly beneficial for improving the quality of drinking water (Kizi et al., 2021; Camel and Bermond, 1998). Currently, research is focusing on the ability of ozone to address virological threats, including the destruction of new viral strains. Advances in technology and scientific breakthroughs continue to expand the potential applications of ozone as an effective method for water purification (Costa and Féris, 2023; Kokkinos et al., 2021).

Table 4: Advantages of Using Ozone in Water Disinfection	
Advantages	Content
Removal of Taste and Odors	Ozone can eliminate unpleasant tastes and odors in water
Improvement of Drinking Water Quality	Enhances the quality of drinking water
Elimination of Viral Threats	Research addresses the removal of new viral strains
New Technologies and Achievements	Expands the possibilities of using ozone as an effective method for water purification

Table 4 outlines the advantages of ozone in water disinfection. Ozone improves the quality of drinking water by removing unpleasant tastes and odors, thus enhancing the overall consumption experience. In addition, research is being conducted to address the destruction of new viral strains, with technological and scientific advancements expanding the potential for using ozone as an effective method.

Experimental studies on ozonation of drinking water contaminated with typhoid-causing bacteria have been previously conducted in both domestic and international research. However, their findings primarily confirmed the possibility of disinfecting water contaminated with typhoid bacteria using ozone. There is comparatively less data on the effect of ozone on bacterial dysentery pathogens (Schoenen, 2002; Bitton, 2014).

The antiviral properties of ozone in water treatment have only recently begun to be thoroughly studied. Research has focused on ozone's inactivation of the poliomyelitis virus and its effect on other viruses found in drinking water that play a significant role in human pathology. These studies aim to prevent intestinal infections through preventative measures. Based on these findings, scientists have begun exploring the efficiency of ozonating drinking water and the inactivation of poliomyelitis and Coxsackie viruses with ozone (Chen et al., 2021; Chen et al., 2021; Kholikulov and Matkarimov, 2021).

In line with these issues, we conducted experimental work in the laboratory using a specially designed ETRO-03 ozonator, based on an electric discharge principle, to study the impact of ozone on various bacterial contaminants in water. The research findings are presented in the following sections.

2.1 Mathematical Model of the Disinfection Process of Pathogenic Microorganisms Based on Ozone Technology

To develop a mathematical model for the disinfection process of pathogenic microorganisms based on ozone technology, it is essential to consider the mechanism of ozone action, the response of pathogenic microorganisms to ozone, and the concentration of ozone during the disinfection process. The following factors can be considered when constructing the mathematical model:

Key Parameters of the Model:

Ozone concentration (C(t)): The concentration of ozone as a function of time.

Number of pathogenic microorganisms (N(t)): The number of microorganisms as a function of time.

Disinfection rate (r): The rate at which ozone acts on microorganisms.

Exposure time (t): The time during which microorganisms are exposed to ozone.

Mathematical Model - the disinfection process can be described using logarithmic equations that model the change in the number of pathogenic microorganisms over time:

$$\frac{dN(t)}{dt} = -k \cdot C(t) \cdot N(t) \tag{1}$$

Where: N(t) is the number of viable microorganisms at time t; C(t) is the ozone concentration at time t; k is the disinfection constant (which characterizes the sensitivity of pathogenic microorganisms to ozone).

Ozone Concentration - the concentration of ozone can vary over time, but for simplicity, if we assume the ozone concentration is constant, then C(t) = C0. If C(t) is constant, solving the differential equation yields:

$$N(t) = N_0 \cdot e^{-k \cdot C_o \cdot t} \tag{2}$$

Where: N_0 is the initial number of microorganisms; C_0 is the constant ozone concentration; t is the exposure time.

Disinfection Efficiency - the disinfection efficiency (E) can be defined as the fraction of the initial number of microorganisms that have been inactivated over time:

$$E = \frac{N_o - N(t)}{N_0} = 1 - e^{-k \cdot C_o \cdot t} \tag{3}$$

This formula demonstrates the relationship between disinfection efficiency, time, and ozone concentration. As the ozone concentration C_0 increases or the exposure time t lengthens, the number of microorganisms N(t) decreases, meaning that disinfection efficiency increases.

Application of the Model - this model can be used to determine the necessary ozone concentration and exposure time for effective disinfection. The parameter k should be determined empirically for each microorganism based on its sensitivity to ozone. Such a mathematical model helps evaluate the effectiveness of ozone technology in disinfecting pathogenic microorganisms.

3. Results and Discussions

The scientific research plan is as follows: The use of ozone technology for the disinfection of pathogenic bacteria and viruses in drinking water is investigated. First, water samples are collected, and microbiological contamination is identified. Then, the water is treated with ozone, and the concentration of pathogens is measured again. The purification results and the effectiveness of ozone are evaluated comparatively.

3.1 Experimental Research

In this scientific research, 12 strains of typhoid bacteria and 36 strains of dysentery bacteria, including Flexner, Sonne, and Shigella, were used. Bacterial suspensions were prepared from 24-hour agar cultures. Before each experiment, the concentration of microorganisms in the contaminated isotonic water was determined, filtered through a No. 2 membrane filter, and final samples were cultured on Endo agar. All studies, except for those aimed at determining the disinfection efficiency of water quality, were conducted in water purified through coagulation, sedimentation, and filtration in accordance with the sanitary regulations 3.02.002.04 SanPiN and GOST 2874 standards.

Preliminary experiments showed that sublethal doses of ozone altered the morphological, cultural, tintorial, biochemical, antigenic, and virulent properties of the bacteria, making it difficult to assess the bactericidal effect of ozone. Therefore, before infecting the water, we sterilized it with ultraviolet rays.

The research was conducted at the Kazakh National Research Technical University named after K.I. Satbayev, at the Department of Electrical Technology and Space Technologies (ET&ST). It was carried out using the ETRO - 03 ozonator device, based on a pilot electric discharge. Figure 1 below shows the laboratory setup and its electrical schematic. This setup allows for ozone treatment of water under conditions close to those used in water pipelines.

In Figure 1, the main elements of the ozone treatment device consist of the ozonator, capacitors, diodes, and a transformer. The ETRO-03 ozonator is used to enrich the water with ozone, effectively disinfecting bacteria and viruses in the water. K75 capacitors store the necessary energy for the ozonator and provide a stable direct current. KC201E diodes regulate the flow of current in the correct direction, while the 220/10kV transformer supplies high voltage to the ozonator, ensuring efficient operation. Together, these components form the ozone generation system essential for disinfecting drinking water.

The technological scheme of the equipment used for conducting the research is shown in Figure 2 below. Ozone treatment of the water is carried out through barbotage (mixing with air bubbles): the output transformer allows voltage to be adjusted from 1,000 to 18,000 (18kV) volts. By varying the voltage at the output electrodes, the ozone concentration in the ozone-air mixture can be regulated from 0.5 to 30 g/m^3.

Figure 1: The electrical circuit of the ETRO-03 ozonator device based on electric discharge

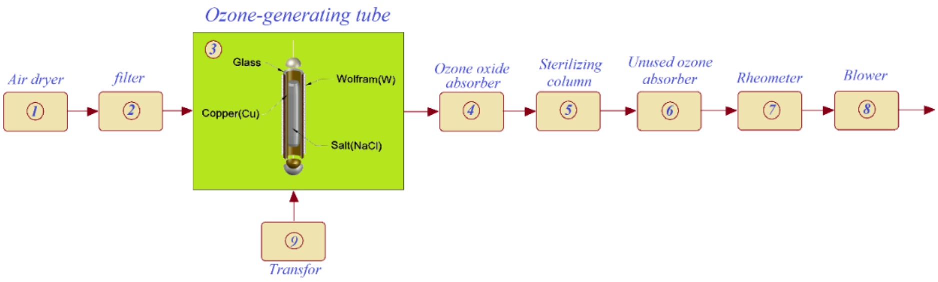


Figure 2: Process diagram of the ozonating installation

In Figure 2, the technological process of the ozone treatment system is shown step-by-step. First, in stage 1, the air is dried (Air dryer), ensuring the efficient operation of the device. In stage 2, the air passes through a filter, removing dust and particles from the air. In stage 3, ozone is generated through an ozone-producing tube, where materials like copper (Cu), tungsten (W), salt (NaCl), and glass are involved. In stage 4, ozone oxide is absorbed by the ozone oxide absorber, enhancing the effect of ozone on the purified water. In stage 5, the sterilization process of the water takes place in the sterilizing column, and in stage 6, unused ozone is removed through the unused ozone absorber. In the final stages, the ozone flow is measured using a rheometer, and the process is completed by distributing it through the blower.

Due to the variation in ozone utilization efficiency, which can range from 20% to 95% depending on the experimental conditions and the method of mixing water with the ozone-air mixture, we considered not only the total amount of ozone introduced into the water but also the actual amount used during the ozonation process. The amount of ozone for treating 1 liter of water was measured in milligrams and conditionally referred to as ozone per liter of water. By subtracting the amount of ozone retained in the absorber, we obtain the "pure ozone" amount (mg/L).

It is assumed that a portion of the pure ozone is used to oxidize organic substances in the water, including microbial dust, while the remainder breaks down into free radicals, with only a small portion detectable in the water (for a brief period, up to about 1 minute, after the water comes into contact with ozone). This phenomenon is referred to as the "short ozone zone." The nature of this process is unknown, but it is believed to involve rapidly degrading radicals or unstable compounds. The decomposition rate of ozone in water depends on factors such as temperature, pH, the characteristics and concentration of contaminants, some of which are present in trace concentrations. These factors catalyze the ozone decomposition reaction.

After completing the disinfection process, the remaining ozone was determined using the iodometric method, and 400 ml of water was passed through membrane filters. Final samples were placed on Endo agar and incubated at 37°C for 5 days in a thermostat. These studies showed the survivability of bacteria, so to check for sterilization, samples were taken immediately after ozonation, every 30 minutes for 6 hours, and after 12, 24, and 48 hours. Each experiment was repeated at least 8-10 times under similar conditions. The microbiological results were processed statistically (see Table 5).

Table 5: Comparison of Ozone Resistance (Within Variation Range) for Typhoid and Dysentery Bacteria (Ozonation Mode: 25,000,000 microbial bodies per liter of water, pure ozone dose of 14 mg/L, ozonation duration of 5 minutes)

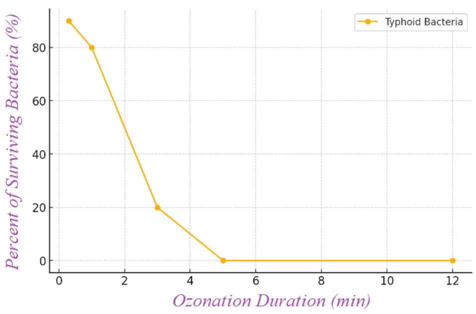
Type and subspecies of pathogens	Number of strains	Jm (confidence interval)	$J_m/N \cdot 100\%$	Average number of bacteria found in one determination
Typhoid bacteria	11	0,83 – 2,40	41,6 – 15,97	1,9 – 14,8
Flexner dysentery bacteria				
Serotype 1 (a)	5	1,27 – 1,85	30,55 – 21,98	3 - 79
Serotype 2 (c)	1	1,00 – 1,25	36,45 – 30,28	2 - 39
Serotype 3 (e)	4	1,11 – 1,52	38,10 – 20,24	3 - 78
Serotype 4 (e)	4	0,68 – 1,25	44,82 – 24,87	2 - 48
Nyukestl	2	1,35 – 2,15	25,00 – 17,85	5,00 – 12
Boyd – Novgorodsky	2	1,45 – 1,68	26,51 – 19,35	5 - 9
Sonne	12	1,28 – 2,56	28,87 – 15,85	2 - 13
Schuetzler	2	1,17 – 1,45	33,37 – 26,38	2 - 45

The results of the research are presented in Table 5, from which it can be observed that, after ozone treatment of 1 liter of water, on average, 2 unstable strains of typhoid bacteria and several microbial cells of stable strains remained. The maximum and minimum concentrations of microorganisms under the ozonation conditions showed significant deviations when calculated based on confidence intervals and average values. The number of typhoid bacteria ranged from 1 to 13, while the concentration of stable bacteria varied from 1 to 13, and the maximum concentration could reach up to 3 microbial cells per liter. Although the effect of ozone on typhoid strains was significant, the resistance of microorganisms to ozone was found to be slightly higher. The level of ozone's impact on contaminated water sources was studied in relation to the ozone concentration and exposure duration. It was determined that the concentration of ozone in these conditions had a certain effect on the contamination level of the water. Much depended on the initial contamination of the water. For example, when ozone concentration was 4-5 mg/L and the water source was exposed for several hours, the contamination by pathogenic bacteria in the first hours of ozonation was less than 1,000 bacteria per liter, but remained at a high level during the first hours of ozonation (over 100,000 bacteria per liter).

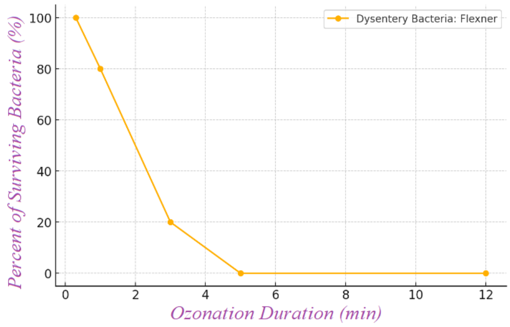
In experiments with ozonation of water contaminated with dysentery bacteria at different concentrations, similar patterns were found as in the disinfection of water contaminated with typhoid bacteria. The bactericidal doses were close to the doses that resulted in the destruction of typhoid pathogens.

The effect of water quality on disinfection efficiency was studied in distilled water (transparency 0°, oxygen acidity 0.8 mg/L), ozone-purified river water (transparency 110°, oxygen acidity 24.3 mg/L, ozone concentration 7.2 mg/L), and untreated river water (transparency 110°, oxygen acidity 24.3 mg/L, ozone concentration 7.2 mg/L).

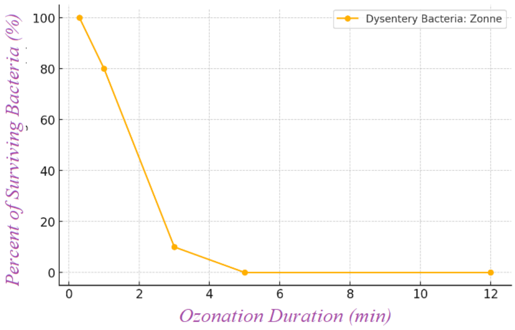
In Figure 3 below, it is shown that the bactericidal dose of ozone increases significantly with the concentration of organic substances and ozone-binding capacity. If 22 mg/L of pure ozone was required to disinfect untreated river water, only about 7 mg/L of ozone was needed to purify the same water according to GOST 2874-54 standards. Therefore, as expected, pre-purifying the water with ozone before disinfection is advisable. If the initial contamination of the water does not exceed 10,000 typhoid or dysentery bacteria per liter, the pH fluctuations of water between 5.8 and 8.0 had little effect on ozone disinfection. Similarly, the data presented in this table show that when disinfecting water that meets GOST 2874-54 standards, the contamination level of pathogenic bacteria ranges from 1,000 to 10,000 per liter, while the remaining ozone concentration is about 0.15–0.2 mg/L, which demonstrates the reliability of the disinfection. The required amount of ozone increases with the contamination level. For instance, when the number of microorganisms in the water reaches 100,000 bacteria per liter, and the residual ozone concentration is 0.2 mg/L, disinfection is not reliable. Disinfection becomes reliable when the number of microorganisms per liter reaches 400,000, but only when the residual ozone concentration exceeds 2 mg/L. Thus, determining the residual ozone concentration is a reliable method of evaluating water disinfection in real conditions, especially as an alternative to determining residual chlorine. The overall effect of the ozonation process on bacteria and viruses, as well as the dynamics of ozone concentration, is shown in Figure 3 below.



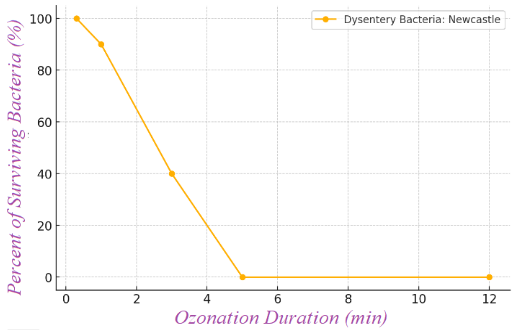
a) Survival of Typhoid Bacteria



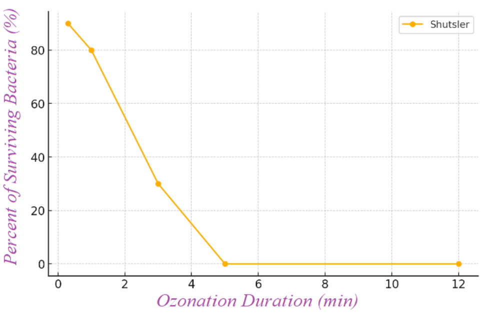
b) Survival of Dysentery Bacteria: Flexner



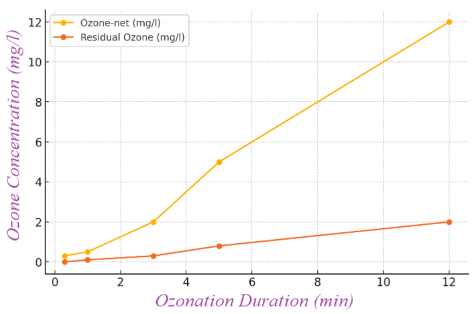
c) Survival of Dysentery Bacteria: Zonne



d) Survival of Dysentery Bacteria: Newcastle



e) *Survival of Shutsler*



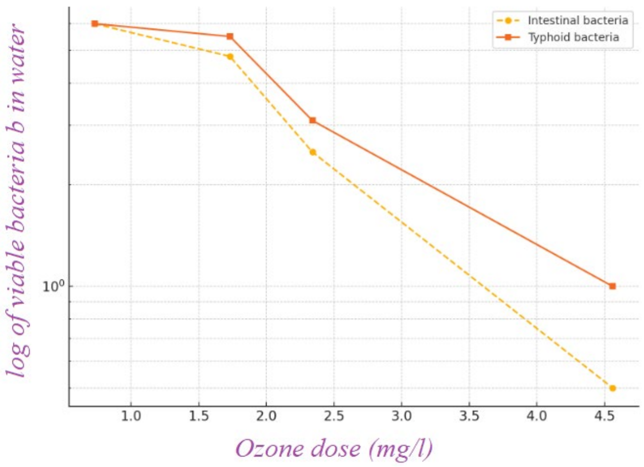
f) Ozone Concentration vs Ozonation Duration

Figure 3: The effect of the ozonation process on bacteria and viruses and the dynamics of ozone concentration

In Figure 3, the impact of the ozonation process on bacteria and viruses and the dynamics of ozone concentration are demonstrated. The initial graphs show how the viability of various bacteria (such as typhoid and dysentery strains) decreases with increasing ozonation time. As the ozone concentration rises, the survival rate of bacteria and viruses significantly decreases, with complete elimination occurring within 5 to 12 minutes. The final graph illustrates how the total and residual ozone concentrations change over time: ozone concentration increases proportionally with the duration of ozonation. This helps determine the required time and concentration to enhance the disinfection efficiency of ozone.

Some researchers indicate the possibility of bacterial reactivation in ozonated water, which they explain by the rapid decomposition of residual ozone. Continuing research in this area, we found that, although the disinfection efficiency was high (99.95%), this does not always guarantee sterility, as several types of bacteria in the water, especially microorganisms that were not directly exposed to ozone, may retain their viability. If water samples are not examined immediately after ozonation, bacterial colony growth can be observed (in 400 ml of water). This effect was seen in samples examined immediately and 30 minutes after ozonation. However, after 6 hours and again after 24-48 hours, the samples once again showed sterility. These findings are consistent with the research results on the sterility of ozonated water by Draginsky V. L. and Alekseeva L. P.

According to GOST standards, the coliform index for drinking water should not exceed 3. Based on these requirements, we studied the viability of various strains of typhoid and dysentery bacteria, which were present in a 1:10 ratio with ozone-resistant microbes. The average data are shown in Figure 4, which confirms that these trends hold even in the presence of pathogenic bacteria.



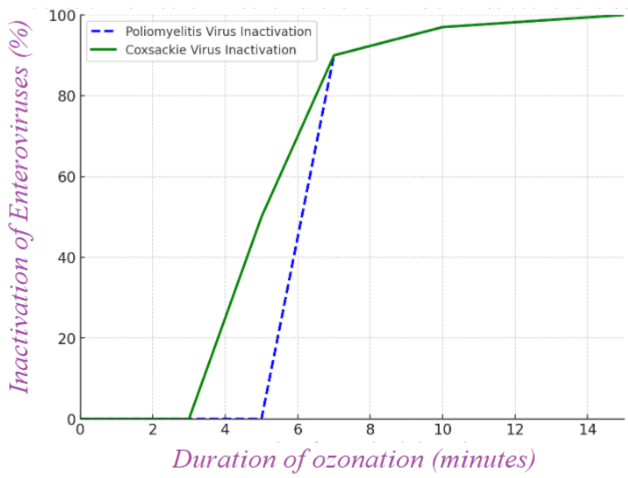
1) die-off of intestinal bacteria; 2) die-off of typhoid bacteria.

Figure 4: The dynamics of the die-off of intestinal and typhoid bacteria during the ozonation of drinking water (the initial concentration of intestinal bacteria is 10 times higher than the concentration of pathogenic bacteria).

This figure illustrates how the survival rate of intestinal and typhoid bacteria in water decreases as the ozone dose (mg/l) increases. Intestinal bacteria are more susceptible to ozone than typhoid bacteria, as they are quickly eliminated at lower doses. When the ozone dose exceeds 4 mg/l, the concentration of intestinal bacteria approaches zero. Although typhoid bacteria survive at higher doses of ozone, their concentration also significantly decreases. This demonstrates that ozone is an effective tool for disinfecting water.

The coliform index, set at 3, along with the presence of intestinal bacteria, can serve as an indicator of reliable disinfection using ozone. We observed instances where bacteria and intestinal bacilli remained alive at residual concentrations, indicating that some portions of typhoid and dysentery bacteria retained their viability even after disinfection. During studies on the virulence properties of ozone, three serotypes of the Coxsackie B virus strains were used. Similarly, some foreign scientific studies have shown that high concentrations of ozone significantly reduce the impact of viruses. As depicted in the graph, after 60 minutes of exposure to ozone, virus viability dropped from 70% to 10%. This highlights ozone's strong antiviral properties. Ozone's effects on various infectious diseases have been studied in this context.

The dynamics of enterovirus inactivation during ozone treatment of water show that the virulence effect of ozone depends on the duration of treatment, the amount of residual ozone, concentration, and the characteristics of the substances (easily and difficultly oxidized) present in the water (Figure 4). No inactivation of viruses was observed during the first 5 minutes; at this stage, no residual ozone was detected as it was entirely consumed in oxidizing organic matter. During this time, the oxidation capacity of the water decreased by 10%. Easily oxidized substances were eliminated within the first minute. Over the next two minutes, by the 7th minute of ozonation, 90% of poliovirus and 97% of Coxsackie viruses were inactivated, and approximately 0.1 mg/l of residual ozone was found in the water (Figure 5).



1 - inactivation dynamics of the poliomyelitis virus; 2 - inactivation dynamics of the Coxsackie virus.

Figure 5: Dependence of the disinfection effect of river water containing poliomyelitis and Coxsackie viruses on the concentration of residual ozone in the water.

In Figure 5, the inactivation levels of poliovirus and Coxsackie virus are shown as a function of ozonation duration. Poliovirus inactivation sharply increases after 5 minutes and reaches 100% after 6 minutes. Coxsackie virus starts to inactivate between 4-5 minutes and is fully eliminated by 7 minutes. This demonstrates that the duration of ozonation has a significant impact on virus inactivation. Thus, the sensitivity of poliovirus and Coxsackie virus to ozone increases over time.

In each experiment, 50 ml samples were used for virus testing. In the first and third trials, the concentration of viruses was measured before and after ozone treatment, while in the second trial, the concentration of residual ozone (lysogenic mixture) was measured using a general method. The inactivation effect of ozone was studied over 7 days in several cases. The quantity of viruses, determined by TCID50/ml, was monitored for 7 days. Virus inactivation was found to depend on ozone's antimicrobial properties and its stability. In new experiments, the effect of ozone on viruses was observed within 3-5 minutes. In some cases, ozone was unable to completely eliminate the virus, while in others, it partially inactivated the viruses. After this period, the inactivation rate slowed, which explains the ozone resistance observed in certain virus strains. Over 15-16 minutes, inactivation levels of 99.7% to 99.99% were recorded. The slow inactivation process was closely linked to the concentration of ozone.

These findings suggest that Coxsackie-type viruses exhibit high resistance to ozone. While ozone was effective at actively inactivating viruses within 15 minutes, its effect did not last for an extended period.

3.2 Analysis of Scientific Research

The results of the scientific study demonstrate that ozone disinfection is highly effective in inactivating pathogenic microorganisms, particularly the pathogens of typhoid and dysentery. When treating 1 liter of water with an ozone concentration of 14 mg/L, pathogenic bacteria were destroyed by up to 99.95%. This indicates the strong disinfection effect of ozone. Poliovirus was inactivated by 99.99% within 6 minutes, while the inactivation rate of Coxsackie virus reached between 99.7% and 99.9% within 15 minutes, indicating varying levels of virus sensitivity to ozone. When the residual ozone concentration was maintained at 0.15-0.2 mg/L, disinfection efficiency was high, emphasizing the crucial role that residual ozone plays.

During ozone application, it was observed that intestinal bacteria were destroyed more rapidly than typhoid bacteria, and their viability sharply decreased as ozone exposure increased. The effectiveness of ozone in water disinfection also depended on the composition of organic contaminants in both purified and contaminated water. During the research, although an ozone concentration of 7 mg/L was sufficient for disinfecting clean water, for highly contaminated water, it was necessary to increase the concentration to 22 mg/L.

When ozone was combined with ultraviolet radiation or ultrasound methods, a significant improvement in disinfection efficiency was observed (Abdykadyrov et al., 2023; Abdykadyrov et al., 2023). This suggests that the combination of ozone with other methods holds promising potential for enhanced disinfection processes (see Figure 6).

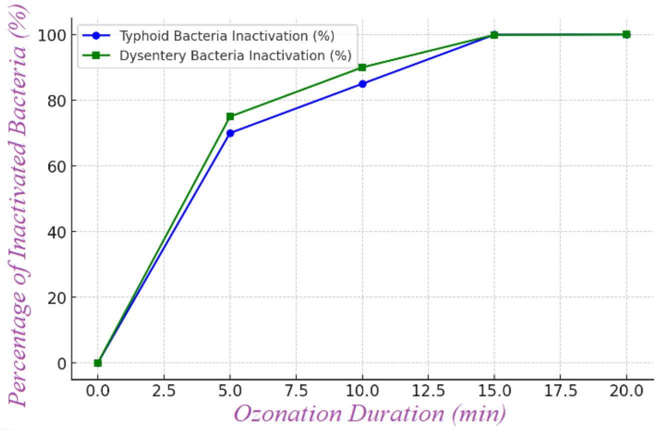


Figure 6: Effect of Ozonation on Inactivation of Typhoid and Dysentery Bacteria

In Figure 6, the graph illustrates the inactivation of typhoid and dysentery bacteria depending on the duration of the ozonation process. The graph shows that the viability of both bacteria decreases significantly during ozone treatment. Within 5 minutes, 70% of typhoid bacteria and 75% of dysentery bacteria were inactivated. After 10 minutes, more than 99.9% of both bacterial types were eliminated. This research confirms that ozone is an effective tool for disinfection, and both the duration of exposure and the concentration of ozone play a critical role in the process.

4. Conclusion

The following key results were achieved in this scientific research:

Efficiency of Ozone in Pathogen Elimination - it was demonstrated that ozone disinfection can eliminate up to 99.95% of typhoid and dysentery bacteria. The study used 11 strains of typhoid bacteria and 36 strains of Flexner and Sonne dysentery bacteria. During the treatment of 1 liter of water with an ozone concentration of 14 mg/L, the inactivation level of the bacteria reached 99.95% within 5 minutes;

Effect of Ozone on Viruses - inactivation of poliovirus up to 99.99% was achieved when ozone was applied for 6 minutes with a residual concentration of 0.2 mg/L. Although the Coxsackie virus was less sensitive to ozone, its inactivation ranged from 99.7% to 99.9% within 15 minutes;

High Ozone Concentration and Virus Viability - the viability of viruses decreased from 70% to 10% within 60 minutes when exposed to high ozone concentrations;

Disinfection Efficiency and Residual Ozone Concentration - complete inactivation of typhoid and dysentery bacteria was observed when 4.5 mg/L of ozone was applied per liter of water. The residual ozone concentration was determined to be around 0.15-0.2 mg/L, indicating reliable disinfection. According to the data, an ozone concentration of 22 mg/L was sufficient to completely break down organic contaminants in contaminated water, while approximately 7 mg/L of ozone was required in purified water;

Advantages of Ozone in Water Treatment - during water disinfection with ozone, the number of pathogenic microorganisms remained very low after reactivation tests, indicating that water treated with ozone remains safe for an extended period (Abdykadyrov et al., 2024; Abdykadyrov et al., 2024). Although the residual ozone concentration decreased over time, water sterility was maintained for at least the first 6 hours;

Efficiency of Ozone in Combination Methods - when ozone was used in combination with ultraviolet radiation or ultrasound, disinfection effectiveness improved, achieving up to 99.99% inactivation of bacteria and viruses. Increasing the ozone concentration and combining it with other methods enhanced the effectiveness of pathogen elimination.

This research has proven that ozone technology is an effective method for disinfecting drinking water from pathogens. Ozone's high oxidative properties and its residue-free decomposition, compared to traditional methods, make water safe and environmentally friendly.

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